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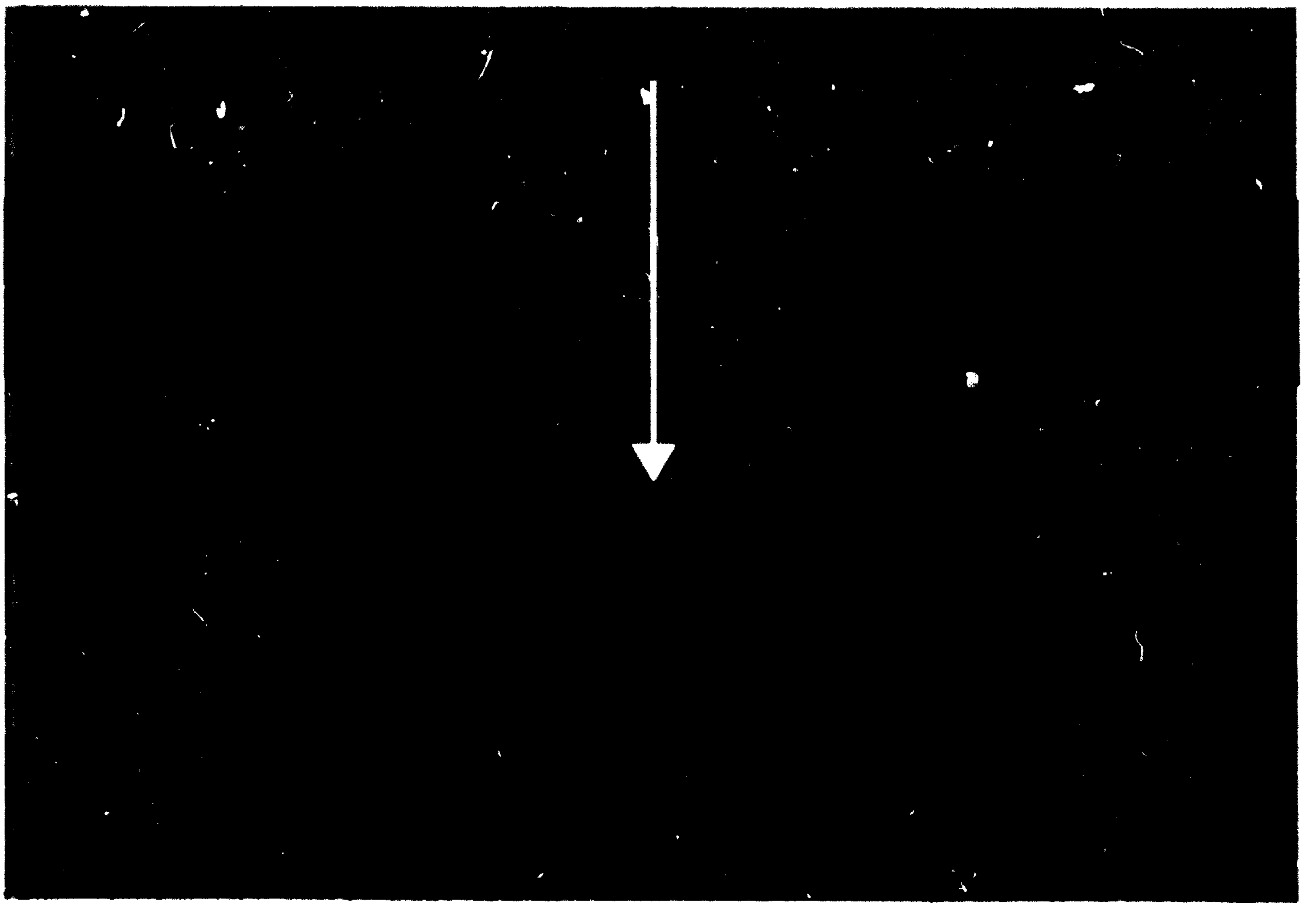
DESIGN, MANUFACTURE AND UTILIZATION OF DIES AND JIGS IN DEVELOPING COUNTRIES



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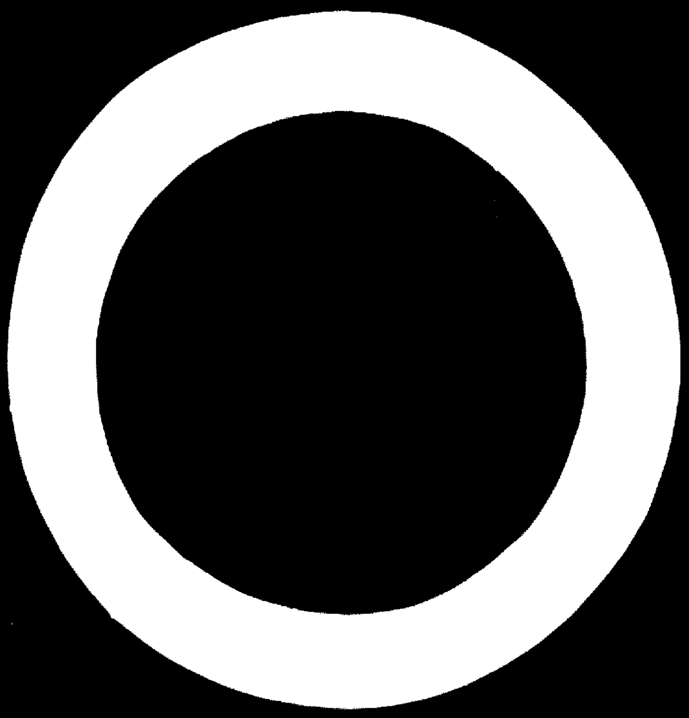

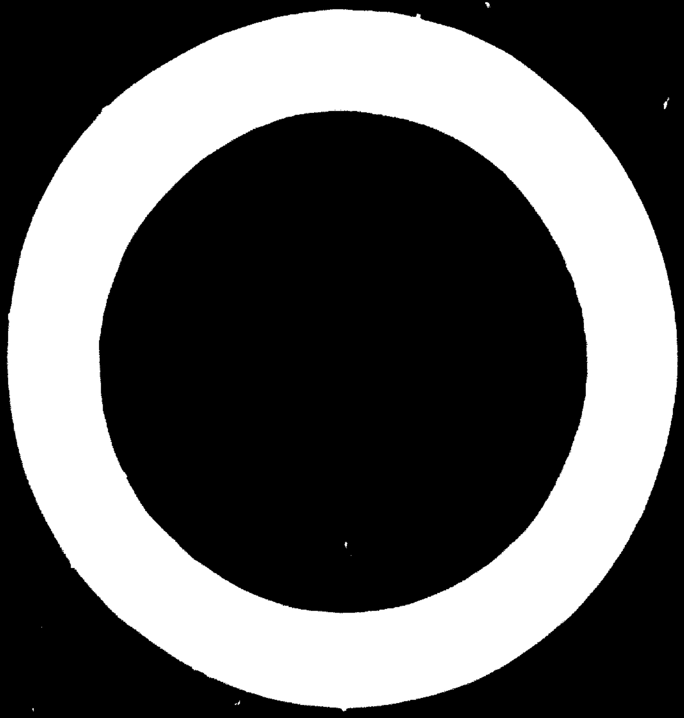

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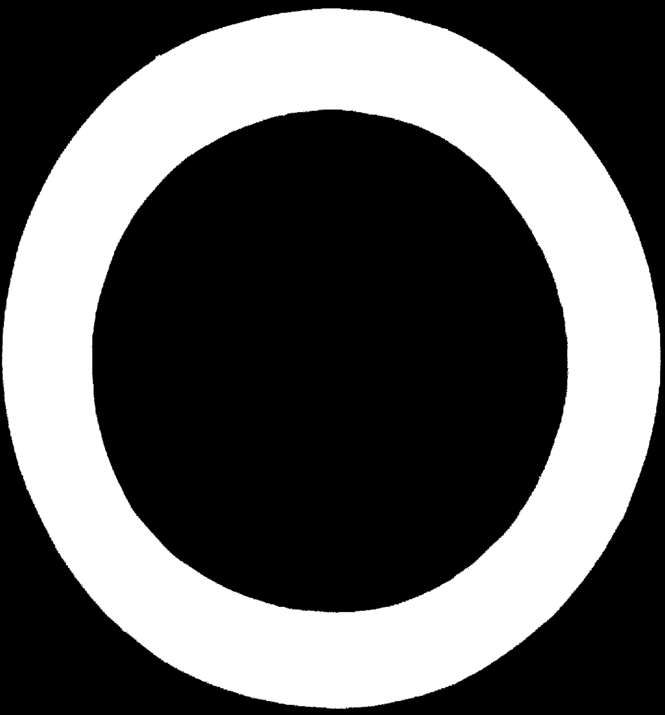

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

DESIGN, MANUFACTURE AND UTILIZATION OF DIES AND JIGS IN DEVELOPING COUNTRIES

Report of the Expert Group Meeting held at
UNIDO Headquarters, Vienna, 10—20 December 1968

UNITED NATIONS
New York, 1970

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PREFACE

THE EXPERT GROUP on the Design, Manufacture and Utilization of Dies and Jigs in developing countries met under the auspices of the United Nations Industrial Development Organization at UNIDO headquarters in Vienna from 10—20 December 1968 to discuss measures for the improvement of metalworking industries in developing countries.

Attention was focused on the problems and prospects of modern industries, using various production tools, machines and processes to lower production costs and raise productivity as a means of meeting the intensive competition in the egineering industries.

Mr. Ibrahim H. Abdel-Rahman, the Executive Director of UNIDO, in opening the meeting and welcoming the participants, emphasized the importance of the discussions since dies and jigs play an important role in the production of machine parts, and he observed that the amount and productivity of manufacturing machinery, and of machine tools in particular, were among the major problems facing developing countries. He hoped that the deliberations of the Group would result in recommendations for concrete action by the developing countries and by UNIDO. (Mr. Abdel-Rahman's statement is presented in Annex I.)

Eleven experts participated in the meetings: one each from Brazil, Czechoslovakia, France, India, Portugal, Tunisia, the United Arab Republic, the United Kingdom and the United States of America and two from the Union of Soviet Socialist Republics. The participants are listed by name in the letter of transmittal which follows this preface.

The proceedings published in this volume are based on the thirteen papers prepared for the meetings, listed in Annex II. These papers, prepared by the experts in their respective fields, were considered by the participants to be valuable sources of information. Annex III is a list of the participants.

To help those unfamiliar with such processes, a limited glossary of casting, moulding and presswork terms have been provided in Annex IV.

The present publication includes the report and conclusions of the Group, prepared during the meetings (Part I), and extracts from the papers presented to the meeting as modified following the discussions (Part II). The papers have been shortened or adapted to remove duplication while at the same time reflecting the diverse approaches and viewpoints of the experts. Some material presented to the meeting has been omitted from the proceedings as the subject was covered in other papers or extended beyond the scope of this publication.

As indicated in the letter of transmittal, Mr. M. F. Hussein served as Chairman and Mr. R. K. Gejji as Vice-chairman. Mr. W. J. Edmonds served as Rapporteur and assisted the secretariat of UNIDO in preparing the final report and proceedings. Mr. V. N. Vasiliev and Mr. Milan Delos, members of the Engineering Industries Section, Industrial Technology Division of UNIDO, organized and assisted in the conduct of the meetings. Mr. Vasiliev also served as Technical Secretary and collaborated with Mr. Edmonds and the editor in preparation of this publication.

The report of the meeting (Part I), as indicated in the letter of transmittal, represents the views of the participating experts as a group. The papers reproduced in Part II represent the views of the respective authors and not necessarily those of UNIDO. The participants attended the meeting in their personal capacities and not as official representatives of their organizations or Governments.

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PART II PROCEEDINGS, BASED ON PAPERS PRESENTED TO THE GROUP

ANNEXES

EXPLANATORY NOTES

The following symbols have been used throughout the report:

A full stop (.) indicates decimals;

A comma (,) distinguishes thousands and millions.

For readers unfamiliar with Soviet mechanical engineering practice, referred to in part II, articles 4, 6, 7 and 8, the following notes may be useful.

Surface finish is defined in the USSR All-Union Standard GOST 2789-59 which includes fourteen classes of surface finish. The roughest surface is No.1 with inequalities of 320 microns height or depth in a base length of 8 mm, the smoothest is No.14 with inequalities of 0.05 micron in a base length of 0.08 mm (80 microns).

There are nine levels of precision of fit in mechanical engineering in the USSR, No.1 being the closest, and No.9 being the least close.

The use of the term "jig" in some of the text should be taken as meaning "jig and fixture". The devices are similar and in many instances the two terms are synonymus, but "jig" is often used alone in the interest of brevity.

Dimensions on drawings are in millimetres unless otherwise indicated.

CONVERSION FACTORS

1 inch (in.) = 2.54 mm
1 pound (lb) = 0.454 kg
1 pound per square inch (psi) = 0.0704 kg/cm² (or 1 kg/cm² = 14.22 psi)
32° Fahrenheit (F) = 0° Celsius (C)
212° F = 100° C
1 rouble = 0.9 US dollar (1969)
Rs. = rupees (7.50 rupees = US $ 1.00, 1969)

LETTER OF TRANSMITTAL

We have the honour to submit herewith the report of the Group of Experts on the Design, Manufacture and Utilization of Dies and Jigs in Developing Countries. The report was prepared during our meetings at the Headquarters in Vienna of the United Nations Industrial Development Organization (UNIDO) from 10 to 20 December 1968.

The Group elected as its Chairman,

M. F. Hussein	Director General, Industrial Design Administration, General Organization for Industrialization, Cairo, United Arab Republic

as its Vice-Chairman,

R. K. Garg	Industrial Adviser (Engineering), Government of India, Directorate General of Technical Development, New Delhi, India

and as its Rapporteur,

W. J. Edmonds	Lecturer, University of Aston in Birmingham, Birmingham, England

The other members of the group were

G. Berecz	Vice-Chairman, Escofier et Cie, Paris, France
M. Bouhanek	General Director, Les Ateliers Mécaniques du Sahel, Sousse, Tunisia
J. Dillon	Plant Manager, Metal Stamping Division, Ford Motor Company, Dearborn, Michigan, United States of America
M. Juza	Chief of Engineering Design Office, Českomoravska Kolben Danek, Prague 3, Sudomerska 1, Czechoslovakia
V. S. Korsakov	Professor, Baumann Higher Technical School, Moscow, Union of Soviet Socialist Republics
J. A. Munoz-Miguez	Lecturer, Instituto Superior Tecnico, Manager of the Technical Office, Precix, Lisbon, Portugal
S. Podgorski	Consulting Engineer, São Paulo, Brazil
E. A. Popov	Professor, Baumann Higher Technical School, Moscow, Union of Soviet Socialist Republics

Mr. V. N. Vasiliev and Mr. M. Delos, staff members of UNIDO, were assigned to assist the group in its work.

The terms of reference given to us by Mr. I. H. Abdel-Rahman, Executive Director of UNIDO, in his opening address were to study and analyse the best ways to: transfer modern technology to the developing countries, especially in engineering manufacture; create new industries where local conditions permit; and examine the current conditions of die and jig production in all countries, the organizational characteristics of the die and jig industry which are best suited to the needs of developing countries, the economic implications of die and jig design and production in the metalworking industries of developing countries, and the significance of labour problems. The problems involved in training personnel of the developing countries in the design and manufacture of dies and jigs were also to be examined in great detail because of their particular relevance.

On the basis of the above, we were asked to reach conclusions and make recommendations for appropriate action by the technically advanced and by the developing countries and by the United Nations.

Our report, based on the preliminary reports submitted by UNIDO, follows the above guidelines.

We recommend that the attention of Member Governments of the United Nations be drawn to this report, and that their comments be invited.

In submitting this report, we have acted in our personal capacities and not as official representatives of our organizations or governments.

We wish to express our gratitude to the following people who, by participating in our discussions, have contributed valuable data and insight into special problems:

A. SMOLA	Consultant to the Institute of Design, Prague, Czechoslovakia.
K. PAWLOWITZ	Professor, Technische Hochschule, Vienna, Austria.

We thank the managements of the AGM Works in Linz and the HEID AG factory in Stockerau for having made it possible for us to visit their plants. We also wish to acknowledge our appreciation to the Industrial Technology Division of UNIDO for collecting and contributing papers that formed an indispensable background to our discussions, for preparing the preliminary report, and for other help that made possible the preparation of our report.

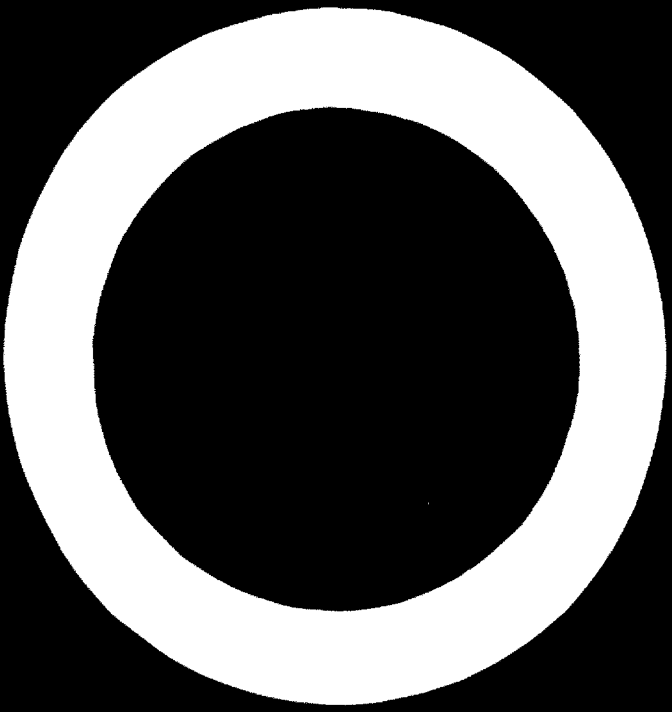
(Signed by)

M. F. HUSSEIN
R. K. GEJJI
W. J. EDMONDS
JAMES DILLON
V. S. KORSAKOV
S. PODGORSKY

JOSE ANTONIO MUNOZ-MIGUEZ
E. A. POPOV
M. BOUHANEK
M. JUZA
G. BERECZ

Part I

REPORT AND CONCLUSIONS



REPORT AND CONCLUSIONS

INTRODUCTION

1. Modern industry uses numerous factors of production, tools, processes machines, manpower and capital investment in order to satisfy increasing demands. Because of the competitive nature of modern manufacture, in order to achieve the necessary high production rates of good quality parts and at the same time minimize production costs, systematic selection and use of each of the factors of production is required.

2. In developing countries, manufactures depend largely on imported tools and techniques which do not always suit their conditions. Therefore, it is of prime concern that local tooling industries be developed. To achieve this, consideration must be given to the upgrading of an existing facility, or to the establishment of an appropriate technological centre or institution, whose objectives may be defined as the development of techniques and tools appropriate to the needs of the developing country.

3. These centres, when successfully established, could accomplish the transition from traditional methods of tool and die making to suitable new techniques. Historically, the tool, die and jig industry has consisted of small companies basically dependent on the skill of master craftsmen. The integration of new machine tools and processes with existing facilities would utilize and supplement existing skills and equipment and help to accelerate the development rate of the developing countries.

CONCLUSIONS

4. The group of experts has studied the problems of the production of dies, jigs and fixtures in the developing countries. Guided by the experience of the developed countries and the changes in die, jig and fixture production that have taken place in them, it has come to the following conclusions:

(a) Introducing or developing the production of dies, jigs and fixtures is of the utmost importance for maintaining and

accelerating the present rate of industrialization of the developing countries. This would be a major contribution towards raising their standards of living.

(b) The expansion of die, jig and fixture manufacturing facilities would accelerate the development of almost every other branch of industry including agricultural machinery, transportation equipment, machine tools, electrical and electronic machines and equipment, consumer goods etc.

(c) The existing unsatisfactory rate of progress in die, jig and fixture manufacturing techniques in the developing countries can be attributed to the following factors:

- (i) Shortage of competent personnel, namely process and tool engineers, tool designers, tool draughtsmen and skilled tool and die makers;
- (ii) Insufficient attention at the national level to the structural development of the die, jig and fixture industry;
- (iii) Difficulty in the adaptation of advanced technology and equipment to local conditions;
- (iv) Lack of suitable tool and die materials;
- (v) Lack of a continuous flow of up-to-date information on new processes and techniques from the developed countries;
- (vi) Lack of adequate organization for the maintenance and repair of existing dies, jigs and fixtures.

THREE SETS OF RECOMMENDATIONS

5. After careful examination of the subject matter of this report, and of the conclusions stated above, the group of experts makes the following recommendations for action to be undertaken by developing countries, by industrially advanced countries and by the United Nations.

A. For developing countries

Development of technology

6. The developing countries should make concentrated efforts to develop the skills necessary for the manufacture of dies and moulds, jigs and fixtures. They should ensure that workers in this field become thoroughly acquainted with modern technology. Development of skills should be attempted at all levels, i. e. from the machine operator and the bench technician to the designer and technical manager, as detailed in the report. For this purpose, each

country should carry out detailed surveys, if necessary with the help of UNIDO experts, to draw up a programme to carry out this training.

7. It is emphasized that modern developments, like the use of the EDM (electrical discharge machine) and production with tools under numerical control, considerably improve the quality, and shorten the time required for the batch production, of dies and complicated toolings, but they add to the problems in the training of personnel. Much capital investment is therefore necessary before these processes can be adopted.

Common facility centres

8. The developing countries should establish independent centres where modern equipment for the manufacture of tools and dies, and their heat treatment, inspection etc., are available for everyone engaged in such manufacture. These centres would also help to standardize the various elements used in the tooling industry (except regular cutting tools). They would also help with the manufacture and supply of such elements by advice on, or the design and manufacture of, new dies, jigs and fixtures as the case demanded. Their consultative service would aim at improving local knowledge of the design, manufacture and use. These common facility centres would also be responsible for the training and upgrading of the various levels of skills, referred to in paragraphs 6 and 7.

Material

9. Because the satisfactory operation of a tool or die depends on the proper choice and use of the correct materials, and because the special materials which are frequently required for tools and dies are not readily available in most developing countries, it is strongly recommended that the common facility centres to be established should maintain sufficient stocks of the more commonly used special materials for their own use for an initial period, the length of which would be dictated by the controlling factors including hard currency problems.

10. The Governments of the developing countries should facilitate the manufacture of dies, jigs and fixtures by providing low-interest loans, foreign exchange, and so on, to enable the individual units to acquire the advanced equipment and special materials for manufacturing purposes. They should also provide financial incentives and other facilities so that modern techniques for making tools and dies are introduced.

B. For industrially developed countries

11. The industrially developed countries, in co-operation with the United Nations, should provide facilities and experts for the training of all levels of personnel from the developing countries, especially in the design of dies, jigs and fixtures.

12. Because the manufacturing industries of the developing countries are often different from those of the developed countries, special efforts should be made to establish training programmes suited to the particular needs of each developing country.

C. For the United Nations

Common facility centres

13. The United Nations should render assistance to the developing countries by conducting surveys in the various countries and co-operating with the Government in the setting up of centralized common facility centres. The assistance should take the form of:

(*a*) Planning the centres,

(*b*) Providing the qualified experts needed,

(*c*) Helping to finance the acquisition of the special modern equipment required, and

(*d*) Helping to provide any special raw materials which are not available in the country for the initial period, the selection of these materials providing a good guide for future stocking.

Training of personnel

14. The United Nations should help to provide training facilities in the developed countries by finding suitable placements and / or establishing scholarships and fellowships.

Manufacture and repair of dies, jigs and fixtures

15. The United Nations should assist existing establishments which are already making and repairing dies, jigs and fixtures, including those set up in the industrial estates. This assistance would include upgrading their techniques by training personnel and by advice in the selection and acquisition of modern equipment. The assistance would be rendered through the appropriate Governments or through any available common facility centres.

Regional information centres

16. The United Nations should establish regional information centres and staff them with technical experts to disseminate the latest available techniques to the various common facility centres. Regional information centres should therefore have a good technical library and it is emphasized that they should regularly issue and distribute pamphlets and other literature containing technical information on up-to-date processes and equipment. They should also answer questions and supply technical information and advice.

International standards for tool and die parts, elements, materials and terminology

17. The United Nations should make the necessary contacts and formulate proposals to the International Standards Organization (ISO) in Geneva for the early preparation of recommendations for standardizing internationally the most commonly used parts, elements, materials and terminology in die, jig and fixture design and manufacture.

BASIC PRINCIPLES AND TERMINOLOGY

18. The terminology used here is only indicative. It is neither detailed, nor universal. The group of experts recommends that ISO gives early consideration to the issuing of recommendations to standardize the terminology of die, jig and fixture design and manufacture.

DIES, JIGS AND FIXTURES

19. The choice of the tools and items of special equipment, such as dies, jigs and fixtures, greatly influences manufacturing costs and the quality of the final product and is one of the major day to day problems for almost all the manufacturing industries.

20. Tools used in industry are devices:

(a) For removing material or forming it into a desired size and shape, e. g. cutting tools, punches and dies, electrodes, and so on,

(b) For holding workpieces and/or guiding tools. These include jigs, fixtures, and machine tool accessories such as chucks, and vices,

(c) For measuring and inspecting parts. These include gauges, and precision instruments, (*d*) For sensing information necessary for the operational control of machine tools. These include tool-force dynamometers, and power indicators,

(*e*) For transmitting instructions to machine tools for desired operations. These include numerical-control tapes and control units.

21. The functions of machine tools are: (*a*) to hold the workpiece and the tool or grinding wheel at their proper, related positions; and (*b*) to generate relative movement between them for the productive motion (cutting, forming, grinding, and so on).

Definitions of workholding devices and dies

22. The term "workholding devices" includes all devices that hold, chuck or support a workpiece in a desired manner and location. When they are items of special equipment, designed specifically to facilitate production in the carrying out of one particular operation on a given component, they are usually known as jigs and fixtures. These are widely used in the manufacture of batch or mass produced parts.

23. A jig is a device which incorporates a tool-guidance element, usually a drill bush, and holds and/or locates the work in relation to it; or it is a device which positions two or more parts in a correct relationship with each other for assembly purposes; or it is a device which facilitates inspection.

24. A fixture both locates and holds the work. Since normally it is itself clamped to the table or face plate of the machine it therefore also locates the work in relation to the cutting, forming or grinding element. Because of this, tool guidance is, in theory, not required; but if the tool is not very rigid (such as a drill, which is likely to wander as it starts to cut) the tool is also guided to ensure positional accuracy.

25. For a more complete description of the types and uses of jigs, fixtures and other production equipment see Part II, articles 6 and 7.

26. Pressworking operations are performed on presses with punches and dies. Generally a complete set of pressworking tools is simply called a "die set". It usually contains a punch holder and a die block with accessories. For a more complete and detailed account of the basic principles and terminology used see Part II, article 1, also Annex IV.

Tool engineering

27. Tool engineering is concerned with the economic production of manufactured goods and deals with the design, development, analysis, planning, construction, operation, application, supervision and

follow-up of production methods, as well as the study of tools, equipment, and facilities for the manufacture of industrial and consumer goods.

28. Tool engineering includes in particular, the analysis, design, selection, construction, application and control of:

- *(a)* Cutting tools and accessories,
- *(b)* Workholding devices (jigs, fixtures),
- *(c)* Pressworking and forming tools (punches, dies),
- *(d)* Measuring instruments, gauges,
- *(e)* Tooling for welding, casting, assembling,
- *(f)* Tooling for non-conventional processes such as EDM, and
- *(g)* Special machine tools and components.

29. The primary function of the tool engineer is to analyse tooling problems and to design or select, and apply, suitable tools and tooling setups based upon technical knowledge, experience and ingenuity. In order to achieve these objectives he organizes men, materials, methods and machines so that quality products may be made economically and efficiently. The tool engineer continually improves manufacturing techniques. The complexity of modern manufacture makes it necessary that many functions of tool engineering be carried out by specialists, usually graduate engineers in either industrial, mechanical or production engineering. Engineering technicians with practical experience in tool and die-making and production processes are also needed. Figure 1 shows the functions and interrelationships of tool engineering in manufacturing, from product design to completion.

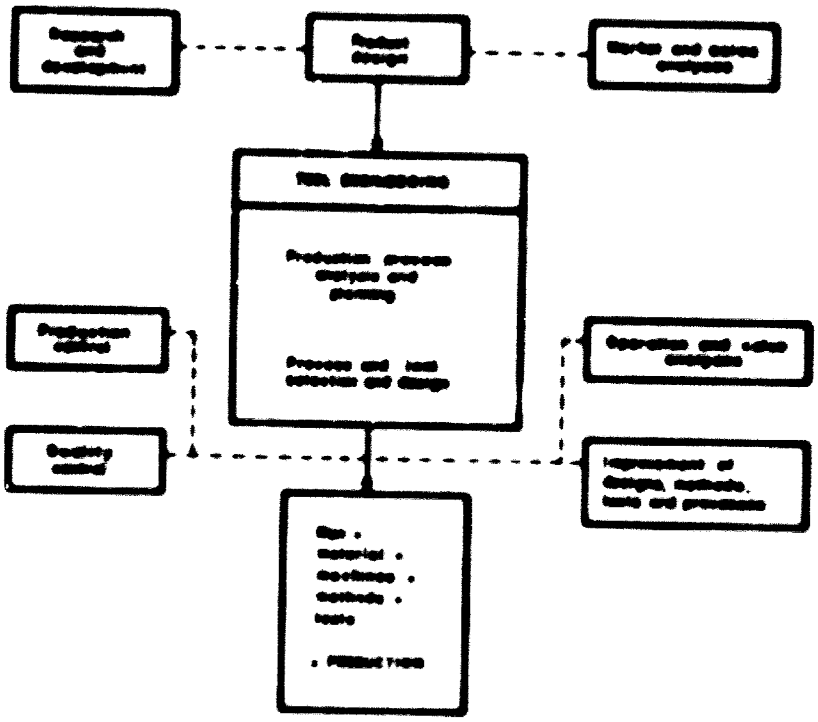


Figure 1. Tool engineering in manufacturing

PROCESS ANALYSIS AND PLANNING

30. The production decisions of management are implemented through process analysis and planning for the selection or design of an optimum process for a specific operation. In process planning the following factors should be carefully analysed:

- *(a)* Functional design requirements of the product; shape, size, material, strength, surface finish, appearance, weight, and volume,
- *(b)* Production requirements of the product; quantity and quality, tolerances, fits, surface finishes, cutting tools, work-holding devices, gauges, machine tools, equipment and facilities available,
- *(c)* Economy of production; tooling cost, setup cost, production cost, material cost, equipment cost, maintenance and power cost, gauging and inspection costs.

31. A process plan, which is usually expressed in the form of a route sheet, process sheet, or operation sheet, describes:

- *(a)* Required processes and operations and their sequence,
- *(b)* Machines and tools,
- *(c)* Specific operating conditions,
- *(d)* Specifications to be met,
- *(e)* Work space available,
- *(f)* Production time required, etc.

The design, construction or purchase, and disposition of all tools are based upon this process plan.

32. Process analysis and planning is continuous. It should always be guided by the simple objective of achieving optimum productive efficiency, i. e. of meeting the conditions for minimum cost per piece, or for maximum production rate, whilst maintaining the required quality standards. Thus, tool engineers must always look for ways of improving methods, e. g. selecting an alternative process, revising product design, changing specifications, advancing the tool design, altering the operational sequence, improving operating conditions, using new cutting tools, etc.

TOOL DESIGN

33. The basic object of tool design is to make it possible to produce the necessary quantity, meeting all specifications with optimum production, maximum efficiency and profit. General rules for good tooling design are:

- *(a)* Satisfactory performance of a specific function with maximum simplicity,

(b) Adequate quality,
(c) Optimum production,
(d) Maximum economy of motion,
(e) Use of available materials,
(f) Economy,
(g) Use of as many standard parts as possible.

By consideration of these factors, analysis of the problems involved and screening of alternative designs, the most suitable design can be chosen.

DESIGN OF JIGS AND FIXTURES FOR MACHINING OR GRINDING

34. The design of jigs and fixtures should be based on sound economic as well as technical considerations. Due attention should be paid to the estimated total number of parts for which the device is to be used, since the aim should always be to amortise cost out of earnings during the period of the production run (see subsequent notes, and Part II, article 9). Within the framework of justifiable expenditure the following design factors should then be considered:

(a) Location scheme,
(b) Loading methods,
(c) Clamping devices,
(d) Clearances for loading,
(e) Tool guidance,
(f) Swarf clearance,
(g) Manipulation,
(h) Rigidity,
(i) Burr grooves,
(j) Foolproofing,
(k) Ejecting devices,
(l) Tenons and table fixings,
(m) Setting blocks,
(n) Safety measures.

35. For consistent production results, it is essential to locate the workpiece accurately relative to the tool. This relationship is achieved by means of locators incorporated in the jig or fixture. The workpiece must be confined and restricted against movement in all directions except those needed for operation or handling.

36. The types of clamps used in jigs and fixtures are numerous, but the majority have several basic, common mechanical features such as a screw, cam, wedge, or hook.

37. To insure proper operation of the jig or fixture, the locating elements should position the workpiece accurately, and the structure should withstand the clamping and cutting forces. The clamps should apply only enough force to hold the workpiece in position.

38. The design of jigs and fixtures differs from the design of machine elements since it is influenced by the design and production specifications of the product. All jigs and fixtures must meet the following requirements:

(a) Perform a specific function,
(b) Meet precision requirements,

(c) Satisfy the production rate and schedule,
(d) Fulfil auxiliary demands such as safety, adaptability and convenience,
(e) Use standard parts whenever possible,
(f) Justify cost.

39. A tool designer must first define the problem and determine criteria for all factors to be considered, and then consider the following:

(a) Will the tool perform its function?
(b) Will the quality requirements be met?
(c) What funds are available for the design and construction of the tool?
(d) When must the tool be completed?
(e) What are the auxiliary factors to be considered?
(f) Would multi-tool or multi-workpiece operations be possible?

JIGS AND FIXTURES OTHER THAN THOSE USED FOR MACHINING OR GRINDING

40. There are many types of jigs and fixtures which are used for manufacturing processes other than machining or grinding, e.g., welding, assembly, inspection, but the basic design requirements and procedures are similar.

ADVANTAGES OF USING JIGS AND FIXTURES

41. The advantages of using jigs and fixtures are as follows:

(a) Elimination of laborious locating of workpiece before machining.
(b) Increase of machining accuracy due to accurate self-positioning of workpiece.
(c) Increase of production rate due to the increase of cutting feed, and depth of cut, made possible because of improved clamping rigidity.
(d) Increase of productivity due to machining of multiworkpieces or the use of multiple tools.
(e) Complete interchangeability of finished components which facilitates assembly and the supply of replacement parts.
(f) Reduction of labour costs per hour since the workers need less skill.
(g) If production quantity justifies the use of mechanical handling devices, labour costs may be further reduced, since one operator may serve several machines.
(h) Reduction of the costs of quality control.
(i) Maximum utilization of both the output capacity and the technical capabilities of the machine tools.

TYPICAL SEQUENCE OF STEPS IN DIE ENGINEERING

42. Briefly, the sequence of events related to the production of a normal die, or family of dies, for a manufacturing operation is as follows.

(a) An approved product specification, usually in the form of a drawing or blueprint, is submitted to a process engineer after manufacturing feasibility has been established. The process engineer determines the sequence of operations by which the part should be manufactured. He then co-ordinates his processing requirements with the facility-loading personnel to insure that the available press equipment can meet the production requirements.

(b) To complete the next sequence of operations the process engineer considers the number of forming or flanging dies required. There may be several such forming or flanging operations dependent upon the die type or the complexity of the part to be manufactured.

(c) In establishing the number of operations and the operational sequence, the processor considers the best method to be used for inserting and removing in-process parts from the various types of equipment in use. The production volume usually determines not only the type of die, but also the mechanical handling equipment required.

(d) The process information and press requirements are then forwarded to the die design source, or directly to the purchasing activity if the dies are to be designed and manufactured by the same outside source.

43. The final die design, based on original thought combined with standard die design data, results in a set of drawings and specifications from which patterns, castings and the finished dies will be manufactured.

44. It is important to be completely informed at all times of tooling costs. Therefore a cost estimate is prepared either by the manufacturing plant or by an approved die supplier.

45. A new cycle or chain of events begins after the various construction sources have been determined. Die component stock lists are prepared and arrangements are made to purchase the materials from approved vendors. A facility-loading co-ordinator reviews the various die estimates by elements to verify for facility loading and containment. This review is made primarily to determine whether or not the estimates are accurate, the proper construction equipment is available and the construction date can be met. This is followed by developing an individual die fabrication schedule. The construction progress is reviewed regularly to ensure that the construction timing is being followed.

THE PLACE OF DIES AND JIGS IN MODERN PRODUCTION ENGINEERING

46. Products offered by industry to the consumer must be manufactured as economically as possible. For this reason, dies, jigs and fixtures have taken, and continue to take a place of growing importance in modern industry.

47. Their use permits:

(a) The manufacture of large numbers of items at a high rate of production by efficient batch or mass-production techniques, instead of by laborious one-off manufacturing and hand fitting methods by craftsmen.

(b) Better utilization of production equipment, ensuring the more efficient use of capital invested.

(c) More effective and economical use of available manpower. The over-all reduction in labour costs is a result of two factors:

  (i) Less skill is required in production. It is therefore easier to find labour of the correct grade, or to train workers if required, and these workers command less pay than the skilled craftsmen who would be otherwise needed.

  (ii) In many instances, if the production run is long enough to make it economical, the processes and operations may be mechanized or automated. In this case one low grade worker can operate several machines, usually by merely feeding stock.

(d) The use of relatively simple, sturdy production machines. These are less expensive initially, and have a longer effective life in terms of parts machined, than the more sophisticated universal machines which would otherwise be needed.

(e) Complete interchangeability of component parts. This considerably simplifies assembly. For all but the most critical mating conditions, hand fitting of mating parts is unnecessary. Even if the fit is critical, selective assembly techniques are usually possible. It also enables a better service to be given to customers. If a replacement part is required it can be supplied from stock, in the knowledge that it will fit and will function satisfactorily.

(f) The holding of a constant and definite quality of production.

48. Considerable advances have been made in recent years in the development of better, more durable, special steels and other materials for making dies, jigs, and fixtures. Although they are relatively

expensive they enable such a large quantity of parts to be produced so efficiently, that their cost, when spread over all the parts they help to produce, becomes almost negligible.

49. As the cost of manufactured articles is reduced so the demand for them will increase. As the demand increases, sales increase and bigger production runs will be undertaken. Dies, jigs and fixtures thus become indispensable items of production equipment, and their use further reduces production costs. Such a process cannot fail to have a good effect on standards of living in the developing countries.

THE INFLUENCE OF DIES AND JIGS ON THE DESIGN, PRODUCTION AND QUALITY OF PRODUCTS

50. Increasing efficiency is vital to the existence and economic success of every enterprise.

51. This goal demands not only the continuous improvement of the products but also the rationalization of production methods by means of the construction and use of effective production aids such as tools, dies, jigs and fixtures, gauges, and so on.

52. In the design of these production aids, quality requirements must be considered, as well as the production time, in order to achieve the highest quality in the finished product in the shortest time.

53. Designers of products are basically concerned with the function of the parts, their reliability and their appearance.

54. The relationship between the functional and commercial characteristics of a product and its manufacturing characteristics should be rational so that it can be economically manufactured, i.e. involving a minimum of time and cost.

55. Designers of products should therefore also consider the manufacturing problems, and in the course of designing different parts they should consider the tools to be used to make them.

56. They should consider not only the form and reliability of the product, but also the interrelationship of the possible manufacturing processes. They should know about already existing dies, jigs and fixtures in the workshop and should keep them in mind when designing the products.

57. Alteration in the shape of a stamping can considerably reduce waste of metal without any detriment to the function of the part.

58. Careful analysis of possibilities of varying the design and dimensions of the part, may enable the manufacturing equipment and production time to be used more economically. It may often prove to be economical to change the dimensions of the parts being stamped so that it becomes possible to stamp small parts from the scrap left after larger parts have already been blanked.

59. Another example consists of separate elements which are stamped out and then welded together to form a given part. Economy in using this technique depends on the proper subdivision of elements, and on the condition that the subsequent welding is neither too complicated, nor too costly.

60. The combination stamping and welding process is of special advantage for small-scale production since it results in simpler stamping work. The over-all cost of the stamped articles is considerably reduced since less complicated equipment is required.

THE USE OF MODERN SCIENCE AND TECHNIQUES IN THE DEVELOPING COUNTRIES

61. Involvement with new techniques must be preceded by technical training in the art of tool and die making. The developing country must have the ability to:

(*a*) Diagnose problems, determine solutions and maintain the specialized equipment, and

(*b*) Train personnel in the application of the new processes.

62. It is not recommended that numerically controlled methods of making dies be considered at this stage of the developing countries. This process is still changing and the machine tools have a high rate of obsolescence. Numerically controlled machines are more profitable for small batch processing and are rarely economical for machining one-off components.

63. Standardization of tool and die design, which is sadly lacking in developing countries, will create duplication of the component parts of dies and jigs and make numerical control more attractive and profitable at some future time.

64. Furthermore, numerically controlled machines must be supported by access to a computer, and require computer programming skills.

ELECTRICAL DISCHARGE MACHINING

65. In 1943 a little noticed process made its appearance in industry. This process was known by several names: electro-oxography, spark erosion, eloxing, and finally, electrical discharge machining (EDM).

66. At first, EDM was not recognized as having a place in the machining process for tool and die making.

67. The process had its humble beginnings in the removal of broken thread taps. The machine used for this purpose generally had the design and configuration of a bench drill press, and was called a

disintegrator. Up until this time the removal of broken taps had been extremely troublesome; in fact, some die steel details were destroyed or severely damaged in the removal of a broken tap. An extension of the process was found in the use of copper or brass tubing electrodes to erode a hole in hardened steel parts.

68. As the use of the process developed, it became evident that this new machining technique had the potential to perform precision operations on hardened steel or the newly introduced exotic metals. The machine had to be re-designed with a servo system to control the spark gap automatically and to include co-ordinate movements of the machine table and precision ways.

69. Over a period of ten years, EDM grew from a simple salvage operation to a high-precision machining system.

70. The use of EDM offers a skills replacement as a machining process and its use in the developing countries should be considered. Application of the process, however, must be preceded by technical training in skilled trades, equipment maintenance, and processing techniques.

71. A first step should be the application of EDM for through-hole work (blanking dies, stamping punches, wire and profile drawing dies, die buttons, etc.). Only after these techniques have been mastered should surface cavity applications be considered. Part II, article 2 gives a more detailed explanation of the electrical discharge machine and its application.

FLAME HARDENING OF DIES

72. Dies are flame hardened by the progressive or scanning method. The flame-quench head hardens the die surface by moving over it. Proper hardening results depend on the judgement and skill of the operator. He must adjust the flame height and quench properly to give proper intensity and depth of hardness. As the head is scanned over the area to be hardened, the operator must judge the temperature accurately and move the head forward at the proper rate to give the maximum hardness attainable without burning the surface. Further details of flame hardening are given in Part II, article 3.

APPLICATION OF PLASTICS TO DIE AND JIG MANUFACTURE

73. The use of plastics for making production equipment has opened up immense prospects for increasing the speed of the preparatory phases of production and has facilitated the application of advanced high-productivity methods in mass production. It is particularly advantageous to use plastics in those branches of machine tool con-

struction in which, because of short runs and the frequency with which the products are changed, less sturdy but more rapidly and easily manufactured production equipment is needed.

74. Although equipment of this type is less durable than that made of metal, it has definite advantages. The replacement of metal by plastics results in a saving of money and of scarce materials. Production equipment made of plastics is considerably lighter and cheaper. In some cases, when plastics are used, equipment can be made eight to ten times more rapidly and at one fourth to one fifth of the original cost. Manufacturing techniques are simpler and more effective, and consequently less complicated tools and less skilled workers are needed.

75. Plastics can be used for making drawing and bending dies, for machine-tool assembly, and for checking jigs, patterns, gauges, certain types of fitting instruments, models, core boxes and moulds.

76. The manufacture of dies from plastics eliminates the need for profile machining and metal-finishing work, which account for 50 per cent of the total labour spent on making metal dies. Plastics can be used to make the working parts of all types of dies but not the cutting components.

77. There are various ways of making the shaping parts of dies (the punches, the matrices and the clamping elements) from plastics, including casting in moulds, or pressing. At present the most widely used method of preparing the shaping parts of dies is to cast them in compounds based on epoxy resins.

78. In the design and production of jigs and fixtures, plastics are used mainly to make small plate jigs by moulding a plate around accurately located jig bushings, to make seatings and certain types of body components, and to cement separate components together.

79. Components for production equipment may be made from various synthetic resins. Not all of these resins however, possess the necessary mechanical properties, nor are they all suitable for one-off or small series production. Plastics cannot always be considered the ideal replacement for metals. In selecting plastics as construction materials, account must be taken not only of their physical and mechanical properties but also of their use and other factors affecting them.

80. In order to speed up the production of equipment, a method has been devised for the manufacture of jig and fixture bodies by casting them in disposable moulds, using master metal parts as inserts. This method considerably reduces, or completely eliminates, the need for subsequent machining. For further details, see Part II, articles 4 and 5.

Precision casting applied to die and jig manufacture

81. Sand castings have long been specified by the tool and die industry for jig and fixture bases, largely because sand casting is a convenient way of making them in cast iron, a material which, because of its high graphitic carbon content, has a natural tendency to dampen out the vibrations set up by machining.

82. Sand casting is also used for making large complicated parts in cast iron, steel and other metals which would be more expensive to machine out of the solid.

83. The use of sand moulds made from wooden patterns, though suitable for one-off and small-batch production, results in notoriously inaccurate castings with many surface imperfections. Where features have to be machined, as much as 5 mm is frequently left on for this purpose.

84. The most accurate casting process is, of course, pressure die-casting, but this is normally used only for alloys of comparatively low melting point. It also involves the use of expensive machines and dies, which makes the process unsuitable for making a few tool and die parts.

85. There is a real need in the tool and die industries of the developing countries for precision castings having a good surface finish which can be produced in any metal or alloy, in small numbers, with the minimum amount of special equipment.

86. Two such processes do exist; investment casting and ceramic moulding. Both of these can be applied to the production of castings so accurate, and having such a good surface finish, that many of the features which would otherwise have to be machined can be left in the as-cast condition, and where machining is essential (for critical fits and for producing flat surfaces) as little as 0.25 mm can be left on.

87. These processes can be used in the production of countless parts for jigs, fixtures and die assemblies. They are also capable of reproducing such excellent intricate detail that punches, dies and moulds of all kinds can be cast with punch faces, or die or mould cavities, which require little more than shot or vapour blasting and the very minimum of hand finishing or polishing.

88. This results in a considerable saving, both in material, and in the labour costs which would otherwise be involved in machining these impressions out of the solid, either by means of copying machines, or by the more modern EDM techniques.

Investment casting

89. Investment casting, which is sometimes referred to as the lost wax process, has been in use in various forms and under a variety of

different names for thousands of years. It is the only process in which castings may be produced in one-piece moulds. This is made possible by the use of thermoplastic or thermoplastic-soluble destructible patterns.

90. The term "destructible" here applies to the shape or form of the pattern—which is melted or leached out to provide the mould cavity—not to the total destruction of the material. Some pattern material is, however, lost during the process—hence the term "lost wax" (although wax is only one of many pattern materials which may be used).

91. Since moulds are created around these patterns in one piece, there are no parting lines, and consequently there is no tendency for the halves (or parts) of the mould to open or flex under the pressure of the molten metal or the gases generated in the mould cavity during casting.

92. The process is capable of producing castings which have multi-directional accuracies of 0.05 mm per linear cm, or better, and an as-cast surface finish having a maximum centre-line average (CLA) reading of 1.5 microns, depending on the alloy cast. There is, however, some limitation in the size of the castings which can be produced by investment casting.

93. The material used for the mould is a liquid slurry containing a refractory filler, which is either poured into a flask surrounding the destructible pattern assembly to form a solid or block mould, or into which the assembly is repeatedly dipped and then stuccoed to form a one-piece ceramic shell mould.

94. So many different materials can be used for the patterns and the moulds, so many variations of the basic principles and techniques exist, and such a variety of alternative methods and equipment may be used, that investment casting is really not one process, but many.

95. In Part II, article 5, the process is described in all its details and ramifications, as applied to large-scale batch or mass production. Alternative materials, techniques and equipment which can be used are discussed at every stage. The article then explains how the process may be adapted to the particular needs of the tool and die industry.

96. The choice of the variation of the process most appropriate to any particular developing country depends first on the raw materials available for making the destructible patterns and the moulds, and secondly, on the equipment available.

97. The purchase of expensive equipment by a tool and die firm, solely to enable it to produce one-off or small quantities of investment castings might be difficult to justify economically; but some equipment will probably already exist which could be used, or adapted to one of the variations of the process.

98. Some equipment which is normally used for large-batch or mass production can be dispensed with where only small numbers are involved. Destructible patterns, for example, need not be injected into dies—most of the materials used machine well and, being thermoplastic, can be initially heated and deformed roughly into shape. Or they can be gravity-cast into cheap, improvised dies.

99. Some of the equipment required is, of course, essential. Part II, article 5 gives details of how this can be improvised, or how cheap, simple versions of it may be made. Utilization, adaptation and improvisation are the key words.

Ceramic moulding

100. Ceramic moulding enables much bigger castings to be produced than are possible with investment casting. It uses the same kinds of liquid slurry mould materials, giving comparable surface finishes and detail in reproduction, but solid patterns are used, as for ordinary sand casting. The moulds must therefore be made in at least two pieces to enable the patterns to be removed.

101. This makes it impossible to achieve the multi-directional accuracy associated with investment casting, although the accuracy in line with the faces of the moulds, and at right angles to them within the individual cavities, is comparable to it.

102. The processes used are, therefore, eminently suitable for casting the larger punches and dies for hot and cold stamping and deformation of metals (pressing, coining, embossing, etc.), dies for gravity and pressure diecasting, and for moulding dies and blow moulds for rubber and plastic.

103. Many aspects of individual ceramic-moulding processes, known under such trade names as the Alphax process, the Unicast process, the Shaw process, the Ceramicast process, and others, have been patented, and the processes are used under licence from the owner firms.

104. Little or no special equipment is required, and only the minimum of additional floor or bench space. Firms in the tool and die industry can easily set up their own mould-making shops, possibly as an extension to an already existing pattern-making department.

105. They might even consider installing metal melting and pouring equipment, if this is not already available, so that they create a self-contained unit for producing their own precision castings.

106. Alternatively, these tool and die firms may produce the precision ceramic moulds themselves, and then send them to some convenient local foundry for the actual casting operation to be carried out. Further details on ceramic moulding are given in Part II, article 5.

Manufacturing families of parts

107. Rationalizing the production of small batches of a part is far more complex than rationalizing the production of large quantities of the same part.

108. Large-scale production of nominally identical parts requires specialized machine tools, but the manufacturer of small batches has to handle a great variety of different components. Continuous flow of material and the use of specialized machine tools are nearly impossible. Rationalization of small quantity batch production is therefore difficult. One way of avoiding this problem is to increase the size of job lots by the use of techniques for manufacturing families of parts. Such techniques take advantage of the similarity of the shape and design of parts to employ the same production methods, thereby permitting batches of slightly different parts to be processed in the same run, so that the same tools, machines, dies, jigs and fixtures may be used for particular operations. These techniques do, however, require considerable skill in the processing of the parts through the manufacturing system.

THE ORGANIZATION OF DIE AND JIG PRODUCTION IN DEVELOPING COUNTRIES

109. The basic structure for organizing the production of dies, jigs and fixtures in the developing countries should provide measures for overcoming the major inherent difficulties which are:

(*a*) Shortage of skilled manpower,
(*b*) Lack of technical know-how,
(*c*) Short production runs,
(*d*) Inadequate equipment,
(*e*) Shortage of funds and general resources.

110. An examination of each of these problems from the point of view of related experiences in developed countries leads to recommendations for remedial measures. But recommendations concerning the structural organization—such as the development of independent versus captive toolrooms—would not be valid without considering specific conditions which vary considerably from one developing country to another.

111. The captive toolroom is one whose output is exclusively for the use of a parent company. The parent company generally makes products other than tooling. For example, a motor car manufacturing company's principal product is automobiles, whilst the principal product of its tool and die plant is tools and dies for the parent company's work.

112. The independent toolroom's principal product is tools and dies. However, it generally supplies more than one manufacturing organization whose principal product is not tools and dies.

113. This group believes that in order to use limited resources to the maximum, a guiding agency is essential. For this reason the proposal for creating common facility centres is put forward. Obviously, there are areas in which, for geographical or economic reasons, the establishment of such a centre may not be feasible. For such areas, this group recommends that UNIDO assumes a guiding function, together with the local government—using the proposals as recommended for the common facility centres.

COMMON FACILITY CENTRES

114. Considering the various possible means and actions which can be taken by the developing nations, in order to expedite and promote their productions of dies, jigs and fixtures, the group of experts recommends the formation of centralized establishments. Their main task would be to promote the general advancement of the tool and die industry in the developing country.

115. It was agreed to name them common facility centres. The basic objectives of each would be to diffuse modern techniques of die, jig and fixture production, in fields indicated by the general economic planning of the given area, by performing the following tasks:

(*a*) Creating a facility, equipped with all the necessary modern die- and toolmaking machines and equipment, and heat treatment and inspection installations.

(*b*) Creating a design consultancy.

(*c*) Upgrading the skills of personnel for die and toolmaking.

(*d*) Maintaining a central technical library.

(*e*) Manufacturing standardized parts and possibly complete specialized dies, jigs and fixtures.

(*f*) Acting as a central testing and inspection bureau for dies, jigs and fixtures.

(*g*) Acting as a lending agency for universal dies, jigs and fixtures.

(*h*) Facilitating the acquisition of cutting tools and special steel and other materials for die, jig and fixture construction.

(*i*) Promoting co-operation between industries in the developing countries and their counterpart industries in the industrially developed countries.

These tasks would be implemented in the ways described in the following paragraphs.

116. The selection of the equipment for each centre (which depends on the needs of local industries) should be determined by surveys carried out with the assistance of UNIDO experts.

117. The advisory and consulting activities of the centre would cover:

- (*a*) Advice on the manufacturing feasibility of products contemplated.
- (*b*) Recommending manufacturing processes.
- (*c*) Making recommendations on toolings and their design.
- (*d*) Making available direct assistance in die, jig and fixture design.
- (*e*) Giving consultative advice on the selection of machine tools and equipment for the new toolrooms and independent tool shops in the area.
- (*f*) Making recommendations to local industry on the correct maintenance and repair procedures for dies, jigs and fixtures.
- (*g*) Establishing a code of practice and promoting national standards and a numerical classification for dies, jigs and fixtures and their elements.

118. To accelerate the manufacture of dies, jigs and fixtures in the developing country it is recommended that the common facility centre should give priority to the upgrading of the skills of existing craftsmen and technicians to the level required for the toolmaking industry.

119. The technical library of the centre, besides keeping a stock of the latest publications, books and manuals on the subject of dies, jigs and fixtures, should collect up-to-date technical information for the use of local industry.

120. Besides manufacturing standard parts and components, and where manufacturing capacities are available, a centre may make or develop dies, jigs and fixtures on behalf of local industry, provided that the management of the centre is satisfied that the facilities for this work do not exist within the companies involved.

121. Similarly, the centre could use its heat treatment facilities for carrying out work on behalf of local industry.

122. Laboratories for metallographic and materials testing, and for the inspection of work, should be available at the centre for the testing and inspection of materials and finished components of the dies, jigs and fixtures made at the centre, and by outside firms, thus providing a central service for local industry.

123. In view of the need for a rational use of resources it is recommended that the centre maintains a stock of universal dies, jigs and fixtures for lending to local industry. The decision on the type of tooling to be maintained at the centre for outside use should be

decided by experts in accordance with local conditions. In paragraphs 125 to 136 below, we have enumerated the types of universal tooling available.

124. The lack of specialized materials for some of the component parts of dies, jigs and fixtures, or the lack of an adequate supply of cutting tools, could cripple a centre's activities. It is therefore strongly recommended that the Governments of the developing countries should help to make available such supplies, by giving importation privileges, stocking them through specialized agencies, or by other means at their disposal.

UTILIZATION OF UNIVERSAL TOOLING

125. There are two main systems of universal dies, jigs and fixtures:

(*a*) Composite system (built up completely of standard exchangeable components).

(*b*) Exchangeable or adjustable-component system.

Part II, articles 6 and 7 give comprehensive studies of the two types referred to above.

126. The universal (sometimes called the "universally adaptable") die, jig and fixture systems save a considerable amount of time and thus reduce the cost of preparing dies, jigs and fixtures for the production of new parts. They enable dies, jigs and fixtures to be remodelled or adjusted easily and quickly if the part being produced is changed.

127. The composite system enables individual elements to be used a number of times for the assembly of different kinds of dies, jigs and fixtures. This system makes it possible to use dies, jigs and fixtures in factories producing only small batches, where their design and manufacture would ordinarily be uneconomical.

128. Among the shortcomings of the composite system are:

(*a*) The lower rigidity of jigs and fixtures in particular, because, in some cases, they contain a large number of joints.

(*b*) Their unsuitability for the incorporation of quick-acting, power-driven pneumatic or hydraulic clamping mechanisms.

(*c*) The high initial cost of a set of parts, due to the large number of parts involved.

129. The exchangeable or adjustable-component system, on the other hand, lends itself more to quick-acting, pneumatic or hydraulic clamping mechanisms, and its initial cost is less than that of the composite system, provided that batches of similar parts are being produced.

130. A complete set of parts for the universal composite system is usually considered to be too costly for a single factory, but it is advantageous to a co-operative operation. The extent of the com-

ponents in the system to comply with the needs of a given area should be determined by special studies for the area.

131. Experience shows that the majority (about 60 per cent) of the parts in composite jig and fixture sets are used for making drilling jigs or fixtures, about 30 per cent of them are used for making milling fixtures, and about 7 per cent are used for making turning fixtures. The remaining 3 per cent are used for making other types of jigs and fixtures such as checking jigs, grinding fixtures, shaping fixtures.

132. It is only natural that these proportions will vary according to the degree of development of the system.

133. The main users of the composite jig and fixture system are:

Textile machinery manufacturers,
Printing machinery producers,
Pump manufacturers, and
General machinery manufacturers.

134. Since the maintenance and upkeep of the various parts of a universal composite system is of the utmost importance, specific arrangements must be made for replacement of lost or damaged parts. This could be the responsibility of a common facility centre for the die, jig and fixture industry.

135. In considering the effectiveness of using either type of universally adaptable dies, jigs and fixtures, it should be noted that their wide use, and their mechanization and automation, not only considerably reduce the time and money spent preparing for production, but also increase the productivity of labour.

136. Part II, article 8 embodies a more comprehensive study on the application of universal dies for stamping.

ECONOMIC AND MANAGEMENT ASPECTS OF DIE AND JIG PRODUCTION

THE ECONOMICS OF DIES AND JIGS

137. In arriving at the selling cost of production items for which any form of special equipment has been designed and manufactured, due attention must be paid to the complete amortisation of the costs of the special equipment. This is particularly relevant to the design and manufacture of dies, jigs and fixtures. In assessing the manufacturing costs per part, allowance should be made for recovering cost out of earnings, and breaking even, or for making an additional profit, either within the useful life of the equipment, or within the term of the production run, whichever is the shorter.

138. The methods by which this may be achieved are well documented and reference may also be made to Part II, articles 7 and 9.

MANAGEMENT ASPECTS OF DIE AND JIG PRODUCTION

Leadership

139. The first priority for a successful toolmaking organization is for the management to assign a qualified leader for the activity. This is a function requiring an individual with a combination of theoretical knowledge and a thorough practical background. With this type of leadership, the organization should develop into a strong and efficient unit. Management must, of course, provide the location, the means, the necessary equipment and the guidelines. A plan for an efficient training unit should be a part of the programme.

Personnel

140. The manpower and skill factor is critical. It is important to apply an efficient training programme, making use of modern training methods including the use of teaching aids, but incentives are also needed so as to keep the trained personnel after the end of their training period.

Materials

141. Another factor of good management for toolmaking is its insistence upon suitable tool steel and other raw materials. The making of good tool steel is an intricate process, it contains many variables. Good tools, however, cannot be made without the correct materials. In this matter management must make an early decision and formulate its policy on the quality of tools it desires. There should be room in this decision for change, if and when change is needed.

142. The scarcity of some raw material, particularly tool steels, both alloy steels and those with a high carbon content, can be a serious problem for the developing country. Normal procedure would call for a one- to three-months' stock of the more commonly used types. The developing country, probably remote from a supplier, will need to look carefully into its supply requirements, and perhaps operate on a six-month, or even longer, lead time for tool steel. Considerable caution needs to be exercised concerning product variety because of tool steel supply problems.

Policy and procedures

143. A plan and procedure needs to be established for a year at a time. The plan and policy should be reviewed after six months, changes made in policy if needed, and a further look taken for

another year ahead. Where possible, a longer period should be considered which would encompass two or even three years, in advance, for establishing future targets.

144. During the period when these reviews are being discussed, and changes made where necessary, all costs should be reviewed, so as to initiate savings wherever possible, while maintaining tool quality and standards.

145. Another factor which calls for long range plans and periodic review is that of personnel training. The human element is one which must be constantly reviewed, always with the objective of upgrading when warranted.

146. A policy of research and improvement is one to be constantly stressed. A key individual should be designated and given responsibility to act where needed, to improve the policy set by management.

Organization

147. Wherever possible, management should designate specific responsibility for the following functions to specialized tool personnel:

(*a*) Design and engineering,
(*b*) Manufacture,
(*c*) Inspection of finished products and raw materials,
(*d*) Care and maintenance,
(*e*) Control, application and testing.

It should also set up and maintain a committee responsible for analysing and reviewing all tool problems and failures.

148. The size of the company may not warrant separate personnel for each of the above. Theoretically, an industrial, mechanical or production engineer with a good background should possess the necessary qualifications to handle all the above. It is unfortunate, however, that an engineer does not always have the practical knowledge that is so essential for the proper design, application and care of tools. It should be emphasized that if more than one speciality is to be designated to one person he must be well qualified to carry out the functions of every division of responsibility allocated to him. Proper experience, both practical and theoretical, is essential for successful tooling manufacture.

MANPOWER REQUIREMENTS AND UPGRADING OF CRAFTSMEN'S SKILLS

Skills required for the design stage

149. A competent designer will be able to make decisions on the following points:

(a) Manufacturing feasibility (decision on the product specification from the point of view of its practicability for production).
(b) The choice of manufacturing processes and sequences. This is the means by which the engineer determines the sequence of operations required for making the part.
(c) Determination of methods for tooling.
(d) Layout of the tooling.
(e) Detail design, draughting, tracing and checking.

Skills required for the execution stage

150. A competent production engineer will be able to decide the following points:

(a) Layout,
(b) Manufacture of templates, cams, models,
(c) Machining,
(d) Heat treatment,
(e) Bench finishing,
(f) Inspection,
(g) Testing and try-out.

Upgrading of skills

151. To meet the urgent requirements for trained personnel in the tool and die industry in developing countries, it is recommended that advantage be taken of the inherent skills already possessed by personnel engaged in related crafts. Provided that care is taken in the selection of the personnel most able to benefit from a system of upgrading training, a lathe operator in a production factory could, for example, be given the necessary further instruction to upgrade him to the skills of a toolroom turner. This could be done in a fraction of the time required to produce a toolroom turner by traditional apprenticeship (see Part II, article 10).

152. The problems of training jig and tool draughtsmen are, however, far more acute and it is recommended that personnel who are found to have an aptitude for expressing their ideas in drawing form should work under the guidance of tool and die experts to acquire the necessary skill for this work.

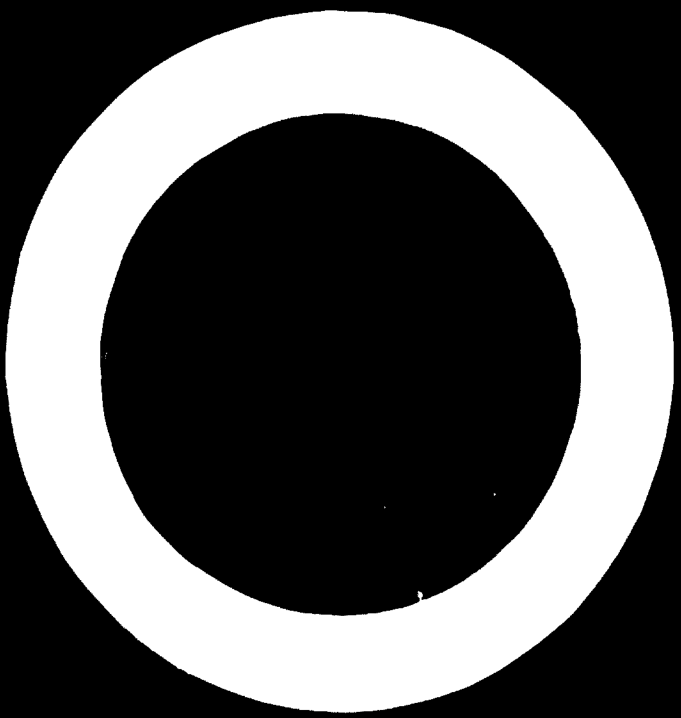
153. Table 4 at the end of Part II, article 10, gives the estimated time required for this training, and that for training personnel for many other skills. It takes into account the fact that engineers and draughtsmen in the developing countries require to be trained to a

higher degree of self-sufficiency than those in the developed countries, because the latter have more facilities at their disposal and more access to professional consultation.

154. The periods of time suggested are only approximate and are meant to be taken as a guide. The table also recommends the locality at which, ideally, this training should be carried out, i. e. whether it should be carried out in the local factory, at one of the proposed common facility centres, or at a specialized establishment abroad. It is realized, however, that the final decisions on the location of this training and the time required for it will depend on local conditions and many other factors prevailing at the time.

Part II

PROCEEDINGS, BASED ON PAPERS PRESENTED TO THE GROUP



BASIC PRINCIPLES AND TERMINOLOGY USED IN MATERIAL-FORMING PROCESSES

I. Ham[*]

Material is formed by numerous processes and operations such as shearing, bending, drawing, squeezing, forging, rolling, and extrusion, are the commonest processes, (see figures 1 *(a)* and *(b)*). Most of these processes employ pressworking operations, in which a press applies a large force through tools, usually punches and dies, to shear or form the work material into a desired shape.

In planning a pressworking operation, the following steps are usually taken:

(a) Product analysis,
(b) Process selection,
(c) Operations analysis,
(d) Selection or design of a die set,
(e) Selection of a punch press.

PRESSWORKING OPERATIONS

Presswork is done with a power press consisting of a structural frame, a bed or bolster plate, and a reciprocating mechanism with a ram or slide which exerts force upon the work material through a punch and die set mounted on the ram and bed. There are many types of presses, possessing different structural and functional designs, capacities, driving mechanisms, and power sources. A complete set of pressworking tools is called a die set and usually contains a punch and punch holder, and a die or die block on a die shoe, which are aligned by guide pins, and other accessories as shown in figure 2. Standard die sets are available commercially in a large variety of styles and sizes, and are used for convenience and economy.

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[*] Pennsylvania State University

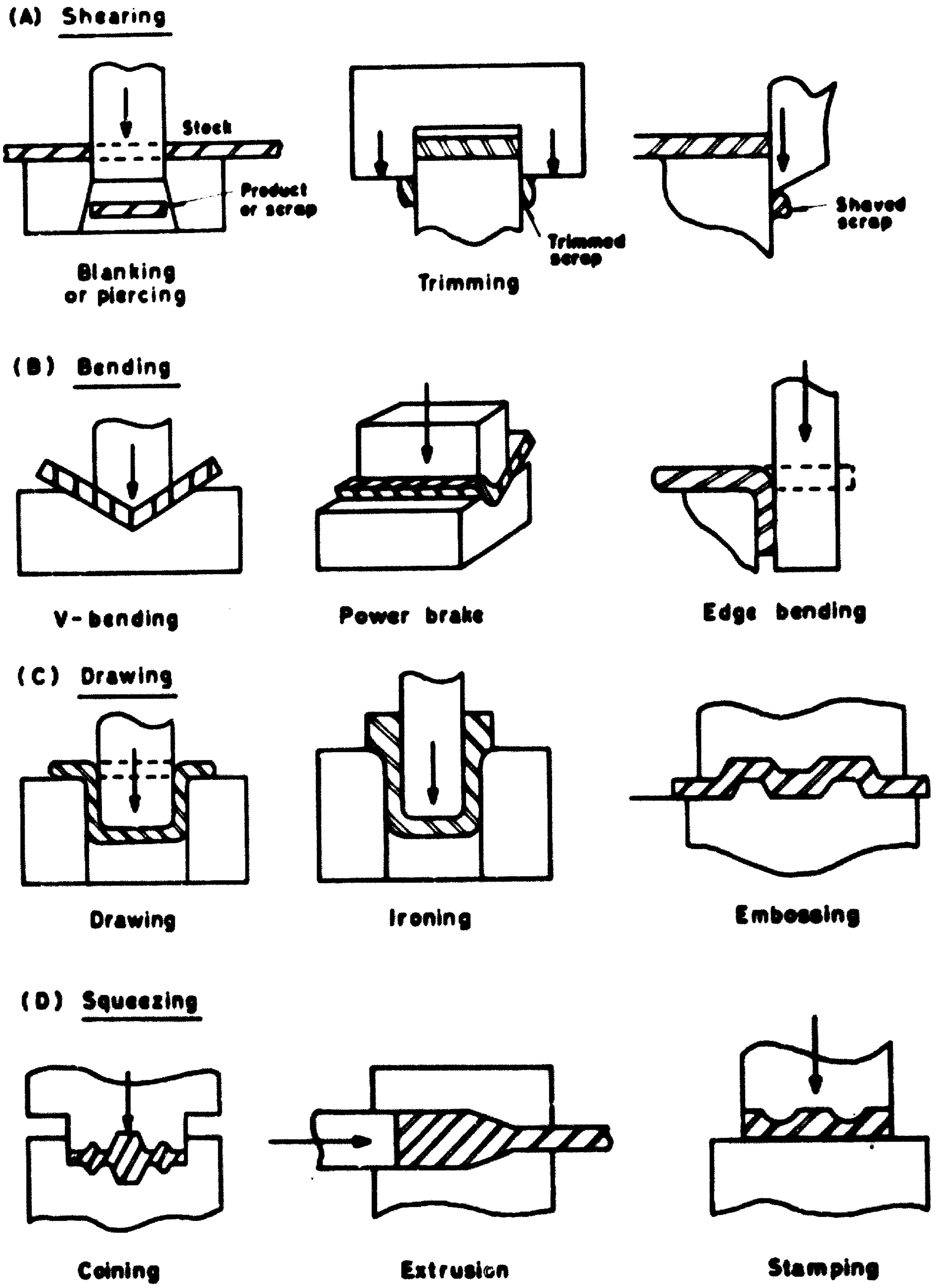


Figure 1 (a). Typical material-forming processes

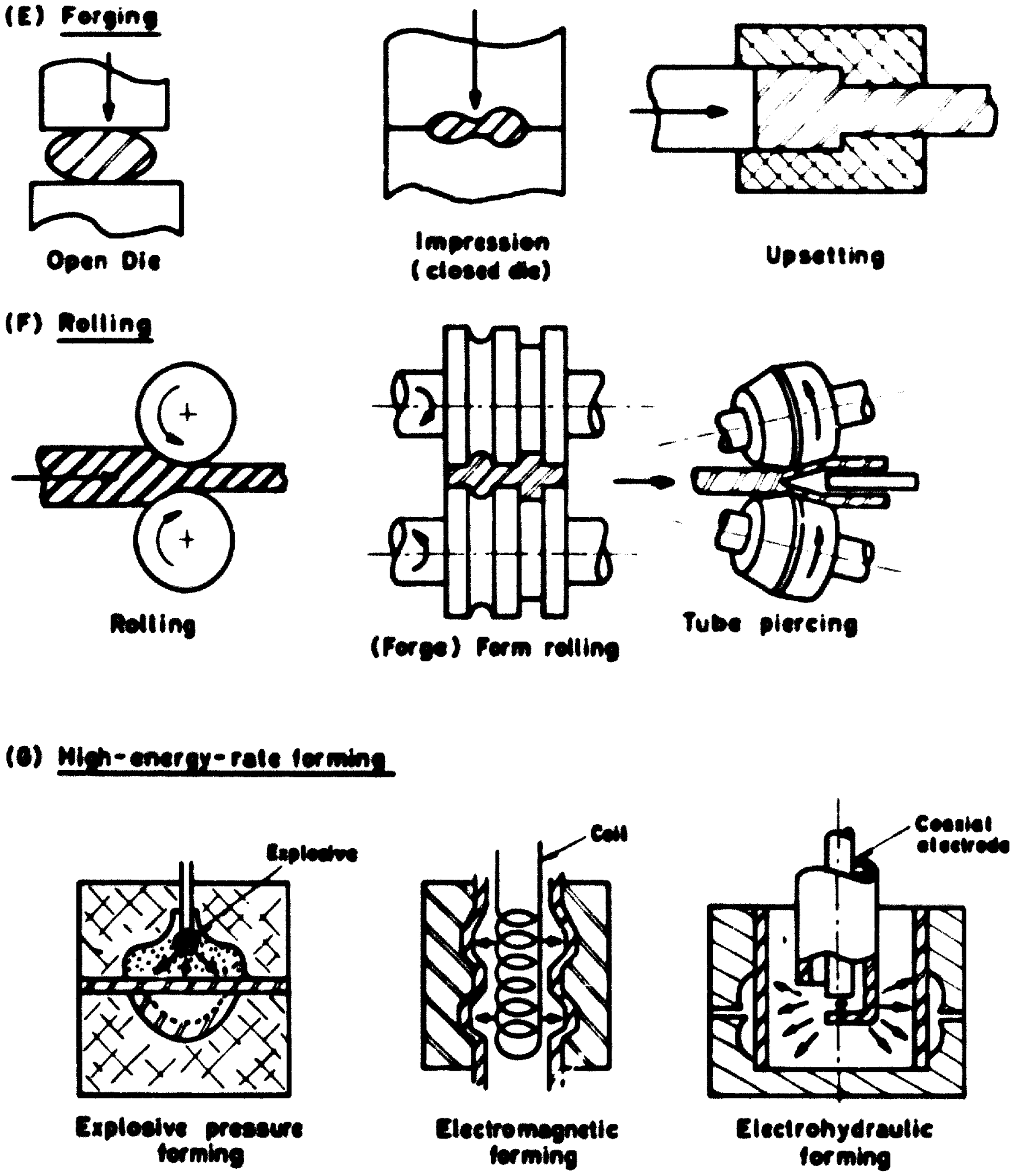


Figure 1 (b). Typical material-forming processes

SHEARING

In pressworking of sheet metal the dies are mounted in various ways, depending upon the operation to be performed. Some of the typical arrangements are: *(a)* simple die, *(b)* inverted die, *(c)* progressive die (see figure 2), *(d)* compound die.

In blanking, piercing, trimming, shaving, there is a shearing process in which the material is stressed in shear between the cutting edges of the punch and die. As the load is applied and

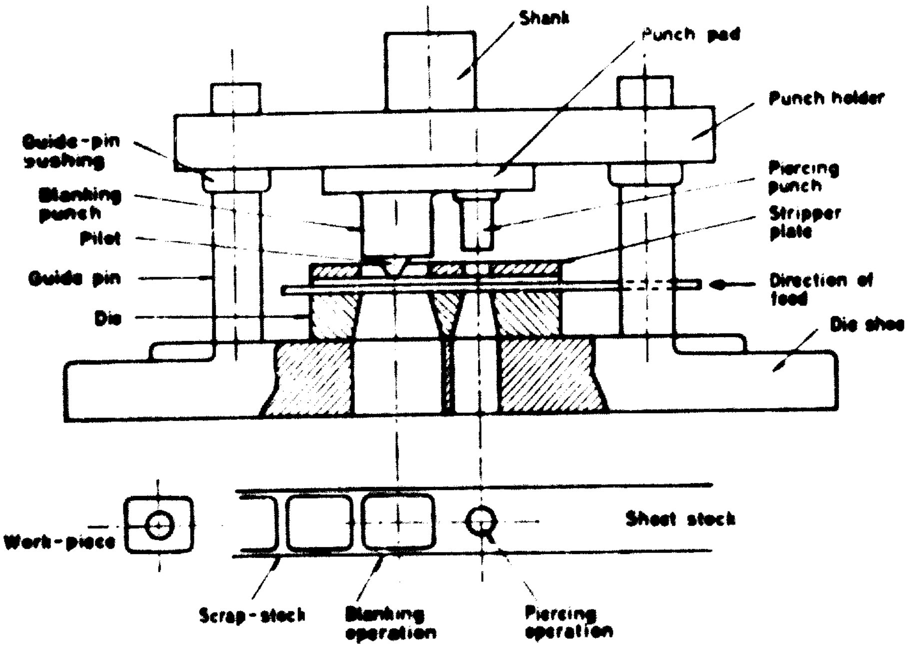
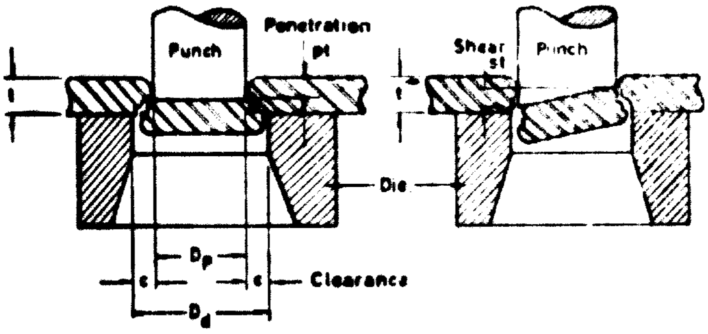


Figure 2. Basic components of a punch-die set (progressive die set)

increased, the material is subject to tensile and compressive stresses, and plastic deformation occurs past the elastic limit. When the ultimate tensile strength is exceeded the fracture occurs. As illustrated in figures 3 (*a*) and (*b*), the punch penetrates the metal to a certain depth before fracture. Penetration, *p*, as shown in the table below



(a) Penetration, p per cent (b) "Shear", s per cent

Figure 3. Shearing process in pressworking

Material	Percentage peneration, p, before fracture
Aluminium	60
Copper	55
Brass	50
Bronze	25
Annealed steel, 0.10% C	50
Cold-rolled steel, 0.10% C	38
Annealed steel, 0.20% C	40
Cold-rolled steel, 0.20% C	28

figure 3, is usually expressed as a percentage of the material thickness and varies with the materials and treatment received. To reduce the peak load of the operation by shearing a little at a time, an angular "shear" is ground on the punch or die as shown in figure 3 *(b)*. This "shear", s, is usually expressed as either a percentage or a fraction of the work material thickness, t. The pressure required for a shearing operation is a function of the shear strength and hardness, the penetration of the work material, the clearance between the punch and die, the sharpness of the cutting edges, and the amount of "shear" on the punch or die.

The force, P, is then expressed by

$$P_0 = \sigma_s Lt$$

$$P_p = \sigma_s Lpt = P_0 p$$

(when p is known and $s = 0$)

$$P_{sp} = \sigma_s Lpt\left[\frac{1}{1 + (s/p)}\right] = P_p\left[\frac{1}{1 + (s/p)}\right] \text{ (when both } p \text{ and } s \text{ are applied)}$$

$$E_0 = P_0 t \text{ or } E = P_p(pt) = P_{sp}(pt + st)$$

where P_0, P_p, P_{sp} = forces required, 1b

σ_s = shear strength of material, pounds per square inch (psi)

L = perimeter of workpiece for shearing, inches (in) for a round workpiece of diameter D, $L = \pi D$ in

t = material thickness, in

p, s = penetration and "shear" as a percentage of the material thickness

E = energy required, inch-pounds (in-1b).

After determining the force in pounds required for the operation, a die set with the necessary components should be selected or designed on the basis of the following factors:

(a) Type and size of press,
(b) Evaluation of the selected press,
(c) Type of die set for the operation,
(d) Tool steels and heat treatment required,
(e) Feeding method and mechanism,
(f) Stock-strip layout,
(g) Stripping or ejecting method,
(h) Shaving or trimming which may be necessary,
(i) Standard die set,
(j) Die space.

For a typical die set, it is usually necessary to design the following components or accessories: scrap strip, die block, punch, punch plate, pilot, gauges, stops, stripper, fasteners.

Selection of press

In the selection of a press for an operation, the following factors should be considered:

- *(a)* Capacity (rated tonnage, flywheel energy and motor horsepower (hp));
- *(b)* Type and size of the press (frame construction, bed opening and space, shut height, bolster plate size);
- *(c)* Feeding method;
- *(d)* Speed of operation and length of stroke (crank velocity and ram stroke);
- *(e)* Number of presses required (production quantity and production rate).

For production economy it is most important to select the right press and to design a scrap-strip layout for the least amount of scrap.

Shearing operations are usually done on mechanical presses having a direct-acting ram which travels straight up and down. Bending and forming operations require a more closely held ram stroke since the ram stroke is stopped by a stationary die block and a dwell is needed at the bottom of the stroke. For drawing operations, control of the ram stroke is critical and a dwell at the end of the stroke also is essential. Provision for blankholding must be considered. Squeezing operations, such as coining and swaging, require a cumulative block with all the flywheel energy utilized as the ram comes to a dead stop.

Punch design

The determination of punch dimensions has been generally based on practical experience. The maximum allowable length of a punch, L, can be calculated by

$$L = \frac{\pi D_p}{8} \sqrt{\frac{E\, D_p}{\sigma_s\, t}}$$

where E = modulus of elasticity, psi

σ_s = shear stress, psi

D_p = diameter of punch, in; D_d = diameter of die, in

$\frac{D_p}{t} \geq 1.1$

Stripper-plate design

The object of a stripper plate is to strip the workpiece form a die or punch. The plate thickness must be sufficient to withstand the stripping force required. The stripper spring also must be designed for the stripping action.

$$P_s = 3500\,Lt$$

where P_s = stripping force, lb
L = perimeter of shear, in
t = stock thickness, in

$$T = \frac{W}{30} + 2t$$

where T = thickness of stripper plate, in
W = width of stock strip, in
t = thickness of stock strip, in.

BENDING

The bending operation involves the plastic deformation of the metal by exceeding its elastic limit but not its ultimate tensile strength.

There are three basic forms of sheet metal stampings, flat, bent and formed. Presswork processes usually combine all three of these and produce various types of uniaxial bends, form bends, seaming, curling and hemming, flanging tabs and lugs, bridges or louvers, beading and ribbing.

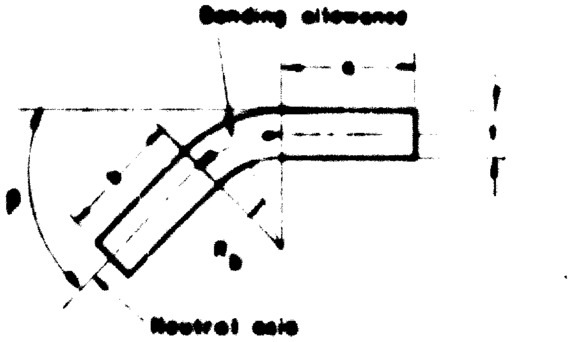


Figure 4. Basic relationships of the bending operation

In designing a bending die the following items are essential and should be analysed carefully (see figure 4):

(*a*) Bend method;
(*b*) Bend radii, R_b, minimum bend radii;
(*c*) Bending allowance, A_b, length of bent metal;
(*d*) Bending force, P_b;
(*e*) Spring back, or change in the bend angle after bending;
(*f*) Stock size and final dimensions;
(*g*) Bend location tolerances.

$$A_b = \frac{2\pi\beta}{360}\,(R_b + c_t)$$

$$P_b = \frac{K\sigma_t l t^2}{W}$$

where β = bend angle, degrees
R_b = bend radius (inside), in (fig. 4)
t = material thickness, in
c = constant; when $R_b < 2t$, $c = 0.33$
$R_b > 2t$, $c = 0.50$
K = constant, 0.67
l = length of bent part, in
σ_t = ultimate tensile strength, psi
W = width of die, in.

Also $$L = a + b + A_b$$

where L = length of material required before bend
a, b, have the meanings indicated in figure 4.

DRAWING

Various cylindrical, conical, spherical, square, rectangular and other shapes are produced by drawing operations in which the metal suffers plastic deformation not exceeding its ultimate strength. In drawing operations the punch forces the metal into the die to flow

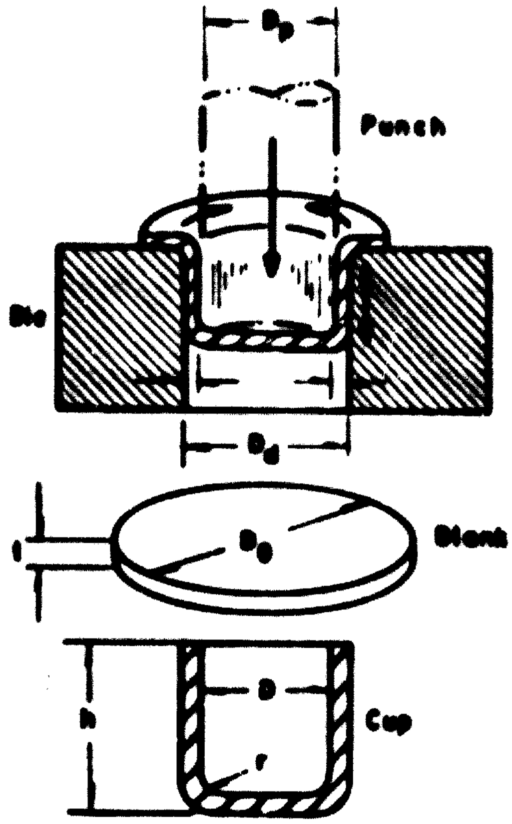


Figure 5. Basic relationships of the drawing operation

along the die face and through the clearance between the punch and die. The metal is compressed at the rim of the blank and stretched on the cup wall (see figure 5). The following basic relationships are essential for the design of a drawing die:

$$P_d = \sigma_t \pi D_t \left(\frac{D_0}{D} - 0.7\right)$$

$$E_d = KP_dh$$

$$R_d = \frac{(D_0 - D)}{D_0} \times 100$$

$$C = 1.1\,t$$

$$D_0 = \sqrt{D^2 + 4Dh}$$

when $r = 0$

$$= \sqrt{D^2 + 4D(h - 0.4\,r)}$$

when $t << 0$

$$= \sqrt{D - 2r + 2t^2) + 4(D - t)(h - r) + 2\pi(r + 0.4t)(D - 0.7r - 0.3t)}$$

where P_d = drawing force, lb
σ_t = tensile strength of work material, psi
D = diameter of finished shell, in
D_0 = diameter of blank, in
t = thickness of blank, in
E_d = drawing energy
K = constant
h = height of finished shell, in
R_d = reduction in diameter, per cent
C = clearance
r = radius of finished shell, in

There are other methods of computing the approximate size of the blank for drawing:

(a) Volume method

$$D_0 = \sqrt{D_i^2 + (D_i^2 - D_o^2)\,(h/t)}$$

(b) Weight method

$$D_0 = 1.1284\,\sqrt{\frac{W}{wt}}$$

Where D_1 = outside diameter of finished shell, in
D_2 = inside diameter of finished shell, in
W = weight of finished shell, 1b
w = weight of material per in^3.

The compression tends to cause thickening and wrinkling, whereas the tension tends to cause thinning of the cup wall. To prevent wrinkling, blank-holding pressure is usually applied, using a pressure pad to hold down the blank during the drawing operation. The amount of clearance between the punch and die controls the final wall thickness of the product and also affects ironing when the clearance is small, and wrinkling, when the clearance is large.

When metal is deformed it strain-hardens, the stress increases as deformation increases. Cold-working can strain-harden the metal to the limit of its plasticity, after which further working of the metal would break it. Therefore, most drawing operations are done in multiple steps, with a varied reduction ratio at each step, rather than in a single drawing.

Standard reductions

Draw No.	*Reduction per cent*
1	40 to 45
2	30 to 35
3	20 to 25
4	15 to 20

For deep drawing, the metal is annealed between successive drawing cycles to restore its plasticity.

In an analysis of a drawing operation, the following items should be considered—particularly in designing a drawing die:

(*a*) Development of the approximate blank size;
(*b*) Reduction factor, R_f : (for determining the maximum single diameter);
(*c*) Reduction ratio, R_d : (for the design of the drawing cycle and intermediate flank sizes);
(*d*) Drawing force, P_d : (for the selection of the press);
(*e*) Blank-holding pressure, P_h : (for the design of the pressure pad);
(*f*) Punch-die dimensions (clearance, draw radii, etc.);
(*g*) Lubrication method and lubricant;
(*h*) Selection of a die material, tolerance and press;
(*i*) Prevention of undesirable wrinkling and ironing;
(*j*) Follow-up operations (re-drawing, ironing, trimming).

The drawing process is seldom economical for small quantities because of the complexity of die construction. It is then more economical to use other production methods such as metal spinning, forming, machining. Thus, economic justification, along with technical feasibility, is essential before using the drawing process.

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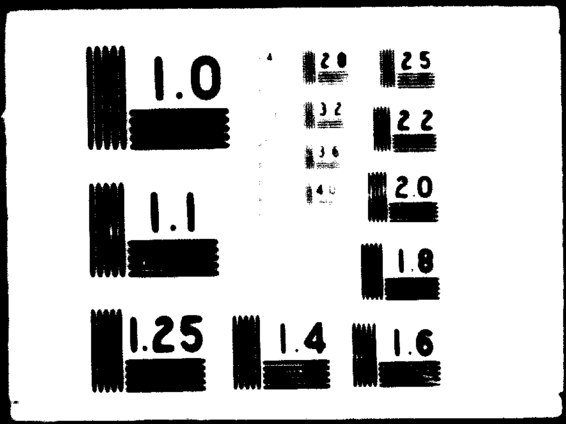
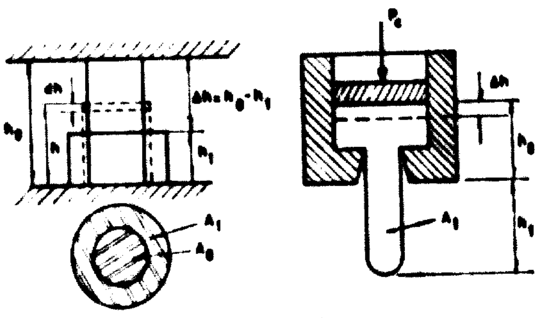


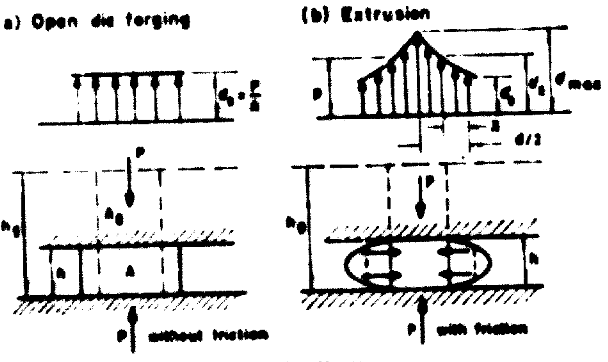
FORGING

Forging is a process by which metal is shaped into a desired form and size, refined structurally and improved in its mechanical properties through controlled plastic deformation in open or closed dies under compression. The compressive forces may be applied by slow squeezing (press forging) or by impact (drop forging). Forging can be done over a wide temperature range, but usually above the recrystallization temperature of the metal. Typical forging operations are:

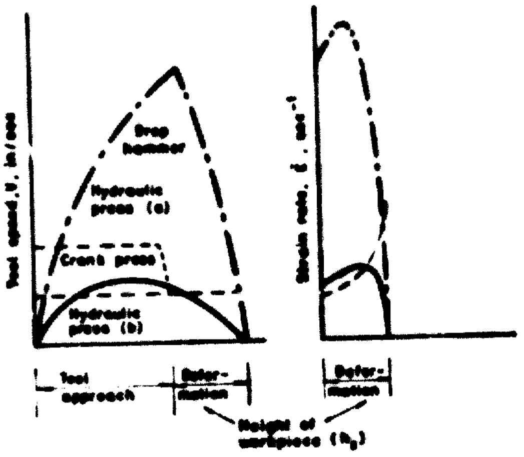
(a) Open die forging (upsetting)
(b) Close die forging (impression or drop forging)
(c) Upsetting (closed-die)
(d) Roll forging
(e) Cold forging
(f) Hand forging



(a) Open die forging (b) Extrusion



(c) Theoretical pressure distribution



(d) Tool speeds and strain rates in upsetting

Figure 6. Basic relationships of the forging operation

For press forging, hydraulic presses are commonly used, whereas power hammers are generally used for drop forging. Special forging machines are often used for producing special shapes.

Various metals respond differently when they are deformed. Plastic deformation may be accompanied by buckling, necking, fracture, or a combination of these defects. Forgeability is a term commonly used to denote a material's relative lack of resistance to deformation and its plasticity, and is evaluated by various test methods such as: *(a)* hot-twist test, *(b)* upset test, *(c)* notched-bar upset test, *(d)* hot-impact tensile test, and *(e)* tensile and compression tests.

A good understanding of metal flow theory, and of the basic concepts of forging metallurgy, is essential for analysing forging operations. Some basic relationships of the forging operation for a die design are as follows and are also illustrated in figure 6.

Engineering strain; $\varepsilon_e = \dfrac{\Delta h}{h_0}$

$$\varepsilon_e = \frac{A_1 - A_0}{A_1} = \frac{\Delta A}{A_1} \text{ or } \varepsilon_e = \frac{A_0 - A_1}{A_0} = \frac{\Delta A}{A_0}$$

Extrusion ratio; $\psi = \dfrac{A_0}{A_1} = \dfrac{h_1}{\Delta h}$

True strain; ε

$\varepsilon = \displaystyle\int_{h_0}^{h} \frac{dh}{h_0 h} = \ln\frac{h_1}{h_0} = \ln\,(1 - \varepsilon_e)$, in which ln means "natural logarithm".

For sliding friction;

$$\sigma_s = \sigma_0 e^{\,2\mu x/h}$$

For sticking friction;

$$\sigma_s = \sigma_o \left(1 + \frac{x}{h}\right)$$

Total force, P_c, required for compression:

$P_c = pA$

p = the average pressure

A = the cross-sectional area

With sliding friction, for a bar of width b,

$$p = \sigma_o \frac{h}{\mu b}\left(e^{\mu b/h} - 1\right)$$

and for a cylindrical workpiece of diameter d,

$$p = \sigma_o \frac{2}{(\mu d/h)^2}\left(e^{\mu dh} - \frac{\mu d}{h} - 1\right).$$

For sticking friction,

$$p = \sigma_o\left(1 + \frac{d}{bh}\right)$$

Total force required for extrusion, P_e

$$P_e = pA_0 = c\sigma_0 A_0 \ln\frac{A_0}{A_1} \text{ in which } c \text{ is a constant.}$$

$$\text{Strain rate: } \dot{\varepsilon} = \frac{\Delta h}{\Delta t}\,\frac{1}{h} = \frac{V}{h}$$

$$\text{Tool speed: } V = \frac{\Delta h}{\Delta t}$$

In practice, the forces required in forging are estimated for the following purposes:

(*a*) To determine the maximum force, the operation, and the size of the hydraulic press needed;

(*b*) To set the limits of elastic distortion permissible in mechanical presses;

(*c*) To select a machine of sufficient capacity.

A simple calculation of forging forces, P, can be made with the following formulae:

$$P = C_1\sigma_m A_t$$

$$\varepsilon = \ln\frac{V}{A_t h_0} \text{ (average strain)}$$

$$E = C_2 V\varepsilon\sigma_m \text{ (energy, in-1b)}$$

where

C_1, C_2, = multiplying factors (see table of multiplying factors)

σ_m = the mean yield stress at the forging temperature, psi

A_t = the cross-sectional area of the forging in the parting plane, in^2

V = volume of the forging, in^3.

TABLE OF MULTIPLYING FACTORS FOR ESTIMATING FORCE AND ENERGY REQUIREMENTS IN FORGING

Mode of deformation		C_1	C_2
Compression of cylinder	$\varepsilon_0 = 0.5$	1.2	1.2
between flat platens	$\varepsilon_0 = 0.8$	1.5 to 2.5	1.5
Impression die forging	without flash	3 to 5	2.0 to 2.5
of single shape	with flash	5 to 8	3
Impression die forging of complex shape	with flash	8 to 12	4

It is often necessary to consider forging for making a new product or in the re-design of existing components. To select the

most efficient forging method for a given job, there are two distinct stages:
(a) to design the part to meet functional and technical needs and *(b)* to design a forging sequence and die, considering the following factors:

- *(a)* Part design:
  - *(i)* configuration and tolerance,
  - *(ii)* size and weight,
  - *(iii)* specification (properties and quality requirements),
  - *(iv)* material and forging stock.
- *(b)* Analysis of the forging operation:
  - *(i)* forces and energy required,
  - *(ii)* design of the forging dies: direction of the fibre-flow lines, (parting line and position of adequate draft, etc.)
  - *(iii)* production quantity,
  - *(iv)* selection of forging press,
  - *(v)* fabrication of forging dies,
  - *(vi)* friction, wear and lubrication,
  - *(vii)* design in-house or sub-contract.

PRESSWORKING TOOLS, PLANNING

Before designing a die set, thorough process planning is required. Some important factors to be considered are:

- *(a)* Design; shapes, maximum size, tolerances, weight, surface roughness, selection of material,
- *(b)* Production; tooling time, production time, quantity, deadline,
- *(c)* Economics; material costs, tool and die costs, presses, finishing cost, direct labour and overhead costs, inventory costs.

Basic procedure of the process planning for pressworking tools includes:

- *(a)* Analysis of the product or part:
  - *(i)* What is to be done?
  - *(ii)* List the required operations and allied processes,
  - *(iii)* Determine the manufacturing feasibility.
- *(b)* Determine the most economic process.
- *(c)* Plan the operation sequence:
  - *(i)* Determine critical specifications,
  - *(ii)* Select critical areas and operations,
  - *(iii)* Arrange the operations in the best possible sequence,
  - *(iv)* Determine secondary or auxiliary operations.
- *(d)* Specify the necessary inspection equipment,
- *(e)* Specify and select the necessary press equipment,
- *(f)* Determine material handling methods for stock and product,
- *(g)* Prepare the route or operation sheet.

PRESSWORKING TOOLS, DESIGN PROCEDURE

Preliminary planning

(a) Develop the blank with special reference to:
  (i) best direction of grain,
  (ii) bending, forming and drawing strain, and
  (iii) available press equipment.
(b) Decide a tentative sequence of operations,
(c) Lay out the stock strip,
(d) Consider the press accommodation of the die set,
(e) Establish the centre-line of pressure,
(f) Establish the location of pilot hole punches,
(g) Select the die type,
(h) Check material specification,
(i) Make the route sheet.

Steps for die design

(a) Layout of scrap-strip,
(b) Design die block,
(c) Design punches,
(d) Design punch plate,
(e) Locate and design pilot, gauges and stops,
(f) Design the stripper,
(g) Select or design suitable fasteners,
(h) Select the standard die set,
(i) Assign dimensions and material specifications (bill of materials and drawings),
(j) Select a suitable press.

Die-making operations

It is often necessary to estimate the time and cost of die-making for various purposes. The operations required for the construction of a blanking die are, for example, as follows:

(a) Cut off the block,
(b) Rough machining and grinding,
(c) Machining screw and dowel holes,
(d) Lay-out of die,
(e) Machining die opening,
(f) Finishing die opening,
(g) Machining and fitting punch to die,

(h) Machining punch holder, stripper, stops,
(i) Machining clearance holes in die shoe and stripper slot,
(j) Heat treatment and grinding,
(k) Assembling die and stripper to die shoe,
(l) Assembly of punch and punch holder,
(m) Assembly of auxiliary parts,
(n) Try out,
(o) Inspection.

RELATIONSHIP WITH PRODUCT DESIGN

During the lay-out of the stock-strip and the design of the dies, the product designer is consulted for possible design changes to improve the tool design. In many cases, a minor change in part specifications such as tolerances, makes a great difference in process planning, tooling setup and tool design. Some of the general points made for product design changes from the standpoint of tool design are:

(a) Flat surfaces are preferable to formed surfaces,
(b) A rectangular outline is preferable to a curved outline,
(c) On drawn forms, a round or circular shell or cut is preferable to a rectangular one,
(d) A symmetrical design is preferred,
(e) The axis about which any bend is formed should if possible be a straight line,
(f) On formed surfaces, tolerances on dimensions affected by part thickness should not be closer than expected variations in the stock thickness,
(g) Dimensions from edges should be assigned with tolerances within those possible on the stock width,
(h) Bends should be at right angles to the grain, or as close thereto as possible.

ELECTRICAL DISCHARGE MACHINING

*J. Dillon**

THIS PAPER on the fundamentals of electrical discharge machining (EDM) is limited to a practical description of the basic process and the various elements of dielectric fluids, pressure and vacuum flow, detritus or swarf, filtration, surface-finish characteristics, and some comments on the most widely used electrode material, carbon (graphite). A brief section is included on the programming of cavity die work.

THE BASIC PROCESS

The theory of EDM has been thoroughly investigated and the results have been widely reported, but the art is preceding the science. Nevertheless, certain theories have been derived to explain EDM. The use of electricity is based on the electron theory that all matter is composed of atoms which are, in turn, composed of a nucleus and billions of tiny particles called electrons and protons. Though these cannot be seen by even the most powerful microscope, it has been determined that some free electrons are whirling around the nucleus at fantastic rates. If a substance gives up its free electrons easily, it is called a conductor.

If a certain potential (or voltage) is impressed for a sufficient period (on-time) across a certain gap created by two conductors (electrode and workpiece), billions of electrons flow rapidly (186,000 miles per sec.) and we have electric current (amperage). The result of this electron avalanche is a spark which will make a crater in both of the conductors. If this procedure is carried out in a medium called a dielectric fluid, it can be more stable and controlled, since the fluid will wash away the particles and keep the workpiece cool. Dielectrics which have been used include mineral and silicone oils, kerosene, ethylene glycol polar fluids, glycerol, de-ionized water, sodium silicate solutions and even compressed air and electronegative gases.

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DIELECTRIC FLUIDS

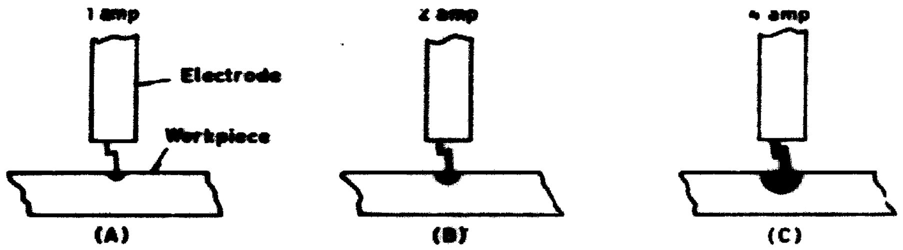
The dielectric fluids most commonly used are mineral oils with certain properties and characteristics, including: low viscosity (approx. 40 Saybolt universal viscosity (SUS) at 100°F), high flashpoint (near 300°F); 200,000 — 250,000 volts per inch dielectric strength, no skin irritation, no unpleasant odour, no excessive smoke, low degree of impurities, and no undesirable electrical gap characteristics.

Some manufacturers are now recommending oils of high viscosity for high amperage work. These oils are usually isoparaffinic hydrocarbons, and, when subjected to gap conditions, give off various combustible hydrocarbon gases, plus some carbon residue. Although the corrosion inhibitors may be consumed, no other significant changes occur in the composition and the oil may be re-used indefinitely. The function of this oil is to ionize locally, become temporarily conductive, allow a spark to pass, then carry away the debris and some of the heat. The motive force may be a pressure pump or a vacuum eductor. Most work will be done in the ranges of 5 to 50 pounds per square inch (psi) positive pressure or at 10 to 29 in. of mercury vacuum. Inasmuch as the pure dielectric gap will be determined by the dielectric strength of the oil and the voltage impressed, it will have a maximum sparking distance of 0.0001 in. at very low voltage and about 0.002 in. at high voltage. However, the metal and carbon particles, also called detritus or swarf, are conductive, and these add to the gap size by acting as "stepping stones". Normal gap distances at 0.1 to 100 amps will be in the range of 0.005 to 0.008 in.

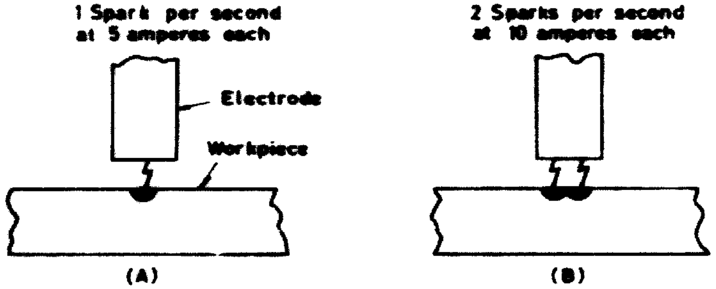
PRESSURE AND VACUUM FLOW

Figure 1 (Fundamentals of EDM) shows the flow of coolant. Pressure flow is most commonly used because it is easier to apply—pin holes in the system are not critical. It also gives more visual indication of good machining conditions—a tendency to short-circuit can be detected by very dense puffs of smoke and small arcs can sometimes be seen. The bubble pattern and size will help to estimate the electrode location and dielectric flow efficiency. An audible "frying egg" sound may assist slightly in setting the gap voltage to its lowest steady reading while advancing the sensitivity, or feed, to its maximum. Pressure flow can be used at pressures above 14 psi, which is its lower limit.

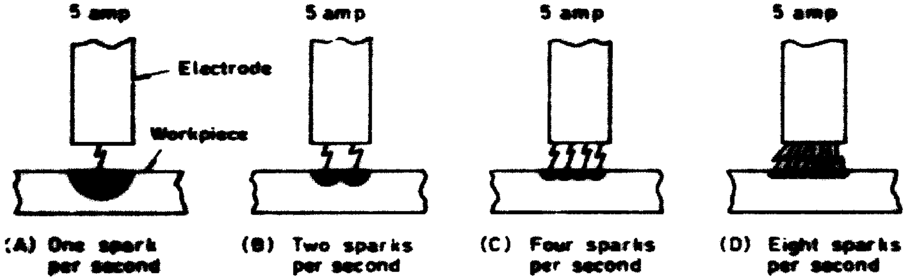
Vacuum flow, however, does have definite applications and is used exclusively by some die makers. Firstly, when cavity dies are machined with pressure flow, all of the gases and detritus are forced out of the gap at rapidly decreasing velocities, causing somewhat



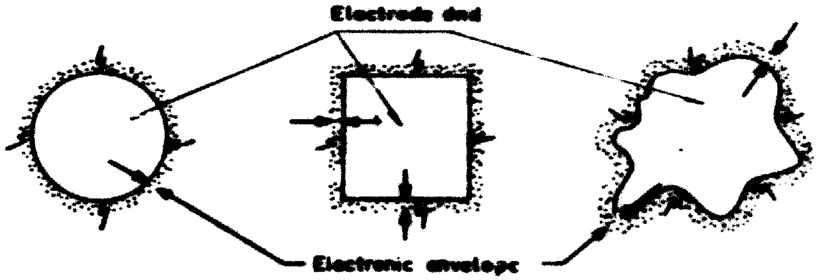
Metal removal : one discharge

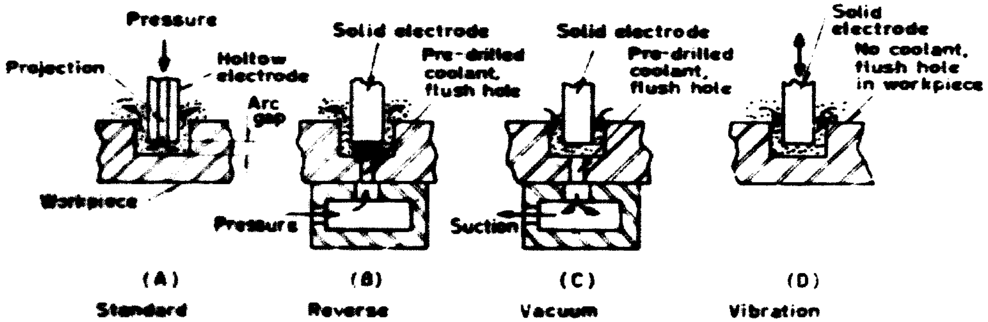


Surface finish as affected by spark frequency and amperes



Surface finish constant amperes, varying spark frequency





Types of coolant flow

Figure 1. Fundamentals of electrical discharge machining (EDM)

erratic machining. Secondly, the slugs or spires in the flow holes will cause continually increasing resistance to oil flow. When cuts are one inch deep or more, these slugs must be broken off periodically. Vacuum flow concentrates the particles around the slug, and excess erosion allows undeterred flow. Vacuum flow can thus permit full amperage and steady cuts to full depth if all of the requirements are met. No air leaks can be tolerated in a vacuum system—the platen is usually submerged in the oil. The system must have enough capacity to handle the detritus and the gas volume. A sustained vacuum of 27—28 in. of mercury should be possible.

Other uses of vacuum, such as reduction of taper, will be discussed later. If vacuum and pressure are available simultaneously, a vacuum chuck can be used to hold parts being trepanned, such as valve discs or tensile test specimens. Vacuum flow can also be used to eliminate smoke and to remove dielectric oil from areas of a cavity that are hard to get at.

FILTRATION

Particle size is determined by the magnitude of the spark and the amount of metal that will be liberated. The latter will relate to the heat generated and the amount of heat required to induce melting of the particular workpiece. A certain amount of suspended particles has been shown to be beneficial in roughing cuts at the higher amperages, and may result in increased metal-removal rates and less electrode wear. On finishing cuts, however, where corner radii or EDM taper are a factor, clean, carbon-free oil is desirable.

Clean oil is achieved by filtering through filters of 3 microns aperture which remove about 85 per cent of particles 0.0001 in. and larger. Various filter systems have different abilities due to their nature and variations in the rating. Asbestos cellulose is considered a polishing medium and is generally used in surface filters. Depth filtration can be accomplished by wound viscose or vacuum-deposited cellulose yarn, or resin-bound flocculants of cellulose, or wool and diatomaceous earth. Large areas of continuous high-amperage machining may require settling tanks as the only means of removing detritus. These installations are quite efficient, economical, and easy to service. Shops involved in forging die work and large stamping or forming dies may find this system advantageous. An auxiliary filtering system can be switched in for final finishing with a cleaner supply.

The temperature of the dielectric may become a factor in high-amperage machining. A maximum temperature of 160°F has been determined by limited tests; above this point the machining efficiency is adversely affected when using mineral oil of 40—50 SUS viscosity. This is probably due to the smaller amount of heat required to vaporize the oil, and to the creation of excess gas. Gas has a low dielectric value and allows premature sparking. Liquid or air heat exchangers have been used, and should be capable of holding the temperature below 120°F.

SURFACE-FINISH CHARACTERISTICS

When an electrode of opposite polarity to the workpiece is brought close enough to it to allow the voltage to break down the dielectric, a spark will occur. The servo-control then takes over, and, by comparing a gap voltage with a variable reference voltage, a steady feed is maintained. When feeding down, the gap voltage will be slightly in excess of the reference voltage, and the mechanism will cause a small flow of hydraulic oil to move the ram downward.

In series-capacitance power supplies, the actual gap size, or overcut, will be governed solely by the amount of capacitance switched into the circuit. Increasing the frequency will, within limits, serve to increase the amperage and removal rate, but the surface finish, or crater size, remains the same. (See figure 1, Surface finish as affected by spark frequency and amperes.)

When parallel capacitance is used, the amperage will divide as the frequency increases and finer finishes will result. The same is true of circuits with zero capacitance in which no wear occurs over a long period of work.

The surface finish obtained by EDM is quite different from conventional finishes. Surface-finish recorders will show approximately the same general roughness pattern; but the geometry is greatly different, as many peaks and craters replace the conventional lines and valleys. Thus we have a multi-directional or no-lay finish versus the directional pattern of a conventionally machined surface. In addition, the EDM surface has a recast white layer, and in heat-treatable metals this will be ultra-hard, with the sub-layer slightly annealed. Minute cracks may be present in some metals, especially where high amperage has been used during EDM. The friction characteristics are also quite different. Whereas conventionally machined surfaces stick and then slip with rapidly decreasing friction, EDM coefficients of friction are linear and considerably lower in value. This has been demonstrated by tests on inclined planes and the performance ratio is about 3 to 1 for the better finishes. An EDM finish reading 45 microinch root mean square (RMS) value has been demonstrated to perform as well as a 15 microinch RMS conventional finish when applied to stamping and hobbing dies.

In forging dies, EDM surfaces soon glaze and the craters form ideal lubrication pockets. If normal draft angles and surface finishes are observed, the part will seldom, if ever, stick.

While EDM has been accepted as a standard machining process on static aircraft jet engine and airframe parts, it is still outlawed on thermocycling, rotating engine parts. This is because of the possibility of failures starting at stress raisers caused by minute cracks. The fatigue strength of the high-strength chrome-nickel alloys, titanium and aluminium will always be significantly lower than that of conventionally machined surfaces.

Graphite as a machining tool

Surface condition, surface finish, metal-removal rate, and cut-to-wear ratios will be affected by the type of electrode chosen to do the job. Certain grades of graphite are fast becoming the universal electrode material for forging and stamping die work in steel. It is the only electrode for use in no-wear machining. Graphite has recently been used for 60°V-shapes only 0.010 in. wide in carbide crush rolls. The grade of graphite chosen for this job has a very fine and dense grain structure and forms well at low horsepower with an angled carbide form tool.

All but the very best EDM grades of graphite are limited in the surface finish attainable without rotation. A surface finish of 40 microinch (RMS) is usually considered the worst finish allowed before switching over to metal electrodes. In fact, metallic electrode materials are more efficient than good grades of graphite when machining at high frequencies and low amperages.

Most graphites will tend to arc and will have exceptionally poor electrode wear in the high voltage range (300—400 V). However, medium voltage is used, with vibration, to achieve tapered slots in plastic die moulds. The finish attained is usually hand worked with a very fine grit stone to improve the 30—100 microinch RMS finish left by EDM.

Programming cavity die work

All cavity work should be programmed for the amount of amperage intended and the degree of draft in the workpiece. By knowing the overcut and pit depth from already established data, the sum can be used as one leg of a triangle. The angle opposite is the amount of degrees of draft, and thus, a trigonometric solution to find the hypotenuse is easy. Accurate programming requires that the final overcut allowance be subtracted from each roughing allowance to find the distance above the bottom of the cavity that the electrode must be stopped in order to prevent overcutting. Taper will be a negligible factor in most die work computations.

MACHINING GRAPHITE ELECTRODES

The rapid evolution of EDM from a "last-resort" repair method to its present acceptance as a practical metal-removal process of tremendous potential is often attributed to the development of graphite as an electrode material, and, it should be added, to the increasing skill of graphite electrode manufacturers.

Yet, in spite of growing experience, EDM users too often conclude that machining procedures for graphite and steel are basically the same, except that graphite permits faster machining rates and requires an adequate dust collection system. This is an unfortunate conclusion, and, in many cases, it limits the application of EDM to jobs requiring electrodes whose cost differential plus EDM time is based on how much faster a man can machine a piece of graphite.

The fact that graphite has a faster machining rate should be considered as a point of departure with regard to different machining procedures. Obviously, graphite machines faster because it offers less resistance to cutting tools. This means, very simply, that the electrode maker has gained remarkable latitude. Straight cutters can be longer, simpler and smaller. Form cutters can be made to machine larger and more complicated shapes in a single pass. Grinding becomes much more flexible. Tooling can become lighter, simpler and less expensive.

Electrodes fall into two main categories: three-dimensional and conventional. Both categories require at least three electrodes per configuration; in the case of conventional electrodes this involves a considerable length. Consequently, setups and tools often comprise the largest portion of the manufacturing cost. It is in this area that wider machining latitudes make their most important contribution.

EDM WITHOUT ELECTRODE WEAR

When machining with a carbon electrode at reversed polarity, (carbon electrode positive, workpiece negative), there is low electrode wear particularly when the discharge time is long, and the off-time, or interval between discharges, is short.

When an electric field is applied between the electrode and workpiece, electrons, due to field emission, initiate an avalanche from the workpiece, establishing a discharge. The field strength required to initiate this avalanche will vary with electrode materials. Carbon requires a smaller electric field than steel. Many factors influence field strength; we will consider two: applied voltage and gap dimension. (See figure 2.) Since the applied voltage for most power supplies is constant, one way to enhance the electric field is to decrease the gap dimension. There will be a difference in gap dimension in the two cases: first, when the carbon electrode is negative with respect to the workpiece; and, second, when the carbon electrode is positive with respect to the workpiece. It would be expected that the latter would have a smaller gap than the former, particularly when the workpiece is steel.

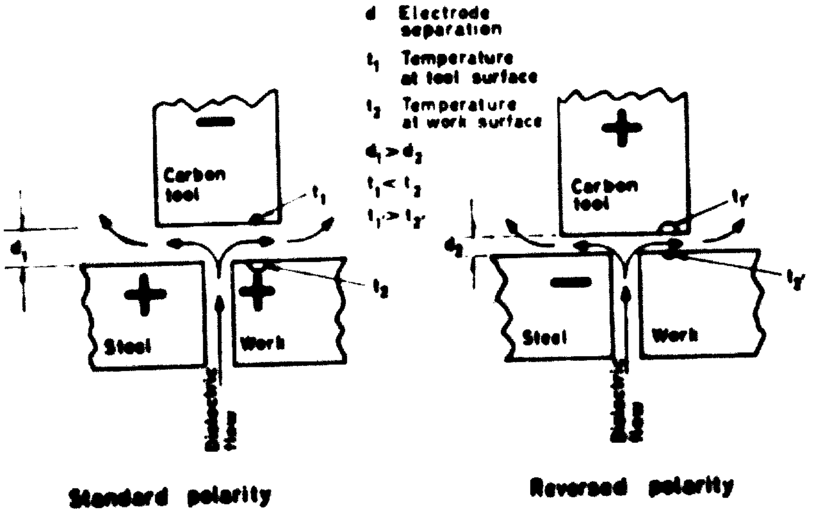


Figure 2. EDM with carbon electrode using standard and reversed polarity

Let us consider the sequence of metal removal during a discharge. Some metal is removed during the later stages; however, most of it is removed instantly following the discharge. When discharge times become long, however, the amount of metal removed during the last stages is greater. So that, with the smaller gap and higher temperature at the electrode surface, most of the metal ejected from the workpiece during the discharge is splashed onto the electrode and adheres to its surface because of its high temperature and porous nature.

X-ray diffraction analysis has shown that some of the steel splashed onto the electrode surface is iron carbide, indicating a reaction taking place at the tool surface and accounting for the tenacity with which the splashed steel adheres to the electrode. With the proper choice of machining parameters, the amount of metal splashed onto the electrode surface equals the amount by which the electrode wears. Thus, in effect, a 'no-wear' tool is obtained, through constant replacement of electrode wear with molten metal from the workpiece.

In order to further the understanding of the "no-wear" phenomenon, tests were run with carbon electrodes on a high-carbon tool-steel workpiece for the purpose of answering two basic questions:

(*a*) What is the effect of energy per discharge on electrode wear?

(*b*) What effect does depth of cut have on electrode wear?

As a means of measuring electrode wear, (see figure 3) a hole was drilled in the workpiece, and the dielectric flow through it was reversed. Therefore, the centre portion of the tool was not carrying out any machining operation, would suffer no wear and served as a zero reference. Since wear on the rest of the tool was small, a profile of the electrode was obtained by feeding the output from a sensitive electronic displacement-measuring device into a strip chart recorder. Profiles of the electrode surface were made before and after each machining operation. In each of the profiles, the dipping of the trace below the zero reference plane indicates electrode wear. Whenever the trace appears above the zero reference plane, the electrode has "grown".

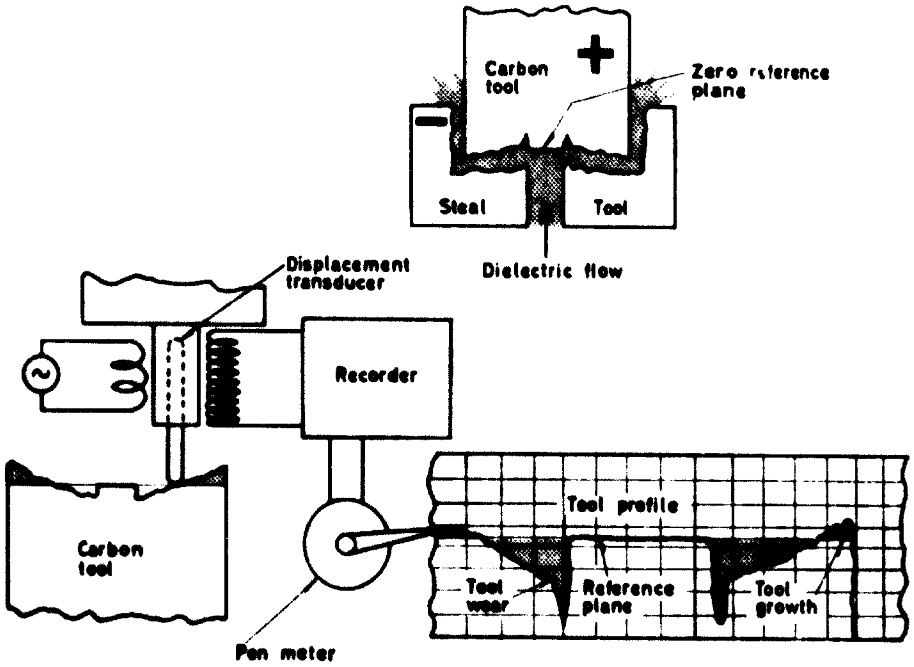


Figure 3. Method of determining tool wear in EDM

TEST RESULTS

As mentioned above, metal is deposited on the electrode face. There is a certain average amount deposited per discharge, or a certain average amount deposited in unit time. Thus, there is a certain rate at which metal is being deposited on the electrode. Although metal is being splashed on the electrode surface at one time, it can be removed at another (either in the course of the same discharge or by a subsequent discharge, or discharges). There is therefore, a net difference between these two rates. This net difference is referred to as the metal transfer rate. When the metal transfer rate is negative, the electrode diminishes in size; when it is positive, the electrode increases in size; and when it is zero, there is a state of equilibrium or "no-wear".

During the course of a discharge, the voltage remains relatively constant at approximately 20 volts for metallic electrodes and approximately 30 volts for carbon electrodes. Energy per discharge may be varied by changing either the discharge current or its duration. Electrode profiles after machining 0.75 in. deep at constant peak current are shown in figure 4. There is a change in transfer rate

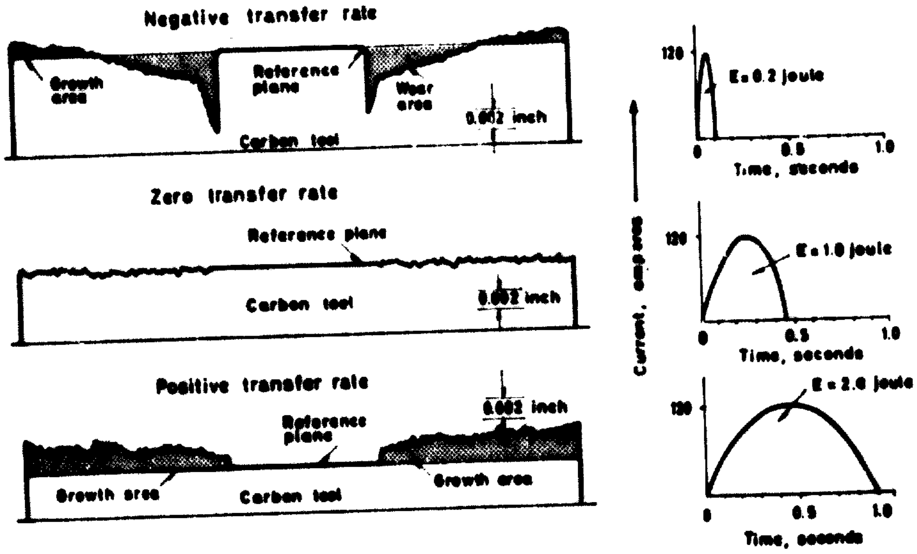


Figure 4. Tool shape after machining 0.75 inch deep with EDM, showing the effect of varying energy per discharge, with constant peak value of current, 120 amp

from negative (at top of figure) through zero (in the middle) to positive (at the bottom). Notice that the "no-wear" condition is obtained at a discharge energy of 1 joule per discharge. It can there-

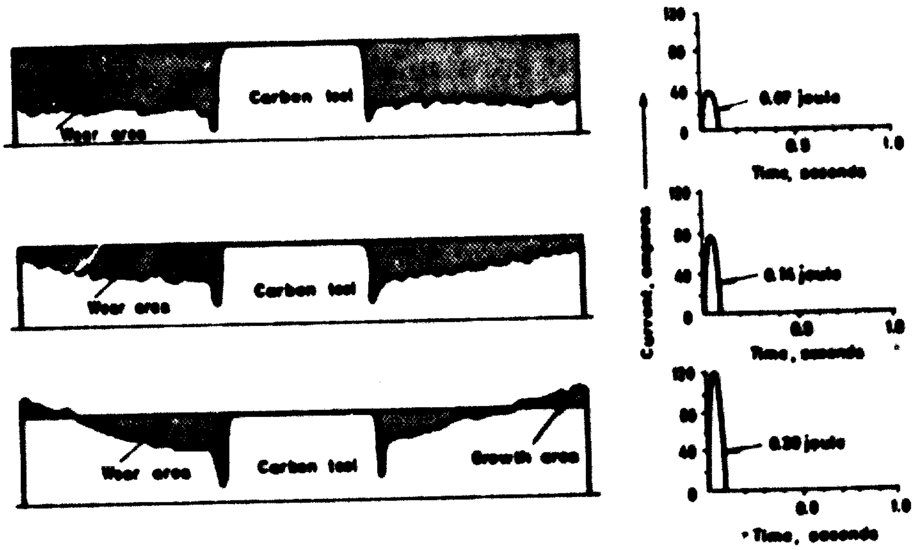


Figure 5. Tool shape after machining 0.75 inch deep with EDM, showing the effect of varying energy per discharge with peak current varying and discharge lasting 0.1 second

fore be assumed that metal transfer rate is related to energy per discharge.

Having seen the effect of increasing the energy by keeping the peak current constant, it is now possible to observe the effect of increasing the energy per discharge by holding the discharge duration constant and increasing the peak current. As may be expected from previous information, there is an increase in the metal transfer rate as the energy per discharge is increased (see figure 5). As 0.07 joule/discharge there is a relatively high wear on the electrode, less at 0.014 joule/discharge, and still less at 0.02 joule/discharge. From the last two figures little doubt remains that metal transfer rate is dependent on energy per discharge.

From figure 4 it will be observed that "no-wear" occurs at 1 joule/discharge with a peak current of 120 amps and a discharge duration of 0.45 second. If the energy per discharge governs the metal transfer rate, as has been seen, then keeping the discharge duration constant at 0.45 second and reducing the peak current should result in a reduction in the metal transfer rate.

Contrary to predictions however, these results, as shown by figure 6, indicate a zero transfer rate for all three levels of energy per discharge (0.33, 0.67, and 1 joule). This indicates that the discharge duration is also important to "no-wear". This really should not be too surprising. If "no-wear" is dependent upon metal being transferred from the workpiece to the electrode, there must be time for this to take place. Also, the temperature at the discharge region of the electrode must be high enough to accept and retain metal particles from the workpiece, and this is also dependent on time. So it is obvious that time is also essential to the "no-wear" phenomenon.

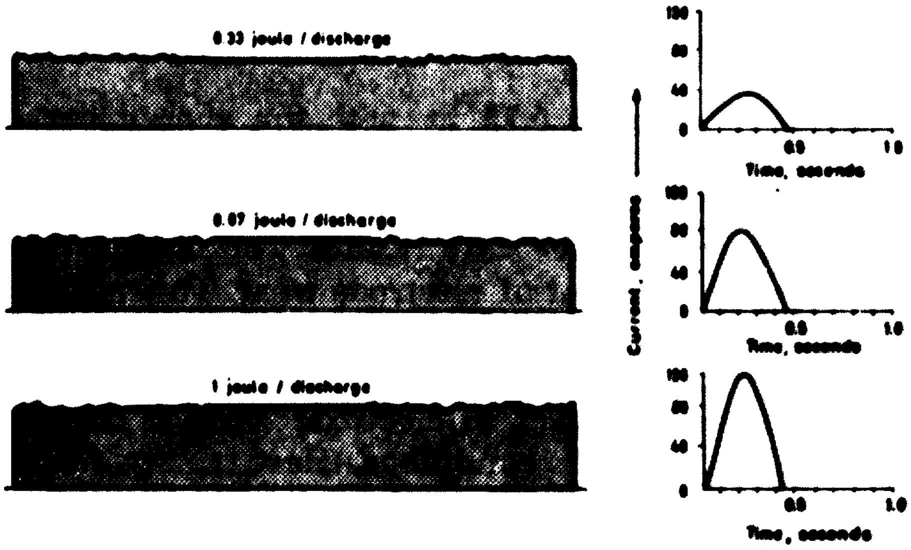


Figure 6. Tool shape after machining 0.75 inch deep with EDM, showing the effect of varying energy per discharge with peak current varying and discharge lasting 0.5 second

At a discharge duration of approximately 0.45 second, time is the dominant factor in "no-wear" and the effect of energy is masked. This is fortunate, for now there is a range of finishers over which "no-wear" can be obtained.

To consider the effect of depth of cut on electrode wear, see figure 7 showing the electrode profiles as the depth of cut is increased from 0.006 in. to 0.75 in. with the energy per discharge maintained constant at 0.2 joule, the peak current at 120 amp and the duration at 0.090 second. From these conditions, as would be expected, a negative transfer rate results. The deeper the cut, the greater would be the amount of electrode wear. This is shown in the lower right-hand corner of figure 7 and is normal EDM electrode wear.

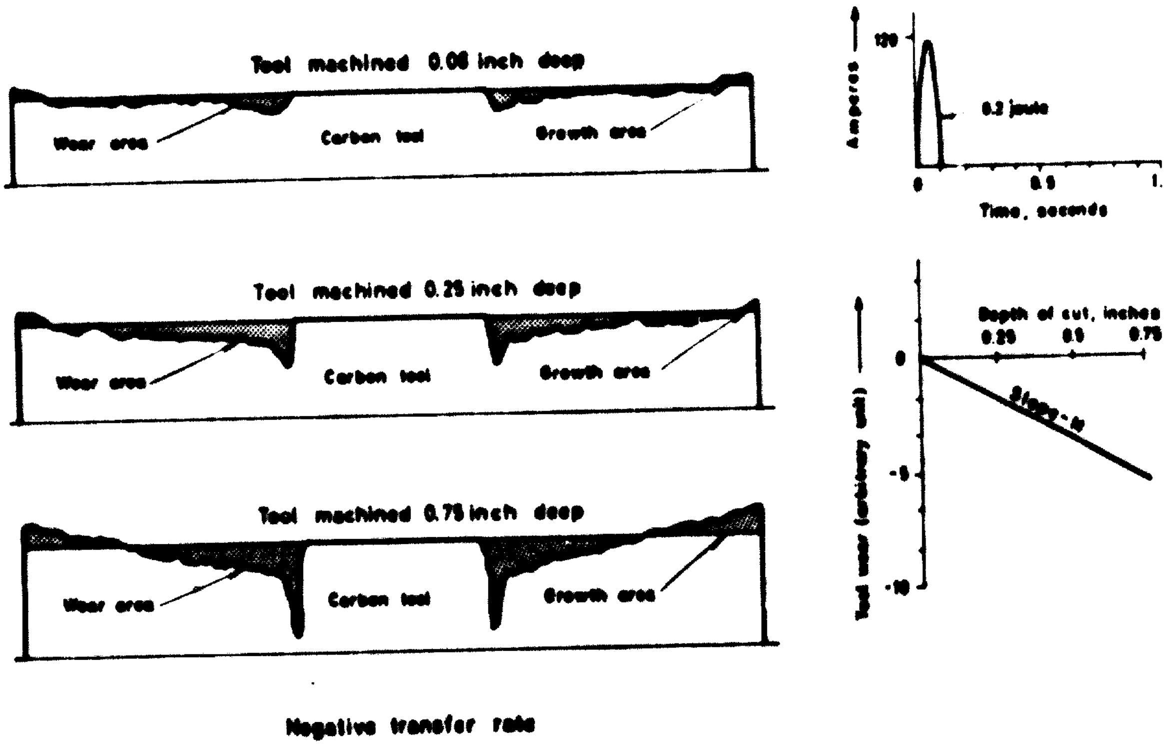


Figure 7. Effect of depth of cut in EDM, using 0.2 joule per discharge

Figure 8 shows the effect of electrode wear as depth of cut is increased under "no-wear" conditions. Here again, "no-wear" is maintained regardless of depth of cut, so that this equilibrium state can be maintained at least to a depth of 0.75 in. If the energy per discharge were to be increased by increasing the time, as shown by the dotted lines in the upper right-hand corner, there would be a positive transfer rate, and the electrode would "grow" as the depth of cut increases. This is also shown in the lower right-hand corner of figure 8 by a dotted line.

With the advent of "no-wear" electrodes, even under limited conditions, EDM users are going to find more and more areas of application for the process. There is a limited range of finishes over which 'no-wear' can be obtained and it is also independent of depth of cut, resulting in extremely long tool life.

Further work will be done in this area of "no-wear" in an effort to extend its potential into much finer finishing ability.

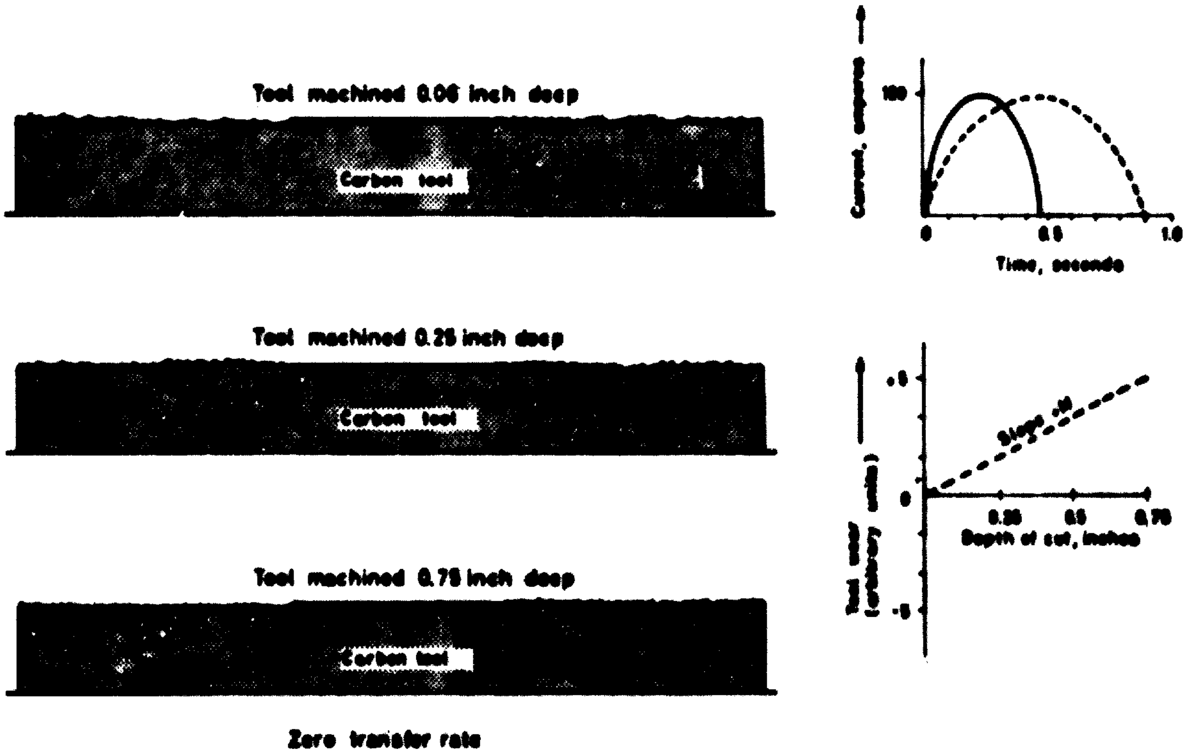
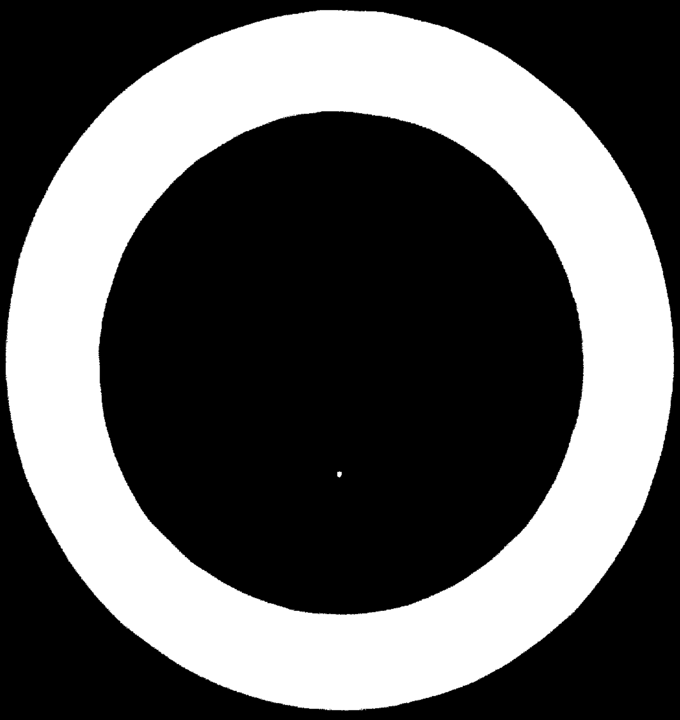


Figure 8. Effect of depth of cut in EDM, using 1 joule per discharge



FLAME HARDENING OF DIES

*J. Dillon**

FLAME HARDENING of tool steel is a growing technology in the die-and-mould industry in the United States. The equipment is inexpensive, but its operation requires high skill. The benefits are in the uniform surface hardness after all machining has been completed. In addition no re-machining, such as the grinding and refitting that is required after conventional heat-treatment, is necessary.

DEFINITION

Flame hardening is a method of hardening a surface of hardenable steels and cast irons. A high-temperature flame is impinged on the surface to be hardened, the surface is heated to the desired temperature and is then cooled in the best manner for the iron or steel being hardened. The hardness obtained is controlled by the type and quality of the iron or steel being heat treated, the speed and temperature of heating, and the choice of proper cooling method. When the process is properly carried out, nothing is added to, or removed from, the surface being hardened.

NEED FOR FLAME HARDENING

Die irons and steels, as received for machining into die shapes, must be relatively soft to make the die machining as easy as possible. Without further hardening, the relatively low 'as-received' hardness does not result in good wear resistance and the surface wears rapidly.

As draw-die components are large in size and weight, normal hardening methods are neither practical nor desirable for them, nor would the desired hardnesses be obtained readily. Flame hardening is the only practical way to harden their wearing surfaces.

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* Ford Motor Company, Dearborn, Michigan

DIE MATERIALS WHICH ARE FLAME HARDENED

For large die components where good wear resistance and resistance to deformation are needed, flame hardening of critical areas is specified. Certain die steels and irons are specified because they have the desired properties.

The table lists some of these die materials which are flame hardenable, together with the approximate flame hardening temperature, quenchant used, and minimum hardness expected.

DIE MATERIALS, FLAME HARDENING TEMPERATURES, QUENCHANTS AND MINIMUM HARDNESSES

Die material	*Flame hardening temperature*	*Quenchant (PVA = polyvinyl alcohol)*	*Minimum hardness (Rockwell C)*
1. Alloy cast iron	1650°F light red	Water + 3% PVA	58—test file
2. Alloy pearlitic nodular iron	1650°F light red	Water + 3% PVA	58—test file
3. Alloy die steel casting	1650°F light red	Water + 3% PVA	55—test file, Rockwell or scleroscope type test
4. Alloy die steel	1600°F light red	Water + 3% PVA	55—test file, Rockwell or scleroscope type test
5. Society of Automotive Engineers (SAE) 1060 steel	1600°F light red	Water + 2% PVA	60—test file, Rockwell or scleroscope type test
6. SAE 1045 steel	1650°F light red	Water	50—test file, Rockwell or scleroscope type test
7. Speed treat or Fremax 45 steels	1600°F light red	Water	50—test file, Rockwell or scleroscope type test
8. SAE 0050A carbon steel casting	1650°F light red	Water	50—test file, Rockwell or scleroscope type test
9. SAE 4150 to SAE 6150 alloy steels	1650°F light red	Water + 3% PVA	55—test file, Rockwell or scleroscope type test
10. SAE G3500 grey cast iron	1700°F very light red	Water + 1% PVA	55—test file
11. SAE W108 bead stock	1600°F light red	Water + 2% PVA	60—test file, Rockwell or scleroscope type test

DEPTH OF HARDNESS

The desired depth of hardening for die surfaces is 0.09 in. to 0.125 in. The depth of hardening is controlled by the temperature of the flame, the distance maintained between the flame head and the die face, and the rate of travel of the flame head over the die face being hardened.

QUENCHING EQUIPMENT

As most die materials contain alloying elements, a quenching medium with a cooling rate less than that of water is used to reduce the cracking of the die surface and reduce the retained austenite to give better hardness. This quenching medium is mixed with water in a mixing tank and is then pumped to the flame-quench heads. The quenching medium should leave the flame-quench head at as high a volume as possible, but when the flame-quench head is positioned on the work, the pressure should not be high enough to cause the quenching medium to bounce off. It should not splash off the die surface being hardened.

Quenching medium

The most commonly used quenching medium is polyvinyl alcohol (PVA), a water-soluble plastic, and this is mixed with water in concentrations ranging from 1 per cent to 3 per cent by volume.

The recommended procedure for diluting the plastic quench concentrate is to mix the measured amount with an equal amount of warm (100—130°F) water. Then add this premix to the metered water already in the tank with the propellor agitator turned on. The propellor agitator in the tank should be on at all times when the quench system is being used.

Each time water is added to the main supply tank, the proper amount of polyvinyl alcohol must be measured and added as outlined above. When mixed with water as a quenching solution, the polyvinyl solution will not burn, so there is no fire hazard. As the polyvinyl leaves a residue of plastic in the flame-quench heads, clear warm water should be run through the quench ports after each use to prevent the build-up of residue.

FUEL GASES

A fuel gas which is commonly used is methylacetylene propadiene, known as MAPP. Although the oxygen-MAPP gas mixture burns at a temperature of 5300°F and oxygen-acetylene burns at

6000—6200°F, there are advantages in die flame hardening from using MAPP gas. It is safer to use and to handle. The lower flame temperature gives greater depth of hardening with less danger of burning the surface, and makes the worker's skill less critical when varying die contours are being hardened.

A ratio between 3 and 5 to 1 of oxygen to MAPP gas produces an efficient heating flame. When properly adjusted, the centre flame colour should be light to dark blue. The coupling distance (distance from flamehead face to work) should be 0.5 in. to 0.375 in., approximately, when the flame is properly adjusted.

MAPP gas can be safely operated at high pressures, so outlet gauge pressures of 20 to 30 psi can be used, as needed, to operate the larger flame-quench heads. The ratios and flame colours for steel and cast iron should be as shown in figure 1.

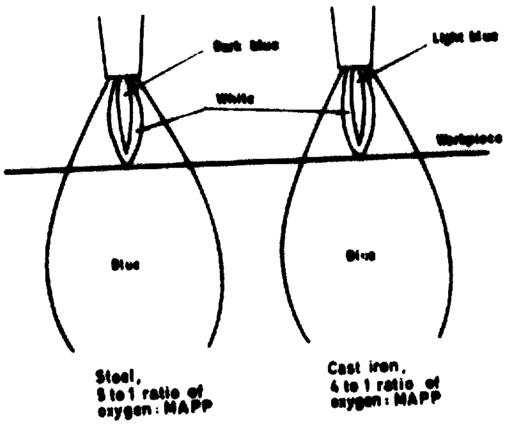


Figure 1. Flame types for hardening steel or cast iron with methylacetylene propadiene-oxygen flame

LIGHTING OF FLAME HEADS

The following general procedure should be followed in lighting flame heads. Care must always be taken to keep the heads cool to prevent them burning around the gas ports.

1. Adjust the MAPP gas and oxygen gas outlet meters to proper pressure settings.
2. Always turn the quench liquid on before lighting the flame. Turn on a small flow of oxygen and MAPP gas and light. Increase the oxygen to shorten the flame to approximately 0.25 in. long.
3. Turn up the MAPP gas and the oxygen in successive steps, increasing the velocity until the flame becomes slightly unstable. The primary centre part of the flame should remain 0.25 in. long with a neutral blue colour.

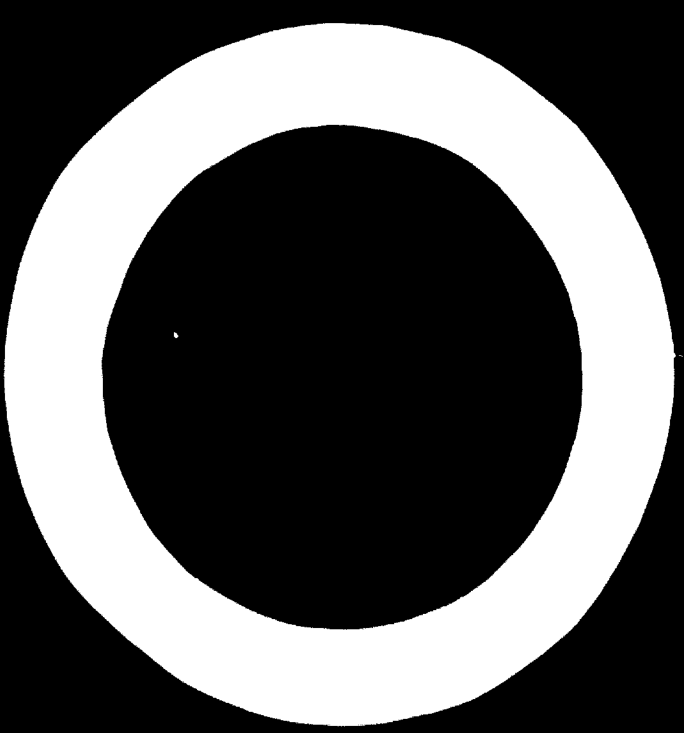
4. When the flames are neutral and are approaching instability at high velocity, operating conditions have been reached. The flames should become completely stable when applied to the die surfaces.
5. When turning the flame head off, turn down the oxygen and then the MAPP gas in successive steps until the oxygen is completely turned off with the MAPP gas still burning, then turn the MAPP gas off.
6. The quench water or solution is turned off last.

The heating flame should never be allowed to remain burning for longer than a few seconds without the quench liquid flowing through the head.

THE OPERATION OF FLAME HARDENING EQUIPMENT

The flame hardening equipment has to be operated by the following procedure:

1. Examine die areas to be flame hardened and select flame-quench heads to be used. Check surfaces for welds, as welded areas must be avoided to prevent cracking of welds. Use 5 per cent nital etchant for checking welds (5 per cent nitric acid added to methyl alcohol).
2. Determine type of steel or iron to be flame hardened and select quench solution strength from chart.
3. Run metered water supply into mixing tank and add measured amount of diluted polyvinyl into tank with mixer running.
4. Connect proper flame head to torch and quench supply hose.
5. Turn on MAPP gas and oxygen supply and start pump that pumps quench solution to head.
6. Light the flame head using the procedure already outlined.
7. Adjust quench solution to proper level.
8. Begin progressive flame hardening of die surface.
9. After a trial area is completed, check for the quality of hardening with a test file and a nital acid etch.
10. Complete the hardening of the areas.
11. Shut off the flame heads using the correct procedure.
12. Check the quality of hardening, using test files and nital acid etch.
13. Shut off pump, mixer, turn off gas and oxygen supply.
14. Run pure, warm water through heads to remove residue of polyvinyl alcohol to prevent clogging of quench ports.



THE USE OF PLASTICS IN THE MANUFACTURE OF DIES, JIGS AND FIXTURES

N. M. Kapustin[*]

POSSIBLE WAYS OF USING PLASTICS FOR DIES

THERE IS A large area of use for plastics in the manufacture of production equipment, and plastic dies, jigs and fixtures can be widely used in small-batch production. They must, however, only be used if *(a)* their reliability is assured, and *(b)* the plastic equipment is justified by its lower cost in time and money than that for corresponding equipment made of conventional materials.

There are many ways of using plastics in the manufacture of the forming parts of dies. It is now most usual to cast a layer of epoxy resin around a strengthening centre portion which may consist of either:

(a) Stabilized sand,
(b) Wood,
(c) Cast iron,
(d) A welded metal frame,
(e) Steel plate.

The first four types of design are used for large punches, the third and fourth varieties offering a high degree of durability. The last type of construction is used for small punches, which can be strengthened by casting the shaping inserts of the die and punch in welded metal casings.

A metal base has the following advantages: *(a)* It enables expensive resin to be saved, since only a thin layer of plastic (12 to 15 mm thick) is applied; *(b)* The rigidity of the punch is increased (this is very important for the stability of the punch and for the accuracy of the parts produced; *(c)* The punch is more durable.

Dies with a plastic coating can be made from wooden models or from a prototype part. The second procedure is simpler. A prototype

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part, made by hand from sheet steel of the same thickness as the part to be stamped, is used for shaping the profile of the working surface. Figure 1 shows the sequence of the four stages in the manufacture of the die.

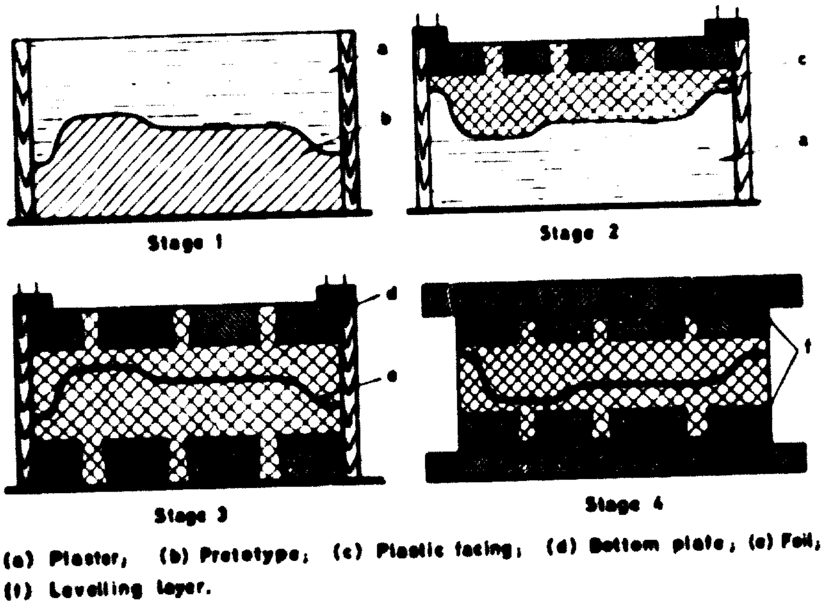

Figure 1. Sequence of operations in the preparation of a die with a plastic lining
a — Plaster; b — Prototype; c — Plastic facing; d — Bottom plate; e — Foil;
f — Levelling layer.

Rapid-hardening acrylic plastics are used to form the sliding surfaces of the die guides.

Plastic dies for stamping sheet are used in many small plants for making machines. Their labour and material costs are from 20 to 50 per cent of those of metal punches. To increase the durability of the plastic coating, the shaping surface is now usually metallized.

REINFORCING PLASTICS

To strengthen the dies to withstand the stamping process, metal inserts will be needed at the points of greatest stress, such as hollow chamfers. For this purpose, keying devices such as holes, recesses, grooves, ribs, ridges, and so on should be provided.

Before pouring the plastic it is advisable to make keying holes which will fill up with compound during pouring and thus strengthen the grip of the plastic coating. The die and punch can be fastened to the plate by means of bolts cast in the plastic.

Rigidity is a basic factor in the efficiency of dies, jigs, fixtures, seatings and other equipment. This can be achieved by the careful choice of the composition of the plastic compound, by using various fillers, and also by reinforcing with metal components. For this purpose, as has been stated, dies and seatings are cast on a metal base or over metal frames. In such cases, however, residual stresses can occur in the metal and plastic structures during polymerization as a result of the contraction of the plastic and differences in the coefficients of linear expansion.

Any contraction in metal-reinforced plastic structures will lead to a state of stress, because the adhesion of the plastic to the metal base impedes contraction.

The pattern of occurrence of this residual stress is similarly influenced by temperature changes. The coefficients of linear expansion of epoxy resin compounds are two to four times as high as the coefficient of linear expansion of steel; consequently, when epoxy resin compound is cast over a steel plate, or steel frame, residual stress occurs with the changes in temperature. These stresses are particularly great when hot,hardening compounds are used. For example hardening may take place at 120 to 160°C, followed by cooling to room temperature.

These residual stresses will be additional to the normal working stresses, which they can increase or decrease. Research has shown that residual stress in composite metal and plastic structures can, in many cases, be quite considerable, and can result in damage to the plastic even without the effect of working loads. A number of

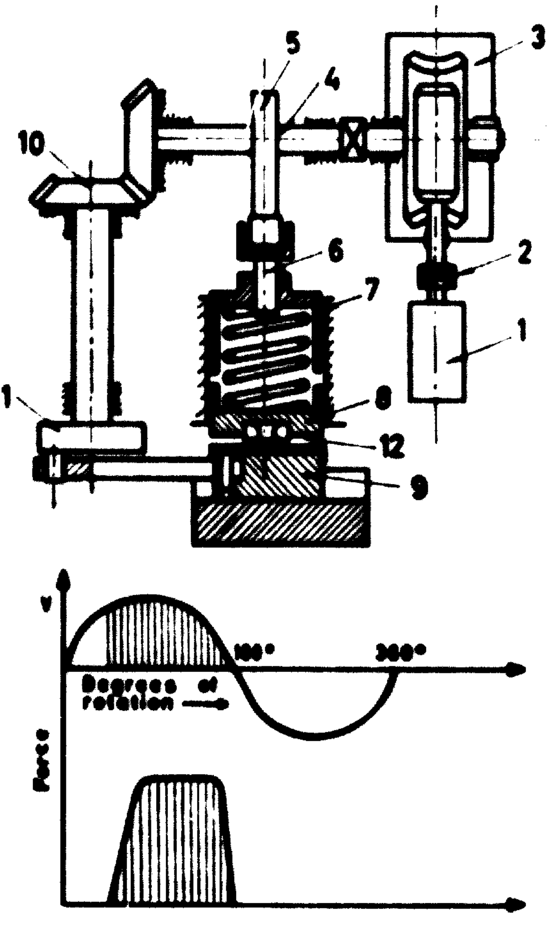

Figure 2. Apparatus for determinig the wear of plastic dies
1 — Electric motor; 2 — Clutch; 3 — Reduction gearing; 4 — Shaft; 5 — Cam with special profile; 6 — Push rod; 7 — Calibrated spring; 8 — Tappet; 9 — Slides; 10 — Bevel gear; 11 — Eccentric; 12 — Test specimen in clamp.

researchers have demonstrated that contraction of the epoxy resin compound largely depends on the hardening time, the composition of the plastic and the hardening temperature.

WEAR RESISTANCE

An important index of the serviceability of production equipment is its wear resistance, and this is particularly important in dies. In stamping, the working surfaces of the die become worn by the high working pressures. The wear process on dies has been reproduced in model form on a special experimental apparatus (figure 2) which fully reproduces the loading cycle taking place in die work. This apparatus can exert pressures on the test specimen within the range of 5,000—30,000 tons/m^2 (500—3,000 kg/cm^2) and can, at the same time, drag a steel sheet across its surface.

PLASTIC MOULDS

In the experimental and small-batch production of thermoplastic test specimens and small batches of special parts by casting from prototypes, metal moulds are too expensive and laborious to make. It is then economic to make temporary moulds from thermosetting plastics, especially for complicated shapes.

An example of a plastic casting mould is shown in figure 3. This shows a mould for the nylon casting of the body and handle of a power screwdriver. The mould consists of upper and lower half moulds contained in welded metal frames. The entire outer surface of the body of the power screwdriver, except for the screw threads, is shaped by the inner surface of the plastic half moulds, while the inner surface of the part is shaped by a number of mould inserts and cores, which also form the screw threads in the part.

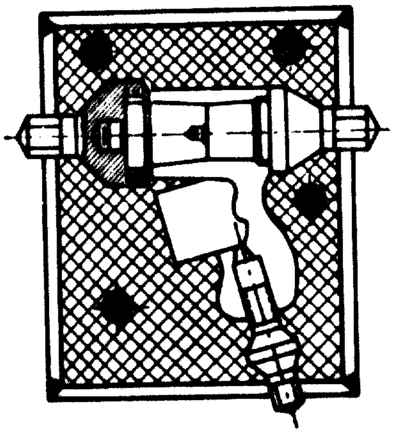

Figure 3. Mould made of plastics in a welded steel frame, for moulding the body and handle of a power wrench

The factor most influencing the dimensional accuracy of the cast part is the variation in the shrinkage of the thermoplastic material used to make the casting. Minor factors, which often are not considered in calculating the initial dimensions of the moulding elements, include: wear of the moulding elements, and fluctuations in their dimensions because of temperature variations.

All the enclosed, or enclosing, elements in the mould must be so shaped as to permit the easy removal of the cast part; therefore, in determining the various working dimensions, it is essential to know the largest and smallest dimensions of the shaping element.

In designing moulds it is essential to bear in mind that the inclusion of a metal framework in the cast part considerably reduces shrinkage of the plastic.

The making of a temporary mould out of plastic comprises the following stages: preparation of the prototype, the mould cores and the mould casing; preparation of the plaster pad; preparation of the first half mould; preparation of the second half mould, and assembly of the two halves.

A metal, plastic or wooden template of the part to be cast can be used as the model for the preparation of the mould. The template must be exceedingly smooth, much smoother than the surface required for the part to be cast. It is therefore recommended that metal parts of models should be chromium plated and buffed, and wooden models should be polished and lacquered.

The mould cores are usually made of metal, and are normally solid in order to conduct heat away more effectively from the part being cast. The dimensions of mould cores and collars must be calculated taking into account the shrinkage of the plastic. The surface smoothness requirements are the same as for original models.

Plastic moulds for making wax patterns for investment casting can compete with metal mounds, but for the pressure casting of

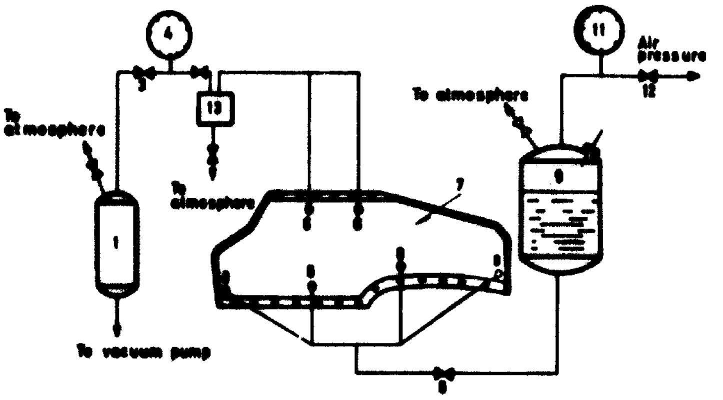

Figure 4. Equipment for making motor-scooter body sections by injecting the binder into the mould

1 — Reservoir; 2 — Tap for regulating the amount of vacuum in the mould; 3 — and 5 — Taps; 4 — Vaccum gauge; 6 and 8 — connecting pipes; 7 — Mould; 9 — Tank containing binder; 10 — Tap for regulating the pressure in the tank; 11 — Pressure gauge; 12 — Air valve; 13 — Trap and settling tank.

articles from thermoplastics, plastic moulds do not have a very long service life (10—300 articles, depending on the pressure and temperature).

For articles to be made from glass-fibre plastics by injecting the binder into the mould (figure 4), a glass-fibre-plastic mould can be used.

In order to speed up the production of jigs and fixtures, a method has been devised for the manufacture of jig and fixture bodies by casting them in epoxy resin in disposable moulds, using master metal inserts. This method reduces, or completely eliminates, the need for subsequent machining.

Disposable moulds

The basic and auxiliary components, together with the previously assembled units of the jig or fixture, are placed on a lay-out block. The appropriate position for each part (supports, locators, clamping devices, guides), in relation to the others is determined from a prototype workpiece or from the assembly drawings for the jig or fixture. When using a master workpiece, the parts are offered up to it in the correct relationship, and are then fixed in place on the lay-out block by wiring, or cementing, or by Plasticene, screw clamps, or other means. When the position of the parts has been checked, a

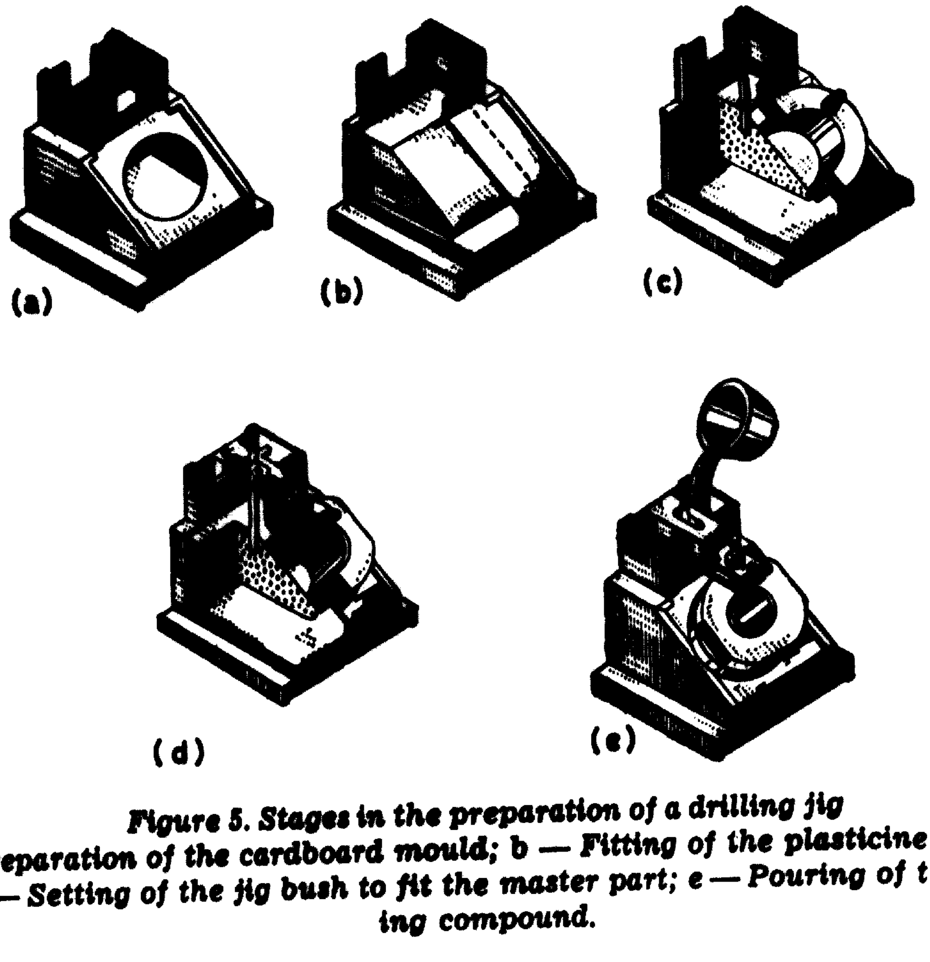

Figure 5. Stages in the preparation of a drilling jig
a — Preparation of the cardboard mould; b — Fitting of the plasticine core; c — and d — Setting of the jig bush to fit the master part; e — Pouring of the moulding compound.

cardboard or sheet steel mould in the shape of the jig body is prepared and placed also on the lay-out block. Any gaps between the mould and the block are filled with Plasticene. The mould is then filled with epoxy resin compound and the jig or fixture is ready (assembled). If the uses of the jig or fixture are such that it requires greater strength, the necessary metal reinforcements (frames, strengtheners, rods, etc.) can be set up on the block before the cardboard form is placed in position.

This method of manufacture thus combines two stages: the preparation of the body or framework of the jig or fixture, and its subsequent assembly. If the use of the jig or fixture necessitates dismantling its separate parts, the surfaces submerged in the plastic must be coated with a separating agent. If this is done, threaded pins and screws can be unscrewed from the plastic after casting.

Figure 5 shows this method used for the manufacture of a special jig. The labour of making this jig is 10 to 14 per cent of that required for making a conventional jig.

COMPLEX WORKPIECES

In modern production there are a number of workpieces of complex shape made by casting or stamping (levers, angle pieces, T-pieces, cross-pieces, tap bodies, brackets, and the like) which are very difficult and inconvenient to machine in all-purpose jigs or fixtures. Special-purpose machine tools have to be constructed for them, and this entails a great waste of time and labour. Such jigs or fixtures are considerably easier and cheaper to produce if the mounting units are made of plastic as negative impressions or depressions, corresponding exactly to the surface of the workpiece.

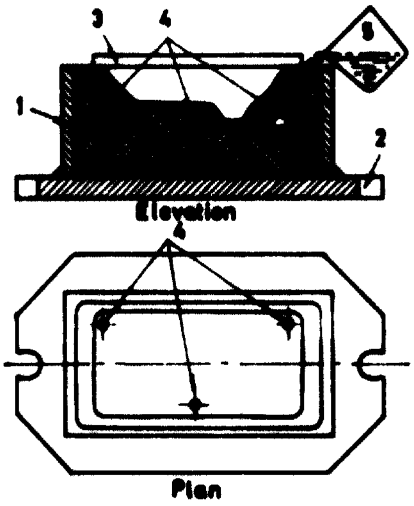

Figure 6. Casting of the mounting surface (seating)) of a machine-tool jig, using a prototype as a moulding core
1 — Body; 2 — Mounting base plate; 3 — Master part; 4 — Supports; 5 — Resin being poured in

The entire surface of the workpiece to be machined is fitted into this depression or seating. A standardized steel body is used to contain this seating. One version of the process for making seatings is shown in figure 6.

Since the workpiece is seated in a matching depression, its location comes within the fourth or fifth class of precision. In order to increase the precision still further, it is necessary to mount the workpieces in seatings manufactured by high-precision methods such as casting with melting cores, skin moulding, chill moulding, stamping.

THE APPLICATION OF PRECISION CASTING TO THE TOOL AND DIE INDUSTRY

*W. J. Edmonds**

As is well known, the casting process consists, simply, of preparing a mould cavity, inserting the necessary cores to provide the re-entrant or hollow features of the resulting casting, pouring in molten metal, allowing it to cool and solidify, and removing the finished casting from the mould.

For successful casting, however, certain conditions must be fulfilled. The mould must be made of a material which is sufficiently refractory to withstand the temperature of the molten metal; obviously the material of the mould must melt at a higher temperature than the metal to be cast. The cavity into which the metal is poured must be accurately formed with the necessary allowances made for shrinkage and must have a good surface finish. Provision must be made for the introduction of the molten metal, and for the escape of the entrapped air, which is normally present before casting, and the gases which are formed during casting.

The chemical composition and purity of the metal to be cast must be maintained during melting, and its pouring temperature must be held within specified limits. If the temperature is too low, the metal will not flow correctly and will not fill the cavity completely; if it is too high, gases will be generated which will cause blow holes. If the metal to be cast is an alloy, it will frequently have constituents with melting temperatures much lower than that of the alloy itself. In reducing the alloy to its molten state these will tend to fume out. Allowance must be made for this in the original composition, or additions of the low-melting-point constituents must be made before casting.

The chart shown in figure 1 depicts some of the various mould-manufacturing techniques which are used in the casting process. The

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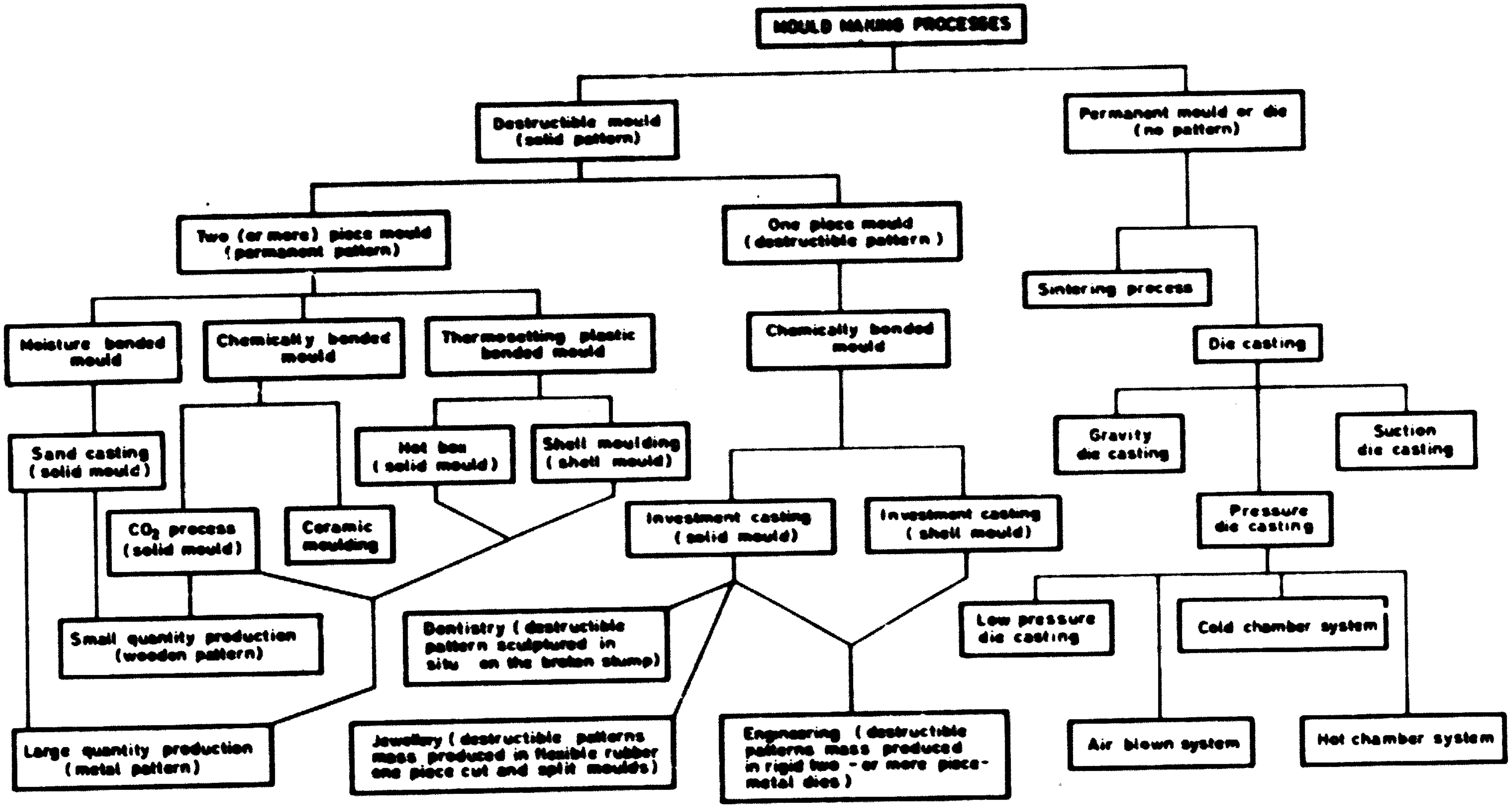

Figure 1. Mould-making processes

choice of the technique which must be used depends on several factors:

(*a*) The melting temperature of the metal to be cast,
(*b*) The accuracy and surface finish required,
(*c*) The number of nominally identical castings to be produced.

The melting temperature of the metal influences the selection of the material from which the mould must be made. For low-melting temperature metals, such as zinc- or aluminium-based alloys, permanent metal moulds, or dies, can be used. For the higher-melting-temperature metals however, such as cast iron, and carbon and alloy steels, non-metallic refractories such as silica sand are required, the refractory particles being bonded together in an open, permeable structure. The so-called gravity diecasting process for iron and steel castings normally utilizes metal dies which are coated internally with a non-metallic refractory. This detracts considerably from the accuracy, definition and surface finish normally associated with diecasting. Much research has been, and is being, carried out on the casting of cast iron and steel in uncoated metal dies, but sophisticated alloys are required for the dies and their useful life for making accurate castings with high definition is limited.

Permanent metal dies which are uncoated except for a releasing agent do, of course, produce the most uniform, accurate castings, having the best surface finish. For refractory moulds, which are normally used once only and are then destroyed to remove the casting, the resulting surface finish depends on the grain size and regularity of shape of the individual particles, and the subsequent treatment of the surface of the mould cavity. Uniformity and accuracy depend on the accuracy of the pattern and the mould-making process, and the degree of control in casting.

The number of nominally identical castings to be produced affects the process to be selected, and the object of this paper is to show how one of them, which is normally associated with high volume production, can be applied to the manufacture of one-off or small-batch-production precision parts for the tool, jig, fixture, die and mould industry. This is the process of investment casting, sometimes referred to as the lost wax process. Mention will also be made of ceramic moulding for the production of high-definition, accurate, metal punches, dies and moulds.

INVESTMENT CASTING

Normally, casting dies or moulds of any kind must be made in at least two pieces. Flat-based objects can be gravity cast in one-piece open moulds but the surface of the metal which is to form the flat base tends to cavitate on cooling and solidification. Obviously, for any pressure-casting process, closed dies or moulds must be used, but even for the gravity casting of flat-based objects it is considered much better practice to use a closed mould and incorporate a runner and riser system which will feed molten metal to the mould cavity during cooling through the liquid stage.

A permanent, completely enclosed die or mould must be made in at least two pieces for the very obvious reason that the resulting casting must be removed. The reason why a refractory mould must be made in at least two pieces is less obvious, as it is normally made for one casting operation only, and is smashed up to remove the casting. The answer is, of course, that the mould must be made in two pieces to enable the pattern or patterns, which are used to form the mould cavity, to be removed, before the mould is finally assembled for pouring.

The necessity for a parting line or lines on most castings imposes some limitation on the freedom of choice during the design stage. The greatest cross-sectional area must be at the parting line, and re-entry conditions above or below it can only be incorporated at the expense of having to provide side closing elements for permanent dies or moulds, or loose pieces or cores for destructible refractory moulds.

Parting lines also affect the consistent accuracy with which castings may be produced. Dies and moulds in two or more pieces tend to open under the pressure of the molten metal and the generated gases. Strong locks must be provided for permanent dies or moulds, and heavy weights or backing-up material for destructible refractory moulds. Even shell moulding by the Croning process, a process of very high consistent accuracy, produces castings which are less accurate in a direction at right angles to the parting line than along it. Castings to be produced by shell moulding are designed to take advantage of the greater consistent accuracy possible in the line of the shells.

The one casting process which is free from all these design limitations is investment casting, which utilizes a one-piece destructible refractory mould. This is made possible by the fact that the pattern around which the mould is created is itself destructible. The term "destructible" here applies to the form and shape of the pattern —not its material—although some of the pattern material may be lost through combustion during its removal from the mould. Hence the term "lost wax", although wax is only one of many possible pattern materials.

Other materials include various thermoplastics such as polystyrene, as well as mercury, and low-melting-point alloys such as Wood's metal. The most commonly used material is, however, wax;

this may be simply thermoplastic (changed from solid to liquid by heat) or it may also be soluble in a medium such as water.

Investment casting, as it is usually called today, is not a new process. It has been in use for many thousands of years. There is every evidence that the two great pillars which stood at the entrance of King Solomon's temple were made by a variation of this process. These, we learn from ancient documents, were seventeen-and-a-half cubits (about 9 metres) high, and four cubits (about 2 m) in diameter, and were cast hollow in molten brass (bronze?) in the clay ground in the plain of Jordan. They were adorned with ornately engraved chapiters and supported spherical balls delineating maps of the celestial and terrestial globes. A very formidable casting proposition, even for a modern, well equipped foundry.

Although these pillars are no longer in existence and much is supposition, smaller castings which were almost certainly made by this process, and dating from about 3500 B.C. onwards, have been discovered by archaeologists. Throughout the ensuing centuries, until comparatively modern times, the process was used almost exclusively for jewellery and works of art. In the sixteenth century, the statues of Benvenuto Cellini were all cast by the lost wax process, the most famous being his bronze of Perseus and Medusa in Florence.

APPLICATIONS OF INVESTMENT CASTING IN DENTISTRY, JEWELLERY AND ENGINEERING

Dentistry

Towards the end of the last century the process was adopted and developed by the dental profession for the capping of broken teeth, usually in gold. The way in which this is done illustrates well the simple basic principles of the process. A small piece of wax is heated slightly until it becomes plastic and pliable. It is pressed onto the broken stump of the tooth and the patient is required to bite on it to obtain the impression of the mating tooth.

When the wax is cool and solid its outside form is carved away, *in situ*, to blend it into the remains of the broken tooth. It is then removed and a pin is stuck into it. This pin serves three purposes: It provides a means of handling without the wax being affected by the warmth of the hand, it provides a run-out hole to remove the wax from the mould, and it provides a sprue hole in the mould for the casting process.

The wax replica of the capping for the broken tooth is then suspended on its pin in a container, and a refractory slurry is poured around it. When this is set, the pin is removed, the mould is inverted, and is heated to melt the wax and cause it to run out, leaving a cavity which is an exact replica of the cap, with perfect mating contours of the broken stump. The molten gold is then gravity or centrifugally cast through the sprue hole provided by the pin.

Jewellery

Also worthy of mention is the way in which the process is used for the production of almost all modern rings and other jewellery. A ring to be ultimately produced in quantity, including the mountings for any precious or imitation stones to be set in it, is first made by a craftsman in common metal. In the making of this ring pattern he incorporates a plain circular portion about 2—3 mm in diameter and about 50—80 mm long. This corresponds to the pin used by the dental profession. Two pieces of natural rubber about 60×100 mm are cut from a flat sheet and the ring pattern is placed between them with the sprue pin protruding from one end. The rubber is then vulcanized on a small press. A frame, with a small hole in it to accommodate the pin, is normally placed round the edges of the block to prevent it from spreading sideways. The vulcanizing press heats and compresses the rubber, causing it to flow into every tiny cavity of the ring pattern and causing the two separate flat pieces to fuse together into one block.

When the rubber block is cool the worker takes a sharp knife and cuts into the sides of it to separate it into two halves again and to free the metal ring pattern. This is not done in a straight line to produce flat parting planes, but as a series of irregular cuts. This ensures that, when the ring pattern is removed and the two halves of what is now a wax injection die are re-assembled, they will line up correctly with each other. These irregular cuts in a rubber die replace the locating pins in a steel, flat-flaced, die for wax or thermoplastic injection. The rubber, being still quite pliable, will strip from every minute cavity in the ring pattern and restore itself to its original vulcanized shape, thus providing all the tiny re-entrant conditions and meticulous detail required for this type of work.

The two halves of the rubber die are then assembled and clamped lightly together, and wax is injected into it through the hole provided by the sprue pin. This operation is usually carried out repeatedly to produce a quantity of wax patterns. A number of these, depending on their size (about 50 for rings) are fused by their wax sprues to a flat, cylindrical, block of wax. The patterns can be quite close together although, naturally, they cannot be permitted to touch.

The wax block, with the patterns uppermost, is then placed on a flat circular base, a hollow, cylindrical, metal container is placed round it, and this is filled from the top with a refractory slurry. This is usually then placed under a glass dome, or in a vacuum cabinet, and the air is evacuated to draw off the air bubbles from the slurry.

When the slurry has set, the base of the container is removed to expose the undersurface of the wax block. Most of the wax is melted out and the mould is then fired to remove the residue and cure the refractory. It is then placed in a simple, often spring-loaded, centrifugal-casting machine, and the gold, or other metal, is cast and flows into the mould cavity under centrifugal force.

When the casting is cold the metal rings, or other jewellery, are cut off the base block, the remainder of their sprues are removed, and they are polished ready for the setting of the stones if required. The whole process is one which results in a good surface finish—no machining is necessary, only polishing—and excellent reproduction of detail, although not necessarily high dimensional accuracy.

Engineering

In spite of its antiquity, and its successful applications in other professions, investment casting was not used to any extent in engineering until the advent of the gas turbine. This created a need for the mass production of very large quantities of nominally identical turbine blades. These are very complex in shape, have to be produced to close tolerances, must have a good surface finish, and must be made from sophisticated, heat-resisting alloys which are notoriously difficult to machine. Initially, all the blades were either machined out of the solid, or were forged to shape and then finish-machined all over. This necessitated frequent tool changing to replace worn, blunt, or broken tools.

Investment casting provided a means of producing blades in large quantities, of high dimensional accuracy and good surface finish. Many of the surfaces which had previously been machined could be merely polished or contour-ground on belt-grinding machines. Other surfaces and features which still required machining, mostly for assembly purposes, could, because of the high accuracy with which they were cast (accuracies of ± 0.05 mm per cm are quite feasible) and their good surface finish, have the very minimum of machining allowance left on them, resulting in a reduction of tool wear and machining time. The cost of the process, although initially quite high, was more than saved in the machine shop.

Today, most of the firms producing gas turbine blades cast all their stationary blades by investment casting. Because of the high stresses resulting from the added centrifugal forces, the blades for the rotating parts of the turbine are often still forged and machined. Even for these however, investment casting is being used more and more as ways are found to overcome or minimize the difference in strengths between cast and forged blades. One method of increasing the strength of the blades is to cast them around high-tensile inserts. Much research and development is being carried out along these lines.

When it was first adopted on a commercial scale in engineering, investment casting was so relatively expensive that its applications were limited to the mass production of small intricate castings in alloys which were difficult to machine. The process has been so developed however, that today it is being increasingly adopted for the production of ordinary commercial castings in iron, plain carbon steel and even non-ferrous metals.

Although the foundry production cost per unit weight of castings produced by precision casting techniques is still higher than by traditional methods, the cost difference is narrowing, and the savings in the machine shop are considerable. The quality of the finished product is also better, both in the finish on unmachined surfaces and in the metallurgical quality of the internal structure. There are, however, some limitations on the unit size and weight of individual castings produced by precision casting methods, particularly investment castings, and for the larger castings the traditional sand casting methods are likely to continue to be used for some time.

Before discussing the ways in which the investment casting process can be adapted for the production of one-off or small-batch quantity precision parts for the tool and die industry, it is first necessary to describe, in some detail, how the process is applied to the mass production and assembly of destructible patterns, how investment casting moulds are made by *(a)* the solid or block mould technique and *(b)* the one-piece ceramic shell-mould technique, and the methods used to remove the pattern material and cast the metal.

DESTRUCTIBLE PATTERNS

Materials

Many different materials have been, and are being, used for making destructible patterns. These come under two main headings:

1. Thermoplastic materials.
2. Materials which are thermoplastic for the purpose of injecting them into dies, but are also soluble in some, usually liquid, agency for leaching them out of the finished mould.

The most commonly used of the thermoplastic materials are proprietary waxes of various kinds which may, or may not, contain a filler. This filler remains suspended in the form of solid particles in the liquid or plasticized wax when the wax is heated. This reduces the amount of shrinkage and cavitation of the surfaces of the pattern when the wax cools and solidifies in the die, but makes injection more difficult. Filled waxes are not normally used for patterns incorporating very thin sections. Polystyrene is also used. This may be injected into dies and allowed to cool into a solid pattern, like wax, or it may, if dimensional accuracy and surface finish are not so important, be used as a foam material to form very light patterns having a closed cellular structure. In the latter case, the polystyrene is not melted out of the mould—no attempt is made to recover it. The material is burnt out, either when the mould is fired, or when molten metal is poured into it.

In the "Mercast" process, developed some years ago, mercury (which is liquid at normal temperatures) is gravity fed into metal dies and refrigerated to produce solid patterns. After the mould has been created the mercury pattern is removed quite simply by allowing it to revert to normal temperature, assisted by the running of liquid mercury onto the exposed surfaces of the frozen pattern. The Mercast process does produce finished castings of very high accuracy and excellent surface finish, but it is expensive compared with those using other pattern materials, and is little used commercially.

Low-melting-point alloys, such as Wood's metal, have been tried, but these tend to leave a dross residue in the mould, resulting in defective castings.

The thermoplastic-soluble materials include a number of low-melting-point inorganic salts such as sodium nitrate, and various urea-based materials. Both of these can be leached out of the finished mould in running water. Firms using a 90 per cent pure, water-soluble, urea material claim that it is only one third of the cost of a good wax, and that by using it they can make patterns having virtually no shrinkage or cavitation. Higher temperatures and pressures are however, required for injecting it into the dies. Other materials used include a number of proprietary water-soluble waxes, and a mixture of urea and either polyvinyl alcohol or calcium carbonate which is ultimately dissolved out in dilute acid.

Dies

Dies used for the mass production of the patterns are normally precision made from duralumin, brass, or steel, in a toolroom. For thick sections in the patterns, wax pattern dies frequently incorporate an internal runner system leading to a secondary cavity in which is produced a cold chill, a wax block of the same shape but smaller than the section of the pattern. This is transferred to the primary cavity after the wax pattern itself has been removed, and on the next injection cycle the wax flows round it to produce the next pattern. This reduces the amount of shrinkage and cavitation, since the only volume of liquid or plastic wax to cool down is that surrounding the already solid cold chill.

If the die can be suitably dismantled, or if ejecting devices are incorporated, vertical surfaces may be reproduced. Draft angles are not necessary. This reduces the amount of machining required for finished castings. Re-entrant conditions in the patterns may be provided by side closing elements in the die. The machine operator normally assembles and strips the die by hand to remove the pattern.

There are three different methods by which hollow castings may be produced.

If the hollow portion is of constant or tapered cross section, a correspondingly sectioned core blade or pin can be inserted in the die, as shown in figure 2*(a)*. The pattern material will flow round this and solidify, and the blade can be withdrawn from it when the die is stripped. This leaves a hole in the destructible pattern into which the refractory will flow to form a core during mould making.

If the hollow portion required in the casting is itself re-entrant there are two alternatives.

Preformed ceramic cores can be made or purchased; a number of ceramic and pottery manufacturers will make these to order. These can be placed in the pattern die with their core prints suitably shrouded, and the pattern material will flow round them, and encase them, when injected. The protruding core prints will be bonded into the walls of the mould when the latter is formed and the preformed ceramic core will be retained in position when the pattern material is melted or leached out.

Alternatively, if the pattern material is thermoplastic, and not thermoplastic-soluble, a soluble core can be preformed in a separate die, and this can be inserted in the pattern die before the thermoplastic material is injected. After the thermoplastic pattern has been made, the soluble core can be leached out, leaving the hollow, re-entrant cavity inside it. Refractory will flow into this during the mould-making process, in the same way as into a hole of uniform cross-section formed by a blade.

Machines

Machines used for the mass production of destructible patterns vary considerably. Where relatively high temperatures and pressures are required, as, for example, for polystyrene and the urea-based materials, traditional thermoplastic injection-moulding machines are used. For wax patterns, the machines used range from a simple, heated and air-pressurized, cylinder with a spring-loaded release tap, to sophisticated machines with a pre-set time cycle, incorporating both an injection and a delayed ramming pressure.

Machines have also been developed to inject wax in a plastic condition instead of as a liquid. Since the temperature range between injection and solidification is less the process is slightly quicker and, more important still, shrinkage and cavitation of the resulting wax pattern are reduced.

Assembly

Concurrent with the manufacture of the patterns themselves, other dies are used to produce a runner system of the same material. Sometimes, as shown in figure *2(b)*, the patterns are assembled directly to a central runner; sometimes, if the patterns are smaller, they are assembled onto sub-runners which are, in turn, assembled to the main central runner. The complete assembly then resembles a "Christmas tree" and, in some countries, it is referred to as such. In other countries it is visualized upside-down, and referred to as a "bunch of grapes".

Assembly is carried out by fusing the sprues of the patterns onto the sub-runners, and the sub-runners onto the central runner, by the application of heat. Sometimes this is done by thermostatically controlled soldering irons; sometimes, because they are lighter and less tiring for the operators, by means of thin blades, or spatulas, heated directly over a flame or resting, when not in use, in a shallow bath of molten wax. Female labour is used extensively for this work which is often carried out on an assembly line basis.

THE MANUFACTURE OF MOULDS

Solid or block moulds

The various stages in the production of a solid or block mould are illustrated in figure *2(c, d* and *e)*. Using the single-investment method, the central runner of the pattern assembly is fused to a base board, and an open-ended metal or cardboard flask is placed around it. This may also be secured in position, and sealed round the bottom edge, before investing, using the thermoplastic material. Investment is then carried out by pouring a fine refractory slurry into the flask.

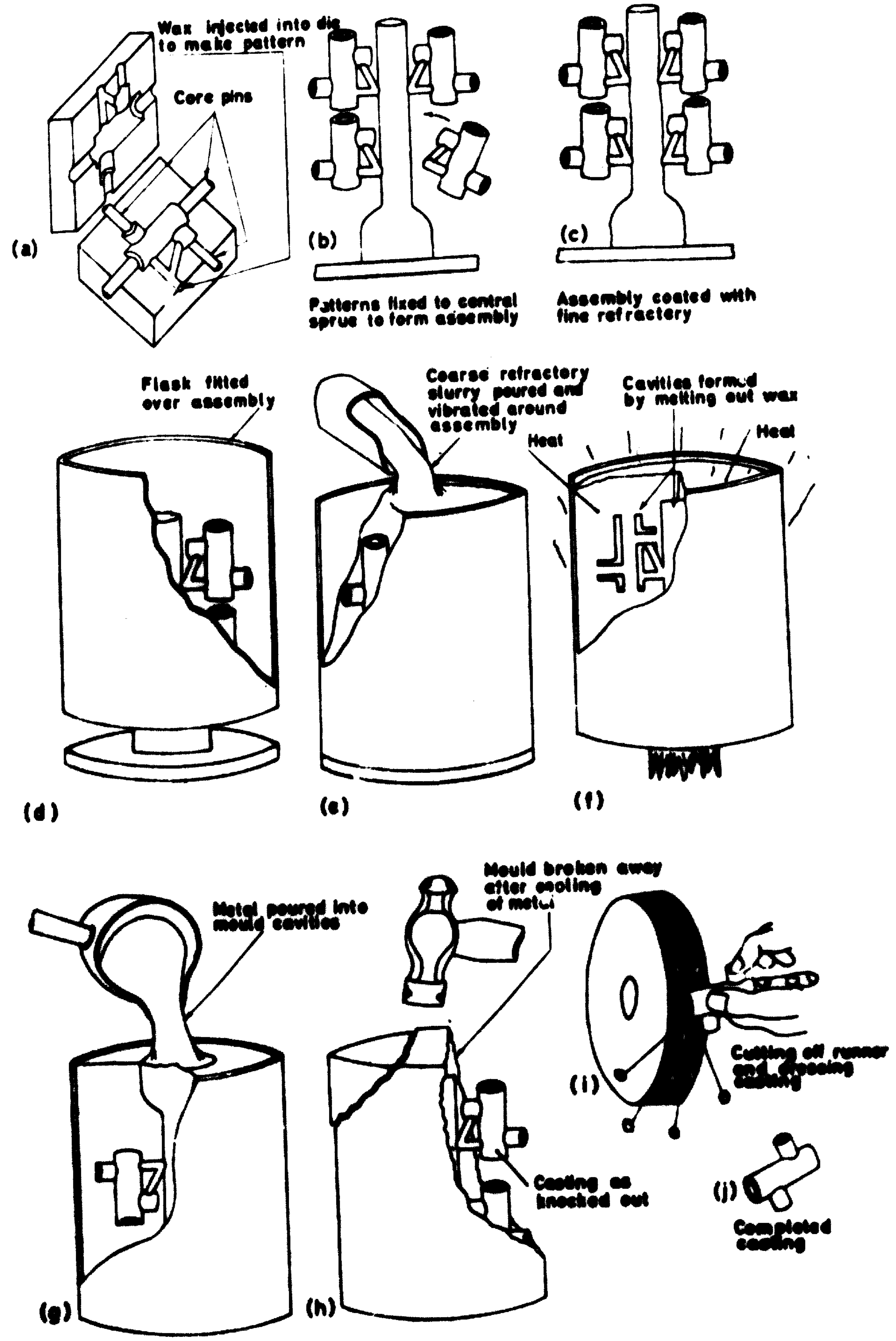

Figure 2. Stages in the production of a solid or block mould for investment casting

In the double-investment method the pattern assembly is first dipped into a very fine refractory slurry (taking care not to cover the base of the central runner). It is then stuccoed whilst still wet with coarser, dry refractory particles, to form a keying surface. When this is dry, the assembly is fused to the base board, the flask is placed around it, and it is invested as before, except that, in this case, a much coarser refractory slurry can be used.

This method gives a much higher permeability to the mould coupled with a very good surface finish on the resulting casting. In both the single- and double-investment methods the flask is then vibrated to release the entrapped air and compact the refractory, and is dried for some hours to a day (depending on size and refractory slurry used) either in air, or in a drying cabinet at about 30°C.

One-piece ceramic shell moulds

The monolithic (one-piece) ceramic shell-moulding process used for investment casting should not be confused with the two-piece shell moulding process originally developed by Croning in Germany during the 1939—1945 war. In the Croning process, permanent, heated, metal half-patterns are used, and dry sand which has been coated with a thermosetting plastic resin is allowed to fall on them.

The evolution of the manufacture of one-piece ceramic shell moulds for investment casting was a natural development from the first stage of the double-investment method for the solid or block moulds. The shell (usually about 5 mm thick) is built up on the pattern assembly by a series of dip coats, each followed by stuccoing with dry refractory particles.

For ease of handling, a metal rod with a hook formed on one end and a thread on the other is often screwed into a small metal block and this is inserted into the central runner die before injection. The thermoplastic material flows round the block which is thereby moulded into the bell-shaped end of the runner. Before melting or leaching out the pattern assembly, the hook is screwed out, leaving only the metal block embedded in the central runner. This falls out when the pattern material is removed.

A preformed ceramic ring is also often placed in a recess in the central runner die to form a firm rim to the finished shell mould. This is particularly advantageous if the mould is to be clamped on a rotatory furnace (either indirect-arc or high-frequency induction) for casting.

The first few dip coats are stuccoed with fairly fine refractory particles; the subsequent ones (sometimes a coarser dip coat is used for these) with much coarser dry refractory particles. This results in a mould of very good interior surface finish and excellent

N. f. metal = *non-ferrous metal*
L. m. p. metal = *low melting point metal*
H. f. induction = *high-frequency induction*

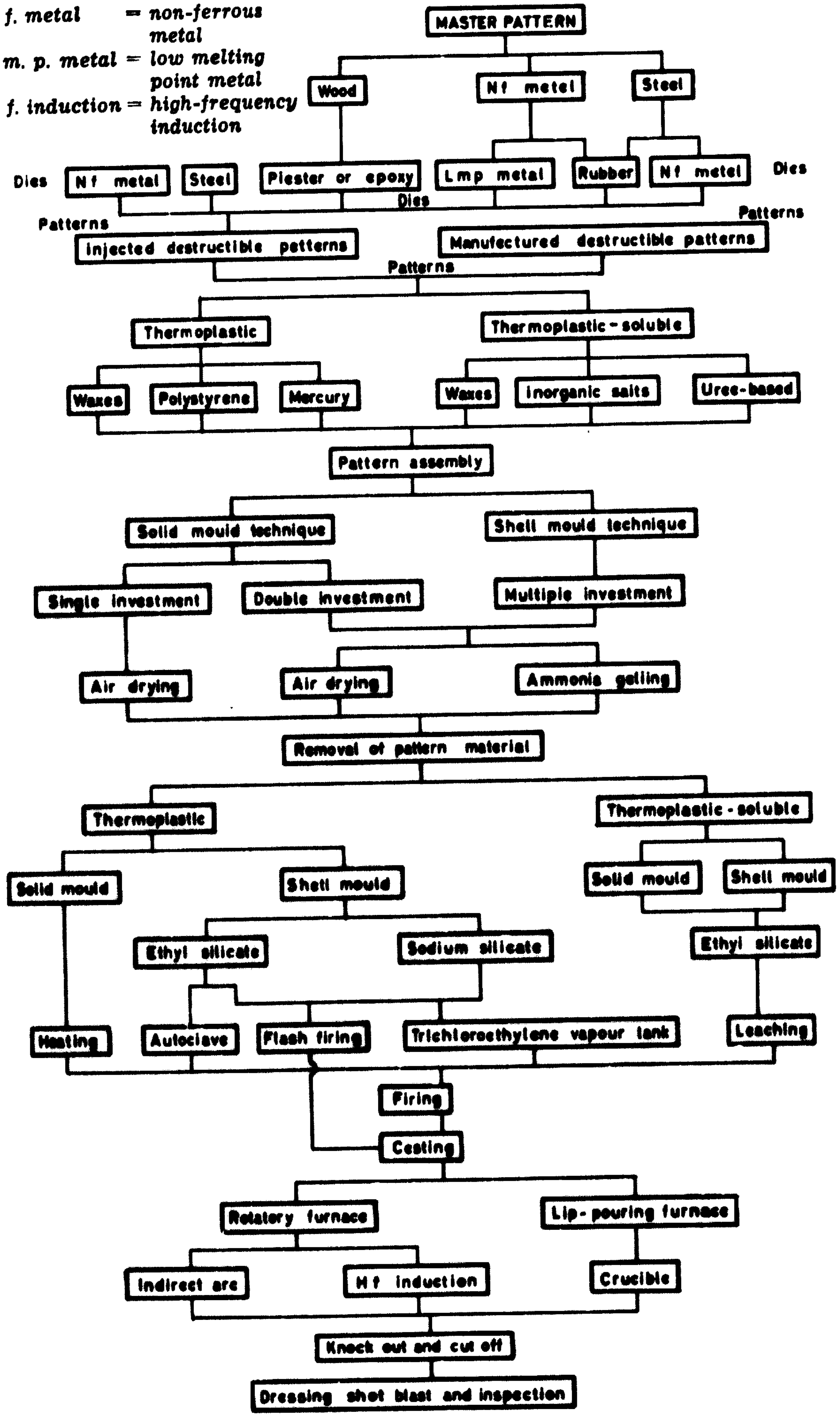

Figure 3. Flow diagram of the investment casting process

permeability, in which it is possible to cast almost any metal or alloy, without difficulty.

The commercial application of the ceramic shell process of investment casting using thermoplastic pattern materials was initially retarded due to the difficulties experienced in removing the pattern assembly. As it was heated slowly to remove the thermoplastic, this tended to expand slightly before melting, and crack the mould. These difficulties have now been overcome. Methods of removing the pattern material and firing the mould are discussed later.

The flow diagram of the various stages in the investment casting process by both the solid or block mould technique and the shell mould technique (figure 3) shows that, in addition to the vulcanized rubber dies used in jewellery, dies for engineering purposes can be cast in low-melting-point or non-ferrous metals from master patterns. These will not be as accurate or have as long a useful life as the cut dies in duralumin, brass or steel, but are quite suitable for smaller batches. The manufacture of destructible patterns for very small quantity production is discussed later.

REFRACTORIES AND BINDERS

The type and grade of refractory material used for making investment casting moulds is of the utmost importance, particularly for initial dip coats, since these provide the ultimate contact surface with the molten metal and must not be incompatible with it.

For the metals of lower casting temperature, such as aluminium-based and copper-based alloys, proprietary mixes containing plaster of Paris are often used to produce so-called plaster moulds. Higher temperature metals, however, cause a breakdown of the cavity surface of these moulds. For these, the dip coats consist basically of very fine particles of refractories, such as silica, zircon, or sillimanite, mixed with a binding agent, the most common being sodium silicate (water glass), silica sol, or ethyl silicate. Others include isopropyl silicate, and various high-temperature phosphate materials and synthetic resins.

For the backing up investment for solid or block moulds, fireclay, grog (crushed firebrick), or chamotte and reconstituted mould materials, are usually mixed with sodium silicate, although aluminous or Portland cement have also been used as binders. The stuccoing material used for keying the initial dip coat for the solid or block mould may be dry particles of silica, zircon, sillimanite, or alumina, but the successive layers of the ceramic shell mould are usually built up by stuccoing each successive dip coat with various grades of calcined china clay, usually known as molochite.

Considering the basic differences between the two most commonly used binders, sodium silicate is cheaper than ethyl silicate; hence its use as a binder for the backing-up investment for solid or block moulds. Much more material is needed for this than for the initial dip coat for these moulds, or for the successive dip coats for the production of ceramic shell moulds.

In considering which of the two should be used as a binder for the dip coats, account should be taken of the fact that whereas sodium silicate will mix with water, and has an affinity for it, ethyl silicate will not, unless a mutual solvent is added.

Mutual solvents used include ethyl alcohol, isopropyl alcohol or their binary azeotropes with water, the most common being ordinary industrial methylated spirit.

A very small quantity of hydrochloric acid is usually also added to act as a catalyst to accelerate hydrolysis and gelation. Too high a quantity will, however, cause premature gelation of the mixture. Gelation can also be accelerated by the addition of a base such as magnesium oxide instead of an acid, but the resulting solution, being alkaline, is unstable and gels within a short time.

It should be noted that the hydrolysis reaction will be accompanied by a 10 to 15°C rise in temperature. This provides an excellent method of determining when hydrolysis is complete, should the mixture be required urgently. If a graph is plotted of temperature against time it will be observed to curve over to a maximum point, and then drop off as the heat generated by the reaction is lost to atmosphere. At the moment of the highest point on the temperature curve, hydrolysis is complete.

Although it is necessary to hydrolyse ethyl silicate in the early stages of the preparation of dip coats by mixing it with water, the finished moulds are impervious to water. Ethyl silicate must therefore be used instead of sodium silicate for all investment moulds created around soluble, water-leached, pattern assemblies, or where the pattern material is going to be removed in a steam autoclave. Silica sol may also be used, but to bring a finished mould based on sodium silicate into contact with water or steam would ruin it.

Another factor which may influence the choice between sodium silicate, silica sol or ethyl silicate is their respective pH values. Sodium silicate and silica sol both have a pH value of about 10. Ethyl silicate is sold at various acidities; it can be neutral, in which case its hydrolysed solution will have a pH value of 2 to 3. Without going into the chemistry of this too deeply, this means that dip coats and investment based on sodium silicate or silica sol must be air dried, whereas advantage can be taken of the lower pH value of ethyl silicate based dip coats to gel off successive coats in about 30 seconds by subjecting them to ammonia vapour to neutralize the excess acid.

Some users of ethyl silicate maintain however that air drying gives a stronger shell and still prefer to air dry between successive dip coats and stuccoing. This is quite practical with a large production output by having a drying room containing as many shell moulds, in various stages of completion, as can be re-dipped and stuccoed during the time that it takes for each successive coat to dry.

Proprietary liquid binders which are basically either sodium silicate, silica sol, or ethyl silicate are manufactured and sold by various firms of industrial chemists under such trade names as Ludox (basically silica sol), Silester OS and Dynasil 40 (both basically ethyl silicate). There are several types of ethyl silicate, one of which is tetraethoxy silane or ethyl orthosilicate. This is prepared from the following reaction between silicon tetrachloride and absolute ethyl alcohol, the other by-product being hydrochloric acid, some of which, as has already been explained, is required subsequently for use as a catalyst during hydrolysis.

$SiCl_4$	+	$4C_2H_5OH$	=	$Si(OC_2H_5)_4$	+	$4HCl$
Silicon tetrachloride	+	ethyl alcohol	=	ethyl silicate	+	hydrochloric acid

So many different refractories and binders are in use in the investment casting industry, and there are so many variations in the basic processes and techniques that it would be difficult to find two completely unrelated investment casting firms in which exactly the same process was carried out. Added to this, almost all firms have their own jealously guarded trade secrets which, they claim, enable them to produce better precision castings than their competitors.

The author lectured for many years on Production Engineering at the University of Aston in Birmingham, England. He was also in charge of the Precision Casting Laboratory there. As a lecturer and not as a member of a rival firm, he was privileged to visit many precision casting firms and would not wish to betray any confidences. The following account of the preparation and application of dip coats, the manufacture of one-piece ceramic shell mounds, and the subsequent casting procedure, therefore describes the methods used in his own Precision Casting Laboratory at the University, not those used by any particular firm.

Stages in the production of an investment casting by the shell-mould process

Stage 1. During the afternoon preceding the day on which the shell moulds are to be made, a quantity of liquid (depending on the number of shells required) is mixed in the following proportions by volume, and stirred:

Ethyl silicate	550
Industrial methylated spirits	440
Water	40
Concentrated hydrochloric acid	1

This is left to stand overnight to hydrolyse. The basic chemical reaction which takes place during hydrolysis is:

$$\begin{array}{llllll} \mathrm{Si\,(OC_2H_5)_4} & +\ \mathrm{4H_2O} & = & \mathrm{H_4SiO_4} & + & \mathrm{4C_2H_5OH} \\ \text{Ethyl} & +\ \text{water} & = & \text{ortho-} & + & \text{alcohol.} \\ \text{silicate} & & & \text{silicic} & & \\ & & & \text{acid} & & \end{array}$$

Stage 2. Next morning a quantity of 200 mesh zircon flour is added and mixed thoroughly with the bonding liquid in the proportion of 3.62 kg of flour per litre of liquid.

Stage 3. The pattern assembly is degreased to remove any remaining parting agent used to facilitate the removal of the individual patterns and runner parts from the dies.

Stage 4. If the casting is to be carried out on a rotatory furnace (either an indirect-arc or a high-frequency induction type) it is necessary at this stage to weigh the pattern assembly. By knowing the specific gravities of the pattern material and the metal to be cast this makes it possible to calculate the weight of the charge for the furnace. Obviously there must be sufficient molten metal to fill the mould cavity, and if there is too much the charge will solidify partly inside the furnace itself, and it will not be possible to remove the mould from it.

Stage 5. The battern assembly is inverted and dipped up to the edge of the base of the central runner in the dip coat solution. It is removed, gently inverted, and rotated to ensure an even coating of the solution. Excess solution is allowed to drip back into the tank.

Stage 6. The still wet assembly is stuccoed with minus 50 plus 80 grade molochite. (See later for methods of stuccoing.)

Stage 7. The dip coat can be air dried for some hours, during which time the alcohol will evaporate leaving only the orthosilicic acid, which has a rubbery texture. Because of the small batches of shell moulds normally produced at the university, it is more usual at this stage, however, to subject the dipped and stuccoed pattern assembly to ammonia vapour for about 30 seconds. This achieves the same result. (See later for ammonia treatment.)

Stage 8. The ammonia-treated pattern assembly is left to stand for several minutes if necessary to disperse the ammonia fumes. These tend to cause the premature gelation of the remaining dip-coating mixture if they are permitted repeatedly to come into contact with it. Alternatively, the fumes may be dispersed with a low-pressure compressed air blast.

Stage 9. Stages 5 to 8 are repeated once or twice, depending on the size and intricacy of the individual patterns.

Stage 10. Repeat stage 5.

Stage 11. The still wet pattern assembly is stuccoed with the much coarser No. 10 molochite. (See later for methods of stuccoing.) This provides a very open, permeable, outer structure.

Stage 12. Repeat stages 7 and 8.

Stage 13. Stages 10, 11 and 12 are repeated to a total of between 5 and 10 fine and coarse stuccoing coats (depending on the size of the individual patterns and the total weight of the metal to be cast). The finished wall thickness of an average-sized mould should be about 5 mm.

Stage 14. The now completed shell mould is then left to air dry for 2 to 4 hours to give a coherent gel structure. At the university it is normally left to dry overnight; subsequent stages are carried out the next day, or even several days later when the process next has to be demonstrated.

Stage 15. The pattern material is melted or leached out. (See later.)

Stage 16. The shell mould is fired at about 1100°C for 10 to 30 minutes (again depending on size) to burn out any remaining pattern material, cure the mould and bring it to the casting temperature. For steel and similar metals, casting should be immediate. For metals of lower melting temperature, it may be necessary to allow the mould to cool down slightly. If thermoplastic pattern materials are used and a flash fired furnace is employed, stages 15 and 16 will be combined (see later for removal of the pattern material and firing of the mould).

During the firing of the mould the following endothermic reaction takes place:

$$\begin{array}{lllllll}
H_4SiO_4 & + & \text{heat} & = & SiO_2 & + & 2H_2O \\
\text{Ortho-} & + & \text{heat} & = & \text{silica} & + & \text{water} \\
\text{silicic} & & & & \text{bond} & & \text{(evaporated).} \\
\text{acid} & & & & & &
\end{array}$$

When the mould is fired the investment is cured, the orthosilicic acid being calcined to a silica bond, which is itself a very hard refractory, and bonds together all the refractory molochite particles. The manufacture of the shell mould is now complete. Moulds may be stored indefinitely, and heated again to pouring temperature as required.

Stage 17. During or before stages 15 and 16, a quantity of the metal to be cast is cut from a bar or from scrap, and is weighed to enable the correct volume of metal to be fed to the rotatory arc furnace (see stage 4). If a lip-pouring furnace is used instead, the weight of the charge is not critical, providing that it exceeds that required for filling the mould or moulds.

One disadvantage of the use of indirect-arc furnaces is that the metal tends to take up carbon from the carbon electrodes. This can be allowed for in the original composition of the metal, but some firms prefer to use rotatory high-frequency induction furnaces instead. Whilst it is claimed that both rotary indirect arc and rotatory high-frequency furnaces give better results metallurgically, firms using lip-pouring furnaces justify them on the grounds of dimensional accuracy.

Their use enables the part of the shell mould containing the component casting cavities to be buried in sand. This creates a similar backing-up effect to that of the main investment in the case of the solid or block mould and retards the cooling rate. The molten metal from the lip-pouring furnace is usually poured into a crucible, which is then used to fill the mould.

Stage 18. When the molten metal is at the correct temperature for casting, the shell mould is removed from the curing furnace, handled with asbestos gloves, and is clamped over the pouring hole in the top of the rotary furnace. The furnace is inverted, the molten metal flows into the mould (an air blast may be employed to assist filling) and is allowed to solidify.

Stage 19. After a few minutes, the shell mould is unclamped and removed from the furnace, with the now solid, but still hot, casting inside it, this time using foundry tongs, and is placed in a sand tray to complete its cooling. Some firms prefer to pass the moulds on a slowly moving conveyor for 3 to 4 hours through a gas-heated tunnel, hot at the entry end and cool at the exit. This retards the cooling rate and gives a better metallurgical structure to the castings.

Stage 20. When cool, the refractory mould is shattered and broken up, often with pneumatic hammers, and the complete casting assembly is removed from it. The runner system is cut up to separate the individual castings, these are dressed on a grinding wheel, and are then shot blasted to clean them up in preparation for any machining which may be required.

STUCCOING MOULDS

After each dip coat has been applied it is invested with dry refractory particles. This may be done by rotating the pattern assembly by hand beneath a curtain of falling particles from a raining device, a vibrating sieve into which the uninvested particles are restored. It is, however, more often done today by immersing the dipped and still wet pattern assembly into a fluidized bed.

A fluidized bed is an open metal tank with a sub-floor of porous ceramic tiles. A blower discharges air at low pressure, but high volume, into the space between the tiles and the bottom of the tank.

The tank is partially filled with the dry refractory particles. With the blower switched off, it is difficult to push one's hand down into the bed. If the pattern assembly were to be pushed into it, it would probably break. When the blower is switched on, however, each individual particle is separated from its neighbours by a layer of air.

Bubbles of dry refractory particles are observed to form and burst on the surface of the bed. The visual effect is that of a boiling liquid, although the refractory particles remain quite cool. The dip-coated pattern assembly can be lowered into the bed of dry particles as easily as if it were indeed being lowered into a liquid, and is lifted out covered with an even layer of particles stuck to the dip coat.

Fluidized beds are made and sold by several makers of ceramic tiles. Most investment casting firms use them for the shell mould process, or for keying the initial dip coat in the double-investment solid or block mould technique. A combined dip-coating tank and fluidized bed has been designed and is being developed at the University of Aston in Birmingham. This incorporates a variable-speed revolving dip tank, with a fixed stationary paddle to keep the dip-coat mixture agitated, handling devices to interchange dip-coat tanks (for cleaning, etc.), and a one-piece stainless steel working surface with two circular holes cut in it, one for the dip-coat tank and one for the fluidized bed. Lids keep the materials clean when the investment bench is not in use.

AMMONIA TREATMENT

If the pH value of the binder for the dip coat is at a suitable level, ammonia may be used to gel off (stiffen) each successive dip coat in only about 30 seconds, instead of waiting hours for it to dry naturally. This used to be done by placing a shallow container of liquid ammonia inside a sheet steel cabinet with a sealing door. The door was opened, the dipped and stuccoed pattern assembly was quickly hung on a rail inside, and the door was shut. After 30 seconds the door was opened again, the assembly was quickly withdrawn, and the door was shut again. However quickly the door was opened and shut, ammonia fumes belched out. This was most unpleasant for the operators.

An ammonia-treatment cabinet was then developed, to work on an automatic cycle. About ten dip-coated pattern assemblies are hung together on a rack mounted on an overhead rail conveyor. The door of the cabinet is opened, the rack of pattern assemblies is pushed inside, and the door is closed. The automatic cycle then injects a quantity of ammonia vapour through a nozzle, causes a fan to circulate it throughout the cabinet, and then, after a pre-set time, opens a port and causes the ammonia to be sucked out and exhausted through a ducting system to atmosphere.

Although this is an excellent piece of equipment it does necessitate batch processing. Research and development in many countries is being aimed at the complete automation of investment casting. Ways will have to be found to make the ammonia treatment continuous, with the dipped and stuccoed pattern assemblies following each other through the equipment, in line with established mass-production techniques.

Many firms are developing these types of devices. One which has been patented and has the trade mark Rotagel has been designed and is being developed at the University of Aston in Birmingham. It is intended to be used in conjunction with two of the investment benches, already mentioned, as a complete dipping, stuccoing and gelling unit for the production of shell moulds.

DRYING OUT SOLID OR BLOCK MOULDS

The methods of air drying, or the alternative ammonia treatment, for gelling off dip coats used for shell moulds, or for the double-investment solid or block mould, have already been discussed in some detail. For the main investment of the solid or block mould, a typical treatment is described below.

After investment the block mould is vibrated (to remove the entrapped air and compact the refractory) and air dried for 24 hours. Batches of the moulds are then put, in racks, in special drying ovens, in which the temperature is automatically controlled to increase slowly from normal air temperature up to a temperature just below the melting temperature of the pattern material. If an ethyl silicate binder has been used for the main investment, this is programmed to take a further 24 hours. If the cheaper sodium silicate has been used, because of the higher water content, it may take three days.

This treatment is in no way standard, however. Firms differ considerably in what they consider desirable or necessary in the interests of the quality of the resulting castings. It does, however, serve to illustrate how much longer it takes to make a solid or block mould, ready for the removal of the pattern material, than it does to make an ethyl-silicate-based shell mould. Using ammonia treatment, and even allowing for the final air drying, an ethyl-silicate-based shell mould can be built up around a pattern assembly, and can be ready for the removal of the pattern material in about 3 or 4 hours.

Any advantages which may be attributed to this saving in time should not, however, be over-estimated. No labour costs are involved while the moulds are drying; the only liabilities are the space and the initial capital for the drying ovens. If moulds are required in

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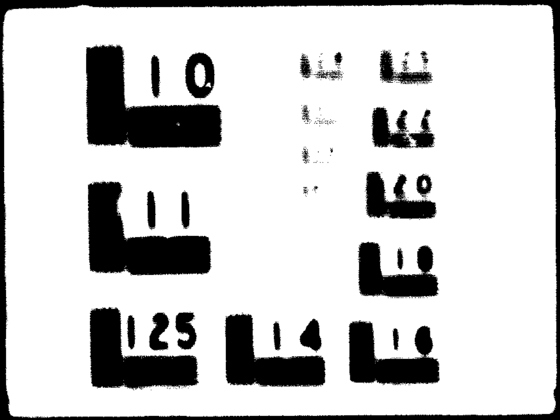

sufficient quantities, and if sufficient drying facilities can be made available, the labour force can be fully occupied and batches of solid or block moulds can be progressed into and out of the drying area continuously.

The overriding consideration is quality. As has already been said, many internationally famous firms making ethyl-silicate-based shell moulds prefer to air dry between dip coats, rather than use ammonia. They claim, rightly or wrongly, that the resulting shell mould is superior. Many firms claim also that solid or block moulds result in sounder, more accurate castings, than shell moulds. Some firms use both techniques, reserving the solid or block moulds for the more critical work.

REMOVING THE PATTERN MATERIAL AND FIRING THE MOULD

Thermoplastic-soluble pattern materials

For leaching out thermoplastic-soluble pattern materials the moulds are immersed in running water, preferably luke-warm, or in a dilute acid. For moulds based on sodium silicate, these pattern materials cannot be used since the water would affect the mould itself. Firms using the 90 per cent pure urea pattern material say that this is reclaimable from the water, but that the material is so relatively inexpensive that recovery is not economical. They discharge the running water into a river, and use new pattern material for each mould.

For leaching out water-soluble preformed cores which have been moulded into ordinary thermoplastic patterns to give hollow re-entrant castings, the pattern is normally held in running water until the water-soluble core is washed out.

Thermoplastic pattern materials

The removal of thermoplastic pattern materials from solid or block moulds presents little difficulty. The moulds are placed in ovens in which the temperature is slowly raised to a temperature above that required for melting out the pattern material. This drips into a tray and is normally re-used.

This technique cannot be used for ceramic shell moulds, because, as the temperature of the pattern material rises through its solid range, the pattern assembly expands at a greater rate than the refractory shell mould. Wax, which is, perhaps, the most commonly used thermoplastic material in use today does not have a completely linear coefficient of expansion, but it approximates to about

0.005 mm per cm per degree C, which is about 100 times greater than the coefficient of expansion of most refractories used for producing shell moulds. In solid or block moulds the internal pressure resulting from the expansion of the wax is resisted by the backing-up effect of the mass of the refractory, but ceramic shell moulds tend to crack.

It was largely because of this problem that the Mercast process was developed. Mercury has a very low coefficient of expansion, and a very short range of solidification. Shells could be built up around solid mercury pattern assemblies at a temperature which was only slightly below that required for melting them. Because of the practical difficulties involved in producing shell moulds at these very low, sub-zero temperatures, however, the process was never widely adopted on a commercial basis and is little used today.

The methods which have been developed to overcome the difficulties of removing thermoplastic pattern assemblies from shell moulds fall into two main categories:

(a) Backing up the shell mould to resist the pressure of the expanding pattern assembly, and

(b) Rapidly removing the skin or outer layer of the pattern assembly at the mould-pattern interface to provide a void into which the bulk of the material can expand.

BACKING UP THE MOULD TO RESIST THE INTERNAL PRESSURE

To back up a shell mould for the removal of the pattern assembly either dry solid particles or a liquid may be used. The latest method to be developed, however, utilizes high-pressure steam.

One application of the dry particle method is to place the mould, pouring cup downwards, over a runout hole. A hollow, bottomless container is placed around it and hot sand or metal shot at a temperature of about 300°C is cascaded into the top of the container, and is vibrated, or rammed down, to compact it. The heat from the sand or shot melts the pattern material out, whilst the backing-up pressure prevents the mould from cracking.

If necessary the space between the rim of the pouring cup and the inside bottom edge of the container can be first sealed with a quantity of unheated sandclay mixture and, after the container has been filled with the hot backing-up material and vibrated or rammed, the top can be sealed or a lid can be put on it. This enables the container to be moved to a different position for the pattern material to flow out, and creates, in effect, a solid or block mould, which can be fired, and ultimately cast, as such.

Another method is to fluidize a bed of hot refractory particles, lowering the shell mould (pouring cup upwards) into the bed, and switching off the blower to allow the hot particles to settle compactly around the outside of the mould. When the thermoplastic pattern material is molten, the bed is re-fluidized, the shell mould is removed, and the liquid pattern material is poured out.

For a true liquid to be used in the same way as the fluidized bed, it should, ideally, be of high density, be immiscible with the pattern material in its liquid state, and be easily burnt out from the structure of the shell mould when this is fired. Although not of high density, hot water has been used for de-waxing small, simple, pattern assemblies made of low-melting-point wax. Low-temperature alloys such as Wood's metal, which become liquid at about 150°C, have also been used. As in the fluidized bed, the shell mould is lowered into the liquid, to within about 5 mm of the rim of the pouring cup, and is lifted out after the pattern material has become molten. This is then poured out.

The use of high-pressure steam is a fairly recent development. Steam autoclaves had already been in use in various other industries before they were adopted for de-waxing shell moulds. Special autoclaves have now been developed for this purpose. These incorporate a steam inlet valve which opens quickly to ensure a rapid build-up of steam pressure, and which is positioned so that the steam is not blown directly on to the moulds. Safety features have been incorporated to prevent the opening of the door when the autoclave is full of high-pressure steam, and a surrounding lagged steam jacket reduces condensation.

A batch of invested shell moulds (depending on their size and that of the autoclave) are placed, in racks, in the autoclave and the sealing door is closed. High-pressure steam at about 80—100 psi is first introduced into the surrounding jacket and then, at a slightly lower pressure, into the autoclave de-waxing chamber istself.

It has been estimated that the input of heat to the pattern assembly from steam at a pressure of 80 psi and a temperature of 160°C is about twenty times that obtained from a furnace at 900°C. De-waxing is, therefore, very quick; it takes about 5 to 10 minutes for average-size wax pattern assemblies. The wax drips into a tray in the bottom of the autoclave. Although about 95 per cent recoverable (as with all these methods, some wax is retained in small pockets in the mould, or is absorbed into its structure) the wax cannot be re-used until the water in it has been separated out.

RAPIDLY REMOVING THE SKIN OR OUTER LAYER OF THE WAX

One of the first techniques developed to de-wax shell moulds involved the use of a trichloroethylene vapour degreasing tank. In these the solvent is boiled at the bottom of the tank and condensed on cold water pipes at its top. Shell moulds are placed on wire grids near the bottom of the tank, pouring cups downwards. Vapour permeates the porous shell and very quickly dissolves the outer layer of the wax pattern assembly before the heat from the vaporized solvent appreciably expands its bulk. Subsequently, most of the wax is melted rather than dissolved, and this runs out into the solvent in which it goes into solution. This method of de-waxing is, however, rather slow, about half an hour being required for large pattern assemblies.

When this solution becomes concentrated it is distilled to recover the wax. This may be done by placing a guttering beneath the cold water pipes to prevent the liquid trichloroethylene solution, which condenses on them, from running back into the tank. The liquid trichloroethylene, together with the solid wax, is collected in the guttering.

Thermoplastic pattern materials of all kinds may be removed from shell moulds by subjecting them, very suddenly, to intense heat. This not only melts the outer layers of the pattern assembly, but transforms them almost instantly into a gas which permeates through the walls of the shell and is burnt in the furnace. Some of the material from the bulk of the assembly does melt, and flows out of the pouring cup at the bottom.

If a suitable runout hole is provided, some pattern material can be collected in a cooled tray beneath the furnace, but much of it is burnt within it. If wax is used as the pattern material, recovery is only about 75 per cent, and as some degradation has occurred (because of the high temperature to which it has been subjected) it is inadvisable to re-use it for making patterns without some reclamation treatment. It can be used, however, for making runner systems for subsequent assemblies.

Firing of moulds

Before going too deeply into flash de-waxing, the methods used to fire moulds will be considered.

Irrespective of the method used for removing thermoplastic pattern material from moulds, 100 per cent recovery is rarely, if ever, possible. Due to the complex shape of almost all pattern assemblies, some liquid material will remain, in pockets, in the mould, and will solidify again when the mould cools down. Even if all this liquid could be removed by shaking the still hot mould, some will have permeated into its structure during the melting process.

It is essential that every vestige of the pattern material is removed from all types of investment casting moulds before molten metal is poured into them; otherwise gases will be created which will cause blow holes in the castings. This removal of pattern material is ensured by soaking the moulds at a temperature high enough to burn every trace of it away. In addition to this, they must be fired to cure the mould, and to heat it up to a suitable temperature for casting.

Solid or block moulds are fired after the removal of the pattern material by putting them into a furnace at a temperature of about 400°C, and raising this slowly to about 1000°C over a period of 3 to 4 hours. Better still, from the point of view of production, a continuous furnace which is at a temperature of about 300°C at the entry end and about 1000°C at the exit, may be used and the moulds may be fed slowly through it. This provides a continuous supply of fired moulds, ready for casting, without any delay and consequent loss of heat.

Shell moulds, which have had the bulk of their thermoplastic pattern material removed previously, may be fired in a similar manner. This may be done more quickly than for solid or block moulds because of the considerably smaller volume of refractory to be cured and raised in temperature.

Simultaneous firing and removal of the whole of the pattern material has been successful for shell moulds, by plunging them quickly into a furnance at 1000°C, or into the hot end of a continuous one. Unless provision is made, however, to run the bulk of the molten pattern material out of the furnace, all of this will be lost, and the resulting smoke and fumes can be a nuisance. Furthermore, if shell moulds, still containing the whole pattern assembly, are exposed for more than a minute or two to the warmth of the furnace room, before being loaded into the furnace, the pattern assembly will expand sufficiently to crack the shells.

Specially designed "flash de-waxing" furnaces are now available. Although the term "de-waxing" is normally applied to these furnaces they may be used to remove all types of thermoplastic pattern material, not waxes only.

One such type of furnace consists of an inverted cylindrical bell, about one metre in diameter, lined with fire bricks. Gas flames, assisted by an air blower, maintain its interior at a temperature of about 1100°C. It is designed to accommodate one shell mould at a time. The mould is placed, pouring cup downwards, over a hole in the centre of a circular table beneath the bell. The table with the mould can quickly be lifted up into the furnace.

An annular channel around the edge of the lifting table is filled with sand, or other refractory, and this forms a seal with the lip of the bell when the table is raised. The hole in the table leads to a runout pipe with an S-bend in it which retains a quantity of thermoplastic pattern material which is liquid when the furnace is in use and solid when it is not. These two innovations prevent air from entering the furnace during firing and reduce heat loss.

The pattern material which does melt and flow out, replaces the liquid material already in the S-bend, in the same manner as water from a domestic sink, and is collected in a tray beneath it. The complete process of melting out some of the pattern material, burning the rest, curing the mould, and raising it to a suitable temperature for casting, takes only about 15 minutes for an average size shell mould.

INVESTMENT CASTING FOR ONE-OFF AND SMALL-BATCH PRODUCTION

It may appear to the small-batch producer that this article has long delayed in coming to the main objective indicated by its title. It should be pointed out, however, that its main purpose is to indicate to industrialists and foundrymen, who may have had little or no knowledge of the ramifications of investment casting, how the process can be adapted to their own individual needs, particularly for making precision parts for the tool and die industry.

The whole question of the application of investment casting to small-quantity batch production is one of improvisation, adaptation, and utilization of existing or easily obtainable materials and equipment. One pattern material may be readily obtainable within the country of the intended user; another may not be available locally, and may be expensive to import. These considerations apply to the other raw materials, such as refractories and binders. In the selection of one of the many possible variations of the basic process, the first consideration should be the material available to produce the destructible patterns and the mould.

The next consideration should be the equipment available. A considerable amount of equipment has been discussed in this article, and many alternatives for carrying out the same stage of the process have been enumerated. It would, in many cases, be uneconomical to purchase expensive equipment merely to enable precision castings to be produced in small numbers. Equipment already existing within the organization, or readily available to it, will, in conjunction with materials available, often dictate the variation of the process to be used and the techniques to be employed.

It is possible that neither a plastic injection machine, nor a wax injection machine is available. This article will describe how a simple wax machine can be made, or how it can be dispensed with altogether. Although desirable, neither a fluidized bed, nor a raining device is essential; investment can be done by hand. Methods for ammonia treatment can, if required, be improvised. Flash de-waxing and firing of shell moulds may be done in an ordinary furnace, or the de-waxing itself may be done in an available autoclave which is normally used in some other process or industry (rubber, etc.), or in a trichloroethylene degreasing tank. Adaptation and improvisation are the key words.

SMALL-BATCH PRODUCTION WITH DESTRUCTIBLE PATTERNS

The manufacture of destructible patterns

Dies need not be employed for making the destructible patterns for one-off or small-quantity production. Fortunately, most of the thermoplastic and thermoplastic-soluble materials used, including wax, polystyrene, and the water-soluble urea-based materials, are easy to machine, and can be sawn, filed, or even carved into shape with a sharp knife.

Being thermoplastic, these pattern materials can be initially heated slightly and bent, or otherwise formed roughly into shape, to reduce the amount of material to be cut away. Complicated shapes can be fabricated by fusing individual parts together, simply by placing a hot knife or hacksaw blade between flat faces to be joined, and drawing it out. By these means hollow patterns having quite complicated re-entrant internal features can be made. From these, moulds can be produced to cast quite accurate parts which would be almost impossible to produce out of the solid.

A mating punch (or a mating die) for sheet-metal press-tool work, such as embossing, can easily be made provided that the other mating part, the die (or the punch), is in existence. This can be heated, and pressed lightly into contact with the thermoplastic to provide a negative, or positive, impression. A casting from a mould created around this will, apart from shrinkage, be an exact replica of it. It will require little more than shot blasting and polishing. One die (or punch) can be used to make any number of destructible thermoplastic patterns for producing mating punches (or dies). Any one of these can be then used to make any number of patterns for reproducing, apart from shrinkage, replicas of the original die (or punch).

Where neither the punch, nor the mating die, is in existence, and for other castings required in large numbers, it is impracticable to make the destructible patterns individually. Short-run dies may be produced for making them. The part required may be made (with allowance for shrinkage, and provision for forming the sprue hole in the die) as a master pattern, out of wood, or any other material, and this may be used to produce split dies in epoxy-resin or even plaster of Paris. The latter gives reasonably good reproduction but can only be used to produce relatively few destructible patterns.

Epoxy-resin dies are obviously better, but cost more, and are only justified if more patterns are required. If these non-metallic dies are pressure injected with the thermoplastic pattern material the pressure must be kept low. For plaster of Paris dies it should not exceed 10 psi. Shrinkage and cavitation are therefore a greater problem than with metal dies injected at a higher pressure. Their poor conductivity also makes the time required for the solidification of the pattern material much longer.

Sometimes, if complicated destructible patterns are required in fairly large numbers and there are no re-entrant conditions or hollow features, it is easier to produce a master pattern in metal, and cast the die, rather than make it direct. Obviously the material from which the die is cast must have a lower melting point than the master pattern. If, for example, the master pattern has been made of steel, it can be used to cast aluminium or other non-ferrous alloy dies. If it has been made of one of these alloys it can be used to cast tin-bismuth or tin-antimony-bismuth alloys such as Cerrolux.

The allowance for shrinkage in master patterns has to take into account the shrinkages of the die away from the master pattern, of the pattern material away from the die, and of the casting away from the mould. The first of these tends to counteract the other two. One advantage of the use of cast dies is that the master pattern can be retained and is available for re-casting a new die, should the one in use become damaged.

The advantage to the tool and die industry of this technique of casting dies for destructible patterns is that any existing metal part can be reproduced in quantity, provided, of course, that a suitable parting line (of maximum cross-section) can be established to enable the part to be withdrawn from both halves of the split die. The injecting or pouring sprue can be machined in the die.

The resulting castings from destructible patterns produced in this die will have a surface finish comparable with the original part, and be very good in detail, but may, of course, be slightly smaller. If the original part has been machined on certain features, and this machining has to be carried out on the castings for dimensional accuracy or improved surface finish or flatness, it is frequently possible to machine out the cast die to make these features oversize on the destructible patterns, and so leave the machining allowance on the resulting castings.

Provided that a small vulcanizing press is available, small parts for the tool and die industry, such as intricately detailed punch faces, may be produced in quantity by means of the variation of the process which is used for jewellery. The original master pattern will have to be made by a craftsman, but it may be produced in a more easily worked metal than that in which the parts are ultimately cast. From this, split rubber dies may be made, and low-melting-point thermoplastic or thermoplastic-soluble pattern materials may be injected into them. The resulting castings should be of excellent detail and good surface finish. They should normally require only a light polishing

Injection machines are not always essential, all the thermoplastic materials can be gravity cast. Much will depend, however, upon the shape of the die cavity and the width of its channels. Also, bigger sprue holes are required for gravity casting, as well as slightly higher temperatures to cause the material to flow correctly—an important point with dies of rubber or low-melting-point alloy.

For very intricate dies, injection may be advisable; otherwise the material may not completely fill the die. Even with injection, provision must be made for the escape of entrapped air, or the die will not fill.

If a wax injection machine is required, a simple one may be purchased at a cost of about US$ 200 or one can be made.

This need consists only of a cylindrical steel or cast-iron pot, with a steel plate bolted to its top and sealed with a gasket. Gas flames may be used to heat it from beneath, or a thermostatically controlled electrical immersion heater may be fitted into it, near the bottom. In either case, a temperature gauge should be incorporated to indicate the actual temperature of the liquid pattern material.

A compressed air supply can be connected through the top plate, or through the side near the top, to pressurize the air above the surface of the liquid. This should be controlled by a pressure regulator and a pressure gauge. At a point near the bottom, below the surface of the liquid, a spring-loaded nozzle should be fitted to release the pressurized liquid, and cause it to be injected, when depressed by a conical shaped bush fitted in the injection sprue of the die.

The thermoplastic, or thermoplastic-soluble, pattern material is usually melted before being poured into the wax injection machine at the top, but can be subsequently re-melted in it. The top plate is then bolted firmly in position, and the heat and the compressed air are turned on and adjusted. Injection is done quite simply, by offering up the die to the spring-loaded nozzle by hand.

Wax injection has been successful with an even simpler device, an ordinary bicycle pump fitted with a nozzle.

Assembly of destructible patterns

The component parts of the runner system may be produced by gravity casting liquid pattern material into simple dies made of wood, plaster or metal. Metal tubes are often used for casting the sub-runners. The parts are then fused together. If the shell mould process is to be adopted, and particularly if ammonia treatment is to be applied, a metal hook or a T-shaped handle can have its end heated and pushed into the base of the pouring cup to facilitate handling.

If a rotatory furnace is to be used for casting, it is advantageous (although not essential) to obtain a supply of preformed ceramic rings. These should have an inside diameter of approximately the same size as the diameter of the pouring cups to be formed on the end of the central runners. When the die to produce these cups is made, it can be such as to make them very slightly larger than the inside diameter of the rings.

The ceramic and pottery manufacturers, who market these rings, normally have their own standard range. If only small quantities are required, it is simpler and very much cheaper to contact a supplier, choose a ring from his standard range, and make the central runner die to suit it, rather than ask him to make special rings.

On assembly, the rings can be heated and pushed onto the end of the pouring cup, ultimately to form an even, solid, edge to the shell mould to ensure that it can be mounted securely on the furnace.

The destructible patterns themselves are assembled to the sub-runners, or directly to the main central runner, by means of their sprues, using heated spatulas. Old hack-saw blades, heated over bunsen burners, are frequently used for this purpose. The opportunity is taken at his stage to effect last-minute repairs to the patterns, or to fill blow holes in them.

THE MANUFACTURE OF MOULDS

The available materials and equipment having largely dictated the type of process, moulds can be produced using the techniques already described. Even for the solid or block moulds, it is recommended that at least one stuccoed dip coat be applied to ensure a good surface finish for the castings. The refractories can be mixed with the binders by means of a large domestic food mixer. If one of these is not available, they can be mixed in a bucket with an electrically driven stirring device, or by hand.

If a rotatory furnace is to be used for casting, a weighing machine, or a simple balance, should be used to establish the weight of every complete pattern assembly. This can be scratched into the flat face at the bottom of the pouring cup. If more than one type of pattern material is in use, the specific gravity of the one being used should also be scratched into this face. This will enable the necessary calculations to be carried out, before the removal of the pattern material, to ensure that the correct volume of metal to fill the mould is melted in the furnace. This calculation is usually done immediately before the removal of the pattern material and firing.

If neither a raining device, nor a fluidized bed, is available for stuccoing, this may be done by hand. A pile of the dry refractory particles (two, of different grades, for ceramic shell moulds) can be placed in a tray. The pattern assembly can be held in one hand and can be rotated over the pile, while the other is used to throw handfuls of refractory at it.

Ammonia fumes are not pleasant. But, if ammonia treatment is to be given, and sophisticated equipment, such as a programmed ammonia-treatment cabinet or a Rotagel, are not available, the fumes must be suffered. They can be minimized, however, either by making a simple sheet-metal cabinet with a sealing door, and a rack inside to hang the shells on, or by using a large bucket, drum, or small tank, with a lid on it.

In the latter case, the lid (it need only be a piece of hardboard or sheet metal) can have a slot in it to accommodate the T-shaped handle embedded in the end of the pouring cup. When not in use, and when the pattern assembly is hanging by its T-shaped handle from the slot in the lid, a piece of cloth can be placed over the slot. Liquid ammonia in a shallow dish, or a brick or piece of cloth soaked in it, can be placed within the cabinet or in the bottom of the drum.

REMOVAL OF THE PATTERN ASSEMBLY AND FIRING

Water-soluble pattern materials can be leached out in a tank of running water, preferably luke-warm, or, in the absence of this, in a sink under a running tap.

Solid or block moulds can have their thermoplastic pattern assemblies melted out in an ordinary domestic gas or electric cooking oven. Whether or not they were originally created around thermoplastic or thermoplastic-soluble pattern materials they can then be fired in any furnace capable of being raised to a temperature of about 1000°C.

Shell moulds created around thermoplastic pattern materials do present more of a problem, because of their tendency to crack if the pattern assembly is slowly heated. If wax has been used for the pattern material and an autoclave is not available, a trichloroethylene de-greasing tank may be used. Alternatively, and this applies to any thermoplastic pattern material, the shell moulds may be de-waxed and fired by loading them, very quickly, into any furnace at about 1000°C in accordance with the principles of flash firing already described. They should not, however, be allowed to heat up slowly by placing them too near the furnace before insertion.

CASTING INTO INVESTMENT MOULDS

Any existing metal-melting equipment may be used for casting. If a rotatory furnace (either indirect-arc or high-frequency induction) is available, the mould will be inverted and clamped on the top of it. Pieces of sheet asbestos with a hole in should be introduced between the top of the furnace and the face of solid or block moulds; for shell moulds, asbestos string is twisted and formed into a washer. These provide a seal and prevent loss of heat from the mould.

Care must be taken in clamping shell moulds. If they are not clamped securely, they may fall off when the furnace is inverted; if too much pressure is applied, they may be cracked. Only the correct weight of metal must be charged to fill each mould. This may be deduced after calculating a factor from the known specific gravities of the pattern material and the metal. This factor is multiplied by the recorded weight of the pattern assembly.

If a lip-pouring furnace or crucible is employed shell moulds may be embedded lightly in sand or broken refractory. Embedding them firmly in sand may improve the dimensional accuracy if the charge is heavy, but it reduces permeability, and the quality of the casting may suffer. If no foundry facilities are available within the organization, the moulds may be sent out for casting. They can be transported safely, provided that they are packed carefully and their pouring cups are covered with paper and taped to prevent the ingress of foreign bodies or material.

CERAMIC MOULDING

Ceramic moulding utilizes moulds in two or more pieces, made of the same refractories and binders as in the manufacture of one piece moulds for investment casting (figure 1). This dispenses with the need for destructible patterns, and the machines and dies to produce them. The processes involved are, as a consequence, cheaper than investment casting. Instead of destructible patterns, solid patterns are used, as in the Croning two-piece shell-mould process, to produce half or part moulds, in solid or block form, which are assembled for casting. As in investment casting, however, the moulds are chemically bonded from a liquid slurry.

Because of the inevitable parting line or lines, these moulds cannot have the same degree of multi-directional accuracy as the one-piece investment casting moulds, but are very accurate in line with their faces, and at right angles to them within the individual mould cavities. Some firms using ceramic moulding processes claim to be able to batch-produce castings to within tolerances of ± 0.10 mm over distances up to 50 mm, and ± 0.25 mm over distances up to 450 mm, with a surface-finish centre-line average (CLA) reading as low as 1.5 to 2 microns, depending on the alloy cast.

If firms adopting ceramic moulding for the first time as a precision casting process for small quantity production are able to achieve accuracies and surface finishes anywhere near these figures, the processes can still be eminently suitable for the production of punches and dies for hot and cold stamping and deformation of metals (pressing, coining, embossing, etc.), dies for gravity and pressure diecasting, and moulding dies and blow moulds for rubber and plastic.

Although not so accurate across complete castings at right angles to the parting line or lines, ceramic moulding does have one big advantage over investment casting. It can be used to produce much bigger precision castings. One extension of one of the processes, consisting of a sodium silicate-carbon dioxide sand mould faced with ceramic material, has been used for the production of large dies for automobile panels.

Many aspects of individual processes known under such trade names as the Alphax process, the Unicast process, the Shaw process and the Ceramicast process (an American version of the Shaw process) have been patented, and the processes are carried out under licence to the firms concerned.

Normally the moulds are made for one casting operation only, and are broken up to get the casting out, but semi-permanent moulds can be produced which are used in the same way as gravity casting dies. These give a finish and accuracy comparable to that from gravity diecasting. One mould can be used to produce up to 200 castings in bronze, or up to 400 castings in aluminium.

Patterns to produce ceramic moulds may be made of almost any material, including wood and plaster. If an intricate die has to be cast, it is often easier to make the pattern as a positive, rather than as a negative, form. This pattern may be made of wood and a plaster cast representing the required casting may be obtained from it. The plaster cast can then be used to make the refractory mould for the production of the casting for the die. This could not be done satisfactorily with sand casting, because of the abrasive effects of the sand, and the destructive effects of the ramming required. With ceramic moulding, the mould is formed by pouring the moulding material into a flask surrounding the pattern in liquid slurry form. It effectively fills even the most finely detailed pattern areas and permits reproduction of almost unlimited intricacy.

In the Shaw process the patterns are invested with a refractory slurry of hydrolysed ethyl silicate and a suitable filler. This is caused to gel to a rubber-like consistency by the prior addition of a suitable accelerator. Gel times should be as short as is consistent with adequate mixing and investing times, usually about 3 to 5 minutes. A 10 per cent solution of 10 g. of triethanolamine to 0.1 litre of distilled water gives gelation times within these limits.

Industrial methylated spirits, water, and concentrated hydrochloric acid, are first mixed together in the following proportions by volume; then the ethyl silicate is added and the whole is stirred.

Industrial methylated spirits	204
Water	91
Concentrated hydrochloric acid	1
Ethyl silicate	704

This is mixed with the accelerator in proportions to give the gel time required, and the refractory filler is added to give a thick cream-like consistency, and is stirred in. The slurry is then poured into the flask, is allowed to gel and set (this takes about as long as the gelling time itself), the flask is removed, and the mould is stripped easily from the minutest detail, even from vertical surfaces. The mould is then ignited to burn out the alcohol vapour and is fired at 1000°C.

The above process involves separate hydrolysis and gelation, but it is possible to combine the two stages. This may be done by using an alkaline hydrolysis accelerator, such as an organic amine, added directly to the ethyl silicate to give a mixture which is quite stable in the absence of moisture. The only further step then required is the addition of aqueous alcohol; hydrolysis and gelation then take place together in a controllable time.

The amine-modified ethyl silicate can be stored for up to three months in air-tight containers, although ageing does increase the gel time slightly. The amines used may be piperidine or dicyclohexylamine, or combinations of both. The amount of amine added will largely determine the gelation time of the hydrolysed solution; 1.5 to 2.5 per cent of amine is often suitable, but the exact proportion should be determined under conditions of use.

In the Unicast process, the mould, after gelling, setting, and being stripped from the pattern has the same rubbery texture, but, like all ceramic moulds at this stage of their manufacture, is not yet chemically stable. It would warp or otherwise become deformed if it was allowed to remain untreated for any length of time. This is true especially of those moulds made with alkyl silicate binders, and is due largely to the unstable form of the polysilicic acid present in the solid gel. Stability is imparted to the Unicast mould chemically, by effecting a catalytic reaction in the gel structure which promotes the formation of a more stable chain of polysilicic acid, either by immersing the mould in a liquid, or spraying it with it. This eliminates up to four fifths of the original rubberiness or flexibility of the mould.

The mould is then baked in an oven or furnace to evaporate its liquid content. The temperature at which this is done is not critical, but obviously the lower the temperature, the longer will be the time required for drying out. A mould 100 mm thick can be dried out in 2 hours at 1100°C, but it would require 12 hours at 260°C. A heat treatment furnace is commonly used for small mould sections. Larger sections are more conveniently cured by passing them under infra-red heaters or, simpler still, by direct firing with a foundry ladle torch. The baking dehydrates the binder which, in turn, bonds the individual refractory particles together.

The individual sections of the mould are then ready for clamping or cementing together for the actual casting operation.

While many tool and die parts will require the over-all precision obtainable from a ceramic mould, accuracy in detail may often be important only in cored sections such as for extrusion dies. In such cases, it is quite practical to make a ceramic core which is subsequently inserted into an ordinary sand casting mould, before casting. casting.

The processes involved may also be used to manufacture preformed ceramic cores for inserting into the dies used to produce destructible patterns for investment casting in one-piece moulds. This is one of the three methods already described for producing hollow castings by this process. They may also be assembled into two-piece Croning shell moulds. The core can be produced in a machined core box or, if more convenient, but with slightly less accuracy, in a plaster mould produced in two pieces from a solid make pattern of wood or any other suitable material.

The metallurgical advantages of ceramic moulding are similar to those resulting from investment casting. The cast structure is extremely fine-grained and lacks the coarseness often associated with sand casting. The bond of the sponge-like structure of ceramic moulds breaks down in areas compressed by the contracting metal after solidification, thus precluding any possibility of hot tearing of thin sections of the casting.

The relative simplicity of ceramic moulding makes it possible for firms in the tool and die industry to set up their own mould-making shops, possibly as an extension to an already existing patternmaking department, and to produce casting moulds under a licensing agreement with one of the patentees of the various processes. Very little specialized equipment is required, and only the minimum of additional floor or bench space. The firms concerned might even consider installing metal-melting and pouring equipment if this is not already available, so as to form a self-contained unit for producing the precision castings. Alternatively, arrangements may be made to transfer the finished moulds and cores to a convenient foundry for casting.

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THE DESIGN, MANUFACTURE AND CHECKING OF JIGS, FIXTURES AND OTHER PRODUCTION EQUIPMENT

V. S. Korsakov

THE USE OF JIGS, FIXTURES AND OTHER PRODUCTION EQUIPMENT

THE DEVELOPMENT and comprehensive rationalization of industrial production are greatly influenced by the choice of production equipment, particularly by the jigs and fixtures which are the most difficult and expensive parts of that equipment to manufacture. The term production equipment, as used in connexion with production and assembly shops, means the auxiliary equipment used in the machining and hand-working of parts, in the assembly of units and whole finished products, and in technical checking.

In well-equipped machine and assembly shops, a large number of the most varied types of equipment are used. In production, an average of ten pieces of special equipment are used for each part produced. The design and manufacture of the necessary special equipment frequently accounts for 70 per cent of the labour and 80 per cent of the time needed to prepare for the production of new parts.

A considerable proportion (80—90 per cent) of the total special equipment is accounted for by machine-tool jigs and fixtures used for the mounting and fastening of workpieces which are to be machined.

The use of machine-tool jigs and fixtures can bring the following benefits: improvement of productivity and precision of machining; easing of the operative's working conditions; widening of the workable range of the equipment, even to the point of being able to use, in a number of cases, obsolete and worn machines without reduction in accuracy or productivity; improvement of operating safety and prevention of damage to equipment.

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The improvement in productivity is achieved by eliminating the need to set up and check the workpiece, reducing the time spent on mounting and fastening it, by the ability to machine at a number of points without readjustment, and to use more than one tool at a time to do one task. The improvement in precision comes from the elimination of personal error, because jigs and fixtures enable machining operations to be done on a pre-set machine tool.

The use of jigs and fixtures enables fuller use to be made of normal multipurpose machines. Thus, for example, relatively cheap, easily available pillar-type drilling machines can take the place of expensive boring machines. Single-spindle pillar-type drilling machines, if fitted with multi-spindle heads, can take the place of multi-spindle special drilling machines. Precision holes can be machined on an obsolete horizontal boring machine by using a boring fixture fitted with jig bushes which guide the boring head accurately on the workpiece.

In the insufficiently developed industries of developing countries, it is very often impossible to replace obsolete machines promptly. In these circumstances, the decisive role in raising the productivity of labour must be played by jigs and fixtures, provided, of course, that their use is economically and technically feasible. The length of the production run must justify their cost, which must be amortised if over-all production costs are to be reduced. The cost of manufacturing jigs and fixtures that have a narrow range of applications limits their use in enterprises with only a small production for each type of part. The advisability of using them must therefore be verified in each individual case by cost calculations.

An effective way of bringing some automation into production processes is to equip multi-purpose machines with automated jigs and fixtures and control gear. If versatile, quickly-exchangeable jigs and fixtures are used, this method of automation can also be entirely suited to producing a wide range of articles. There are many designs of these which are quite simple, reliable and profitable in use, do not require skilled operators, and can be used for various machining operations in factories in developing countries.

CLASSIFICATIONS FOR JIGS, FIXTURES AND OTHER PRODUCTION EQUIPMENT

The production equipment used in machining and assembly work can be classified, according to its function, into five basic groups:

(a) *Machining-and-grinding jigs and fixtures*

This is the largest group and includes machine-tool jigs and fixtures used for mounting workpieces so that they can be machined to suit the requirements of the production process.

These are divided up, according to the type of machining, into jigs and fixtures for drilling, or turning, or milling, or boring and so on. This group also includes special-purpose jigs and fixtures for bending, straightening and other tasks in the production of parts from sheet or bar on a machine, or by hand.

(b) *General-purpose equipment*

General-purpose equipment for mounting and fastening the working tool on machine tools. A characteristic of these items of equipment, which are also called auxiliary tools, is that they contain many standard parts, due to the extensive standardization of the working tools themselves. In most cases, equipment in this group is purchased by factories in finished form. Only a relatively small number of pieces are designed and made to special order. General-purpose equipment is best made in specialized factories making production equipment, while special-purpose jigs and fixtures are best made in tool shops.

(c) *Assembly jigs*

Assembly jigs and fixtures used for assembling parts into units or whole finished products. Regardless of the types of assemblies and the methods of assembly, the following types of assembly jigs and fixtures are used: *(a)* those for fastening the base parts (or units) of the item to be assembled; *(b)* those which hold the parts which are to be assembled in the correct and accurate relationship to each other; *(c)* those for the preliminary deformation of flexible parts (such as springs, split rings) so that they can be assembled, and *(d)* those used in pressing, riveting, expanding and other operations, where heavy force must be applied during assembly. Many designs of assembly jigs and fixtures are standard. They are used not only for manufacture, but also for repair and servicing.

(d) *Checking jigs*

Checking jigs are used for checking the original blanks, for the intermediate and final checking of parts during machining, and for checking the proper assembly of units and complete articles. They increase productivity and raise the standard of technical checking, facilitate the work of technical inspectors and free some of them for other work. Manual, semi-automatic and fully automatic checking jigs may be used, depending on the production programme and the type of articles produced. Under mass-production conditions, fully automatic checking and grading machines with highly specialized functions are used. The present continuous improvements in the quality of goods tend to increase the importance of checking jigs.

(e) *Manipulators*

Equipment for the clamping, raising, transfer and rotation of workpieces and units during assembly is used for parts too heavy to be easily moved by the worker. Where production processes are fully or partially automated, however, equipment in this group is also used for light objects. In order to reduce the costs of these devices, quite extensive use is made of standardized designs. These can best be manufactured in special enterprises; therefore developing countries, which need few of these devices, would be best advised to purchase them in finished form.

Production equipment can also be classified according to its degree of specialization, into universal equipment, specialized equipment, and special-purpose jigs and fixtures.

(a) *Universal equipment*

Universal equipment used in one-off or small-batch production can be further subdivided into *(a)* standard equipment and *(b)* specially designed universal jigs and fixtures.

(i) The standard equipment is usually manufactured by specialist enterprises in accordance with accepted specifications or standards and is purchased by factories in the finished form. This group includes: machine vices, chucks for fastening workpieces on lathes, chucks for holding bits on drilling machines, indexing heads for milling machines, turntables, lathe centres, faceplates, and other similar equipment. These items of equipment are not designed or manufactured by the factories which use them. They are used for machining a wide range of parts of different dimensions. In industrially developed countries, these items of equipment are produced in factories that make production equipment. They may also be produced by machine manufacturers to equip their own machines, or else to customers' special orders. Many factories produce large quantities of such equipment both for the home market and for export.

(ii) Universal jigs and fixtures of special design are designed and manufactured on an individual basis, primarily for use in the one-off or small-batch production of parts of a given type but of different dimensions. In use, these jigs are altered to take parts of a different size by changing one or more of their components or by moving stops or altering the position of bushes, clamps or other devices. Among such jigs and fixtures are those used in the drilling of radial holes in parts such as shafts, bushes and sleeves, those used to drill holes in flanges of various dimensions, and other similar types. In the conditions of developing countries, universal

jigs and fixtures can be widely used in factories producing a large range of parts.

(b) *Specialized equipment*

Specialized equipment is intended for use with the standard equipment and universal jigs and fixtures. These are set for the machining of specific parts by the installation of additional or exchangeable specialized equipment or devices (special jaws for machine vices and lathe chucks, special locating and mounting plates for universal plunger jigs, etc.). Because they can be relatively easily exchanged or re-set to carry out different production jobs, these items of specialized equipment are used in production. Their manufacture is neither expensive nor lengthy, as they are constructed on the basis of existing universal equipment.

(c) *Special-purpose jigs*

Special-purpose jigs and fixtures are intended to do specific machining jobs on a given part, and are therefore single-purpose equipment. They are best used in mass production, where identical parts must always be located and clamped in the same way and the production programme provides for the manufacture of a large number of parts over a considerable length of time. These jigs and fixtures are the most expensive and labour-consuming to produce because their wide range of designs involves individual manufacture for each. Special-purpose jigs and fixtures become useless and must be written off when a change is made in the parts produced, and this often takes place long before they are physically worn out. When new parts are introduced, it is necessary to design and construct new jigs: this may take up 70—80 per cent of the total time required for the technical preparations for production.

STANDARDIZATION OF JIG AND FIXTURE PARTS AND UNITS

For production, it is important to develop and introduce convertible and quick-change jigs and fixtures, as well as those suitable for variable production lines and production lines manufacturing groups of parts. Considerable experience has been accumulated in the Soviet Union in these fields, and it can be passed on for use by the industries of developing countries. In recent years, production equipment has been made more versatile. Considerable use is now being made of universal built-up jigs and fixtures, universal exchangeable-component jigs and fixtures, jigs and fixtures which can be assembled and dismantled, exchangeable-component magnetic jigs and fixtures, and so on. The principles and applications of these systems are dealt with below.

The standardization of jigs and fixtures is also very important for developing countries, although in small countries the scale of standardization cannot be very wide. In these circumstances, jigs and fixtures are best standardized in selected directions and in accordance with pre-planned stages and target dates. Production equipment must be standardised in accordance with a carefully thought-out plan. The importance of this measure is evident from the following considerations.

The launching and development of the production of old or new parts is closely linked with the preparation of the production equipment, particularly the most expensive and labour-consuming part of that equipment: the machine-tool jigs and fixtures.

The rapid development of modern manufacturing methods and the constant improvement of the articles produced make it essential to replace products from time to time with new and improved types.

In these circumstances, the previously-used special equipment usually becomes unsuitable for further use and must be written off, since new special equipment has to be designed and built in order to begin producing the new articles. When much complicated equipment is required, the production preparation period is frequently so long that, by the time a new article has come into full production it is already, in effect, obsolescent.

At the same time, there is a tendency to try to increase the amount of modern production equipment in both large and small enterprises, to increase productivity and to lower production costs.

This has given rise to attempts to find ways to speed up and cheapen the development and manufacture of production equipment as a whole and of special-purpose jigs and fixtures in particular. Efforts to solve this latter problem have mainly been based on the standardization of the units of jigs and fixtures.

Standardization reduces the volume of design work, and the number of different parts, and increases the number of parts of identical function and dimensions which have to be produced. Standardized parts can be produced in large batches by a single specialist enterprise, thus considerably reducing production costs. In particularly favourable circumstances, standardized parts or units can be taken out of used jigs or fixtures and put into temporary storage, if necessary after partial overhaul, for use later in new ones.

At present, as many as 70 per cent or more of the components of special-purpose jigs and fixtures are standard parts. In order to give them a special incentive, jig and fixture designers are frequently paid not only on the basis of the number and complexity of the drawings which they produce, but also in proportion to the extent to which they use standard elements in their designs.

The first stage in standardizing jigs and fixtures is applied to their general design and dimensions. The objective of standardization is to establish dimensional classes for the various elements and units, to lay down over-all dimensions and dimensions for mating elements, to standardize design elements (such as screws, fastenings, pins, keys, tapers), to specify the accuracy with which parts must fit together, and to establish tolerances for the main parts.

The second stage of standardization concerns the component parts of the jigs and fixtures. Among the parts which are thus standardized are the components of special-purpose jigs and fixtures (the adjustable parts, the parts making up the clamping devices, the jig and fixture bodies and their components, the fittings for checking the position of tools, and the component parts of auxiliary devices) and the blanks (castings or forgings) for all these components).

The third stage of standardization covers jig and fixture components with various other functions. Among the components to be standardized in this stage are units forming part of clamping systems (pneumatic cyinders, pneumatic barrels, the locks of rack and lever clamping devices), units making up auxiliary mechanisms (indexing and turntable mechanisms, index pins, ejectors) and other mechanisms forming part of special-purpose jigs and fixtures.

Technical standards are established by the leading machinery manufacturers, technical planning and scientific research institutes, and other organizations. The standards established may be internal standards (works standards) or national standards. The issue of national standards is preceded by extensive correction and collation of existing works standards.

In practice, wide use is also made of works standards established for body components and units of jigs and fixtures which are designed to be assembled and disassembled (SRP jigs and fixtures). A feature of this system is that the standard elements are suitable for repeated use.

Standard units are stored in ready assembled form. They are designed to be installed, not within the body of the jig or fixture, but on its periphery, so that additional machining of the body parts can be avoided. The machining of the jig body (drilling, cutting of apertures, etc.) does not prevent its repeated use in other versions. Jig and fixture bodies are assembled from standard interchangeable components, of simple geometrical shape, which are designed to be fastened together by screws, or bolts, or synthetic adhesives. Such fastenings make it possible easily and rapidly to strip the bodies and whole jigs and fixtures. This must be done when the part being produced is changed. This system can be used for jigs and fixtures fitted with both normal and quick-acting (pneumatic, or hydraulic) clamping mechanisms, reducing the time spent on the design and manufacture of special equipment.

UNIVERSALLY ADAPTABLE JIGS AND FIXTURES

Universally adaptable jigs and fixtures are used for small or large-batch production. They are so designed that their components can be rapidly exchanged or adjusted as often as desired, to enable them to be used for several different parts or operations. They are therefore extremely effective in promoting high-productivity machining methods in small-batch production and in reducing the preparation time for production equipment.

In recent years, two main systems of universally adaptable jigs and fixtures have found special favour, namely, composite jigs and fixtures, with universally exchangeable components (USP), and exchangeable or adjustable component jigs and fixtures (UNP) which are basically special-purpose jigs and fixtures that are capable of being modified to suit different parts by exchanging or adjusting their components.

COMPOSITE JIGS AND FIXTURES

The composite (USP) system consists of a set of standardized parts from which it is possible to assemble various single-function jigs or fixtures. This system began to be used in experimental and small-batch production in many countries in the mid 1940s. After the assembled jig or fixture has been used, it is dismantled and its component parts are returned to store, from which they can be withdrawn at a later date for assembly into a new type of jig or fixture. Thus, the USP system is only universal because it can include different kinds of jigs or fixtures. The jigs or fixtures themselves are not universal, but are special (single-function) jigs or fixtures.

In factories where the composite (USP) system has been used for a number of years, the stock of individual elements may amount to 25,000—30,000 parts, together with a certain quantity of standardized units which cannot be dismantled. As many as 300 jigs or fixtures can be assembled at one time from such a set of parts.

The parts in the basic set are divided up into eight groups, the parts in each group being of several types and dimensions. The groups are as follows: base parts (square and rectangular plates, face plates, angled base sections, rings), the faces of these parts being provided with T-section intersecting grooves so that the various components of the jig can be fastened on them in different layouts, body and supporting parts (blocks, angles, packing pieces and supports of various shapes), likewise provided with T-section grooves, slots and apertures, so that different assemblies can be built up, fitting parts (keys, dowels, intermediate bushes, fixing pins), guide parts (various types of jig bushes, guide strips, pillars and spindles), clamping parts (various types of clamps and other parts), universal fastening parts (screws, bolts, threaded pins, nuts and washers), miscellaneous parts (handles, strips, eccentrics, springs, pivot units, and so on), and standard units which cannot be dismantled (adjustable-height supports, clamps, indexing mechanisms, etc.).

When starting up, small factories frequently use a reduced set of USP jig and fixture components consisting of 1,500 to 2,000 parts. Such a set is sufficient for the assembly of 300—400 jigs or fixtures per year.

The body and support components are manufactured to the second class of precision, and their mating surfaces are ground to the ninth or tenth class of surface finish. The dimensions of these components, on which the accuracy of the various other components of the assembly depends, must come within a tolerance of 5—10 microns. The tolerances for corners or angles are set at 5 microns per 100 millimetres. Parts on which the accuracy of machining does not depend must come within the third to fifth classes of precision.

The parts in a composite (USP) set must be strong and wear-resistant, and must keep their exact dimensions and shape for a long period. The base parts are made from high-quality steel with 0.12 per cent chromium and 0.3 per cent nickel, carburised and case-hardened to a Brinell hardness of 60—64. Fastenings are made from a steel with 0.38 per cent chromium hardened to 40—45 Brinell and annealed. Guides and adjustment parts are made from steels with 0.08 and 0.10 per cent carbon, carburised and hardened to 50—55 Brinell and annealed. The remaining, less important parts are made from ordinary steel with 0.45 per cent carbon (clamps and so on) or with 0.20 per cent (washers).

In practical experience of the composite (USP) system in factories, the wear of the base parts over 10 years has been less than 0.01 mm.

When a set of USP parts is available, the preparation of jigs and fixtures amounts simply to the assembly of the parts in accordance with a given scheme. There is usually no need to make any special parts. In exceptional cases it may be necessary to make special parts, but they do not usually amount to more than 1 to 1.5 per cent of the total number of parts in the system. Use of the composite (USP) system reduces the time taken for the manufacture of jigs and fixtures to a small fraction of that otherwise required. The assembly of jigs or fixtures of average complexity requires 2.5 to 5 man-hours.

Jigs and fixtures are assembled in conformity with a drawing of the part to be machined in a particular operation, or else on the basis of an actual metal specimen of the part. Assembly is carried out by highly skilled workers, without any drawings for the jig or fixture, on the basis of what is considered to be the best selection of components. If a particular jig or fixture may be required again at a later date it is desirable to photograph it from several angles, indicating on the photograph the identification numbers of the various components used to make it up, instead of making drawings of it. If this is done, repeat models of the jig or fixture can be made quickly.

The composite (USP) system saves a considerable amount of time and greatly reduces the cost of preparing for the production of new parts. It enables jigs and fixtures to be remodelled easily and quickly if the part being produced is changed, and it also enables individual parts to be used a number of times for the assembly of different kinds of jigs and fixtures. This system makes it possible to use jigs and fixtures in factories producing only small batch quantities, where it would be uneconomical ordinarily to use jigs.

Among the shortcomings of the composite (USP) system are the lower rigidity of USP jigs and fixtures (because in some cases they contain a large number of joints), their unsuitability for the building in of quick-acting, power-driven (pneumatic, hydraulic) clamping mechanisms, and the high initial cost of a set of USP parts due to the large number of parts in a set and their high accuracy.

As a complete set of parts for a composite (USP) system may cost 50,000 to 80,000 roubles, this system may be uneconomic for a single factory. In this case, it is advisable to arrange for one or more USP sets to be available for hire to interested enterprises in a given economic area. Practical experience of the operation of such hire sets both in the Soviet Union and abroad shows that their original cost is relatively quickly repaid (in two or three years), while their total service life is about fifteen years.

The average utilization period of each jig or fixture (the average hire period of a USP set) is fifteen days, including one day for assembly, two days for transport and one day for dismantling.

A need is now becoming felt for the further development of the composite (USP) system by the provision of narrower or wider T-shaped grooves for different branches of industry (instrument and heavy machinery manufacture) and the incorporation of pneumatically or hydraulically operated units for clamping the workpieces.

EXCHANGEABLE JIGS AND FIXTURES

The system of universal exchangeable or adjustable-component jigs and fixtures (UNP) is based on the use of exchangeable mounting, clamping and guide elements (units), fastened on a universal standard jig or fixture base. The mounting elements of such jigs and fixtures are frequently designed to be adjustable so that the jigs or fixtures can take workpieces of different types and dimensions.

UNP jigs and fixtures can be effectively used in series production. When a batch of new parts is to be produced, these jigs and fixtures are not removed from the machine tools. All that is necessary is to replace certain of their exchangeable elements with different ones, or to adjust their stops to take the new parts.

Therefore less time is spent on preparatory and final work and the machines can be used more intensively. The UNP jig and fixture system thus reduces the expenditure of time and money on preparing for production. The exchangeable parts and units of the UNP system are not returned to store, but are kept at the workplace, by the machines. They are installed on the jig or fixture by means of centring spindles, pins or guide channels, without the need for measuring instruments. Only a very short time (2—3 minutes on average) is needed for replacing the exchangeable parts.

For machining small parts, UNP jigs and fixtures with exchangeable adaptors are used. Each adaptor serves to locate parts of a given type and size. In this system, re-setting of the jig or fixture amounts only to the replacement of the appropriate adaptor.

In both the UNP and USP systems, conversion is easy. The jigs or fixtures can be used for a number of different parts or operations.

Among the standard equipment which also forms a basis for the UNP system are machine vices and chucks (exchangeable jaws) and lathe faceplates (adjustable brackets for boring parts of irregular shape).

The number of items of standard equipment which are capable of adaptation and modification is continually increasing, thus forming a solid foundation for the further development of the UNP system. Various designs of exchangeable or adjustable UNP systems, prepared in recent years by many planning and technical design organizations are being successfully used in engineering production.

COMBINATION JIGS AND FIXTURES

On variable production lines, in addition to the USP jigs and fixtures and the UNP types already described, combination-type jigs and fixtures are used for mounting, in sequence, without re-setting or re-adjustment, the various parts which are to be machined on a given machine tool. Jigs and fixtures of this type are usually designed to take all the parts in a given class.

In recent years, these combination jigs have been widely used for simultaneously mounting several different workpieces on production lines where a whole group of parts are manufactured. Good practical results have been obtained with them in a number of engineering factories. Jigs and fixtures of this kind are suitable for machining parts of different types and dimensions, and they can be used for drilling, milling, flat grinding and other machining work.

The simplest layout, which does not call for a combination fixture, operates in the following manner. The rotating table of a vertical milling machine is equipped with a number of different fixtures, each capable of taking parts of different types and dimensions. The worker operating the machine loads these fixtures in a given sequence and removes the machined workpieces from the unloading section of the table.

The use of this system on variable production lines may not be so effective, however, when machining batches of identical parts only, as the saving of time on the exchange of jigs will not make up for the considerable time lost during the empty travel of the table.

In group production line conditions, combination jigs and fixtures which are designed to accept several different exchangeable parts, can also be used. In this case, the workpieces of different types and dimensions which can be accepted by these jigs or fixtures can be sent down the production line either individually or in batches.

The use of combination jigs and fixtures for variable production lines and group production lines enables the lines to be used to the maximum. The design of these types of jigs, however, calls for a great deal of work in choosing the right layouts and the general make-up of the jigs and fixtures, as well as for ingenuity on the part of the designer.

Universally adaptable jigs and fixtures of all three types—composite (USP), exchangeable (UNP), or adjustable component, and combinations of them—can be widely used in the industry of developing countries, both in existing factories and in new ones.

MANUFACTURE OF JIGS, FIXTURES AND OTHER PRODUCTION EQUIPMENT

Production equipment is manufactured by various production methods. Standard equipment is produced in considerable quantities to supplement new machines which form part of the existing range of production equipment. A considerable proportion of the items (three- and four-jaw chucks, face plates, etc.) are standard, or comply with official specifications. These are produced in specialized factories or in special departments of engineering factories, by mass-production methods or in large series. Universal jigs and fixtures and the various units and individual parts for them are produced in a similar manner.

Special-purpose jigs and fixtures, and the specialized equipment which is fitted to standard equipment and universal jigs and fixtures, are manufactured individually or in small batches in the tool shops or toolrooms of manufacturers (for the factory itself) or in machine-tool factories (for fitting to special machines). They are delivered finished to the purchaser. In many developed countries, they are also produced by specialized factories. Their manufacture is usually a one-off process. Where extensive use is made of standardized parts in their manufacture, however, they can be manufactured in series production.

The workpieces from which the parts for special-purpose jigs and fixtures are to be made are likewise manufactured by one-off production methods. Cast workpieces are produced by sand casting with wooden patterns or by precision casting methods, forgings are produced by free forging, and small parts are cut out of various kinds of sections. Items of medium and large dimensions and of complicated shape, such as jig and fixture bodies, uprights, and brackets, are sometimes welded.

Castings for important parts such as jig and fixture bodies may be advantageously subjected to rough machining and natural or artificial ageing so as to remove any internal stresses before being sent for final machining.

WELDING AND HEAT TREATMENT

Welded elements are fabricated from previously prepared parts, such as plates, strips, angles, corner pieces, discs and bushes. These parts, thoroughly cleaned of rust and grease, are assembled by means of clamps or other mechanical locating devices, the accuracy of their location with respect to each other is carefully checked, and they are then tack welded at various points. After the clamps have been removed they are again checked for accuracy, and the final welds are then made.

In order to reduce distortion, it is best to use electric-arc welding. Gas welding is used for thin parts not more than 4 mm thick. The danger of distortion of welded units is reduced by making discontinuous welded joints.

In order to remove internal stresses, welded components are annealed for 1.5 to 2 hours at a temperature of 600 to 650°C. If a component is large and difficult to anneal, the welds are peened with a hammer. The components of special-purpose jigs and fixtures are varied and must normally be made to the second or third class of accuracy, so they must be machined by highly skilled toolmakers. Standard parts are machined in batches on pre-set machine tools, frequently with a progressive, or parallel or parallel-progressive arrangement of machining operations.

The manufacture of parts with holes that must be accurately located with respect to one another (bodies for drilling jigs and fixtures, boring fixtures, laid-on jigs, discs, indexing mechanisms) is a special process. Because of the close tolerances (0.01 to 0.001 mm) for the distances between centres, normal methods of laying out and drilling and reaming or boring do not give satisfactory results.

If a large amount of work is to be done involving extremely accurately located holes, it is best to use a jig-boring machine, which bores holes with great accuracy not only along parallel axes, but also, if the machine tool is fitted with a rotating table, along intersecting or cross axes. By fitting special planetary heads, these machines can also be used for grinding accurately located holes, apertures, circular grooves and curved surfaces described along the arcs of circumferences.

THE USE OF PLASTICS

Plastics offer great possibilities for time and money savings in making jigs and fixtures for small or large-batch production. Epoxy resin compounds are usually used in machine tool jig and fixture manufacture as these compounds are the strongest kinds of plastics. A good epoxy resin moulding compound consists of 100 parts by weight of epoxy resin, 200 parts by weight of filler (iron powder, iron oxide, fine quartz sand, cement, etc.), 15—20 parts by weight of plasticizer (dibutyl phthalate) and 8—9 parts by weight of hardener (polyethylene polyamine).

This composition can be moulded in various ways to make the basic and auxiliary components. After hardening, the epoxy resin compound has the following mechanical properties: Brinell hardness 20, ultimate tensile strength 6 kg/mm^2, ultimate compressive strength 13 kg/mm^2, impact strength up to 12 kg-cm/cm^2. Depending on the filler used, the specific gravity of the compound varies from 1.2 to 2.0. Shrinkage of the compound in hardening is about 0.1 per cent. The wear resistance of the compound is close to that of aluminium alloys, and the rigidity of parts made from it can be increased by building a steel frame into them.

The disposable mould used for shaping the compound can be made of plaster of Paris (using a wax model of the part to be cast as the pattern), cardboard (by drawing, cutting out and then sticking together the developments for parts of simple shape) or Plasticine. Only a small amount of time (frequently about 1 to 1.5 man-hours) is required for making such moulds.

Epoxy resin compound can be used to mould housings (negative impressions) for mounting workpieces. The base for the housing is a welded box into which the epoxy resin compound is poured. A negative impression of the part to be machined is then made by pressing a standard specimen of the part into the surface of the compound.

Epoxy resin compound can also be used to make jig-bush plates with accurately located holes. The jig bushes are placed in the required position on a flat base with the aid of gauge blocks, and are then fixed in place with clamps or adhesive. A frame determining the external shape of the jig-bush plate is then fastened in place and the space between the jig bushes and the frame is filled with compound. The low shrinkage of the compound ensures the accurate location of the bushes relative to one another.

The assembly of special-purpose jigs and fixtures involves a good deal of alignment work and machining *in situ*. In order to obtain high-precision assemblies, careful filing, scraping and lapping are necessary.

The assembly of jigs and fixtures can well be broken down into the operations of assembling individual units and that of assembling the jig or fixture as a whole. This reduces the total assembly time.

In the assembly process, the mutual positions of the parts and units of the jig or fixture must be adjusted and accurately checked. The correct positions are usually determined by means of locating pins, for which suitable holes are drilled and reamed in the mating surfaces. For non-removable assemblies and units of jigs or fixtures which operate under compression or shear, it is better to use adhesive joints instead of mechanical fastenings. Epoxy resin adhesives can give a shear resistance of 3 to 3.5 kg/mm^2. Locating pins must be used, however, for accurately locating the parts relative to each other. Assemblies of parts which are cemented together can be dismantled by heating them to a temperature of 150°C.

In order to achieve increased accuracy, several parts are often machined together after their assembly. Thus, in order to achieve strict coaxiality of holes running through several parts, the holes are bored or reamed out after assembly. In order to achieve a smoother finish on multi-component mounting surfaces, such surfaces are often ground in one piece after the components have been assembled in the jig or fixture body. When assembling jigs or fixtures, attention must be paid to the proper alignment of the parts by means of which the jig or fixture body is fixed to the machine.

INSPECTION OF JIGS AND FIXTURES AND THEIR PERIODIC CHECKING DURING USE

Newly manufactured jigs and fixtures must be carefully inspected before they are put into operation. Such inspection should comprise a visual inspection, a check that the jigs or fixtures are complete in accordance with the drawing, a check of the basic elements and assemblies of the jig or fixture to ensure that they have been properly manufactured (smoothness and ease of movement, freedom from jamming), an operational test, including the necessary adjustments and setting operations (checking of the operation of the mounting and clamping mechanisms, the rotating devices, fasteners, ejectors), and a check of the precision of the work done with the jig or fixture.

The precision of manufacture of machine-tool and assembly jigs and fixtures is usually checked in one of three ways: by direct measurements of the various dimensions of the jig or fixture on which the precision of its work depends; by the test machining of several workpieces (or the assembly of several units) in the jig or fixture, after which the workpieces are checked for precision with measuring instruments, gauges, or other checking instruments; or by the use of specially-made test parts, finished to the correct dimensions (or assembled in the correct way) as gauges.

The first method, involving the use of measuring instruments (surface plates, gauge blocks, height gauges, clock gauges), is labour-consuming and can only be done by highly skilled inspectors. The second method is purely functional and is more suitable for production conditions, but it involves the wastage of the test workpieces. The essence of the third method is that a standard gauge part is placed in the jig and its position with respect to the various guide elements is then checked.

Jigs and fixtures used in factories must be inspected periodically and checked by special inspectors. In batch production conditions, they are periodically removed from the machine and either returned to store or else kept at the workplace. This period of inactivity can be used for inspecting them and checking them for accuracy.

Under mass-production conditions, however, the jigs and fixtures are often inspected on the machine while they are not being used. In these circumstances, checking by means of standard gauges is more convenient. In large factories, periodic checks are carried out by a special group of inspectors. The results of each check are recorded in a card index.

These periodic inspections and checks may show up the need for preventive maintenance or overhaul, or for the replacement of worn parts and units in the jigs or fixtures. New checking jigs must be adjusted and tested before being put into service, and must there-after undergo periodic checks at the workplace and in metrological laboratories.

The periodic testing of checking jigs during use is carried out in the technical checking department or a metrological laboratory. If the total stock of all jigs and fixtures is not large (not more than 100—150 jigs), inspection is usually done by inspectors from the central metrological laboratory.

Inspections are made in accordance with instructions from the machine setting section. In order to make the inspection, it is necessary to have both the drawings of the jig or fixture and its periodic checking card. After overhaul, jigs and fixtures are inspected in the central checking department.

The measurements are made during these inspections with universal measuring instruments and often with special standard test parts. These special standard test parts, which are used also for the periodic inspection and adjustment of checking jigs, are provided with direct-reading measuring devices such as gauges, or micrometers. Certificates of accuracy are prepared for these special standard test parts, which must be inspected themselves periodically in the central metrological laboratory.

THE DESIGN AND ECONOMICS OF VERSATILE JIGS, DIES AND MOULDS

S. Mitrofanov[*]

MULTI-PURPOSE JIGS AND FIXTURES

JIGS AND FIXTURES are divided, according to their universality, into the following groups:

- *(a)* Special-purpose (SP) jigs and fixtures designed for a single part-operation or a single operation on a group of parts of similar design and production characteristics. These jigs and fixtures cannot be adjusted.
- *(b)* Universal (UP) jigs and fixtures, which can be used for making different parts because their design enables them to be adjusted.
- *(c)* Exchangeable-component multi-purpose jigs and fixtures, including:
  - *(i)* Universal exchangeable-component (UNP) jigs and fixtures, which are universal jigs or fixtures with exchangeable components enabling them to be used for parts of various types;
  - *(ii)* Group-adaptable (GP) jigs and fixtures, which are designed for a certain group of parts. These may be:
    - Jigs or fixtures with exchangeable components which can be fixed to suit given parts (GPN);
    - Fixtures which are designed so as to enable several different parts to be fastened in a single unit for simultaneous machining without the need for changing the fixture components (GPP);
  - *(iii)* Composite or universal fabricated jigs and fixtures (USP).

Universal, universal exchangeable-component and group-adaptable jigs and fixtures are designed for use on groups of parts which all require setting up and fastening in a similar manner.

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The machining of parts of different shape in a single jig or fixture is made possible by the existence of adjustable or exchangeable jig or fixture components. In order to achieve the requisite productivity and accuracy in machining, these jigs and fixtures must have the following features:

(a) They must permit the rapid and stable setting up of any part from a given group in them, and they must have quick-acting, manual, mechanized or automatic clamping devices;
(b) They must be simple in operation;
(c) They must be suitably rigid;
(d) Fixtures must be designed for rapid mounting on the machine and rapid removal after use.

The provision of all these features may increase the complexity and cost of a jig or fixture, but even so, universal, universal exchangeable-component and group-adaptable jigs and fixtures are economically justified because the expense of their design and preparation is covered by the increase in the number of different parts which they can accept.

GROUP-ADAPTABLE JIGS AND FIXTURES

When designing group-adaptable jigs or fixtures, the designer must consider the production capabilities of the enterprise, the characteristics of its machinery and equipment, the layout of the group process, the special features of the parts forming the group, and the size of the batch of parts to be produced.

In designing such jigs or fixtures, it is essential to make use of accumulated experience by studying existing designs of special jigs or fixtures which have previously been used for the parts making up the group.

The method of design for group-adaptable jigs or fixtures is basically the same as for special-purpose jigs or fixtures, and comprises the following stages:

(a) Study of the basic design data;
(b) Preparation of a draft or rough outline of the jig or fixture;
(c) Calculations regarding accuracy of setting, strength, and clamping forces;
(d) Determination whether the selected design is economical;
(e) Final working out of the design.

The design requirements for group-adaptable jigs and fixtures are established basically from an analysis of the design and production features of the parts belonging to the group in question and from a study of their mounting surfaces and means of fastening.

The basic data for design are:

(a) Drawings of the group of parts for which the jig or fixture is being developed;

(b) Details of the production process for the parts;

(c) Details of the machine on which the group-adaptable jig or fixture is to be used;

(d) Drawings of the individual jigs or fixtures previously used, if the group-adaptable jig or fixture being designed is intended to replace individual jigs or fixtures;

(e) Details of the tool to be used for machining the parts.

The designer will obtain information about the machine on which the parts are to be worked, the cutting tool, the cutting rates, and the sequence of operations or transfers, when familiarizing himself with the production process.

There are close links between the development of a group production process and the design of the jigs or fixtures for it. Sometimes it is not possible to plan group operations without knowing the design of the jig or fixture. Therefore, the production engineer and the jig and fixture designer must work frequently together. During the design of a jig or fixture, it may become necessary to make certain modifications in the grouping of parts and in the production process.

In designing special-purpose jigs and fixtures, the first process in the design is usually to draw outlines of the part to be produced, in the appropriate number of projections. Sketches are then made of the proposed jig or fixture incorporating the construction which the designer has in mind.

The design of group-adaptable jigs and fixtures, however, is complicated by the fact that it is necessary to solve the problems of mounting and clamping a whole range of parts rather than a single part. Therefore, the necessary exchangeable units and components must be designed at the same time as the fixed (basic) part is designed.

In order to solve this problem as effectively as possible, the parts to be manufactured in such a jig or fixture must also be classified by the way in which they are mounted for each operation.

At this stage of the classification of the parts according to the features referred to above, the subject of the grouping process is no longer just the part itself, but the part-operation. This is necessary for the following reasons: When exchangeable jig or fixture components are used, a series of part-operations which are similar from the point of view of equipment and fittings are carried out at each working point. The basic features of any part-operation are: the surfaces of the parts which are to be machined, the machine to be used, and the jig or fixture and tool to be employed. If the surfaces to be machined are identical in shape, accuracy and surface finish, then the methods of producing such surfaces will be invariable also. Consequently, the feature "nature of mounting" means that all the parts in a group, regardless of their design, must share a common feature in the way they are mounted in the jig or fixture. In any jig or fixture, there are a number of elements which determine the location of a part in it. A characteristic feature of group-adaptable jigs or fixtures is that their locating elements are usually designed separately for each part-operation, i. e. they are exchangeable and are changed when a new part in the group is machined.

The primary element of a group-adaptable jig or fixture is its base section or bed, on which the exchangeable components holding the part are fastened. The bed is the same for the entire group of part-operations for which the jig or fixture is designed. There are usually only a few possible different methods of mounting and fastening the components of a given jig or fixture.

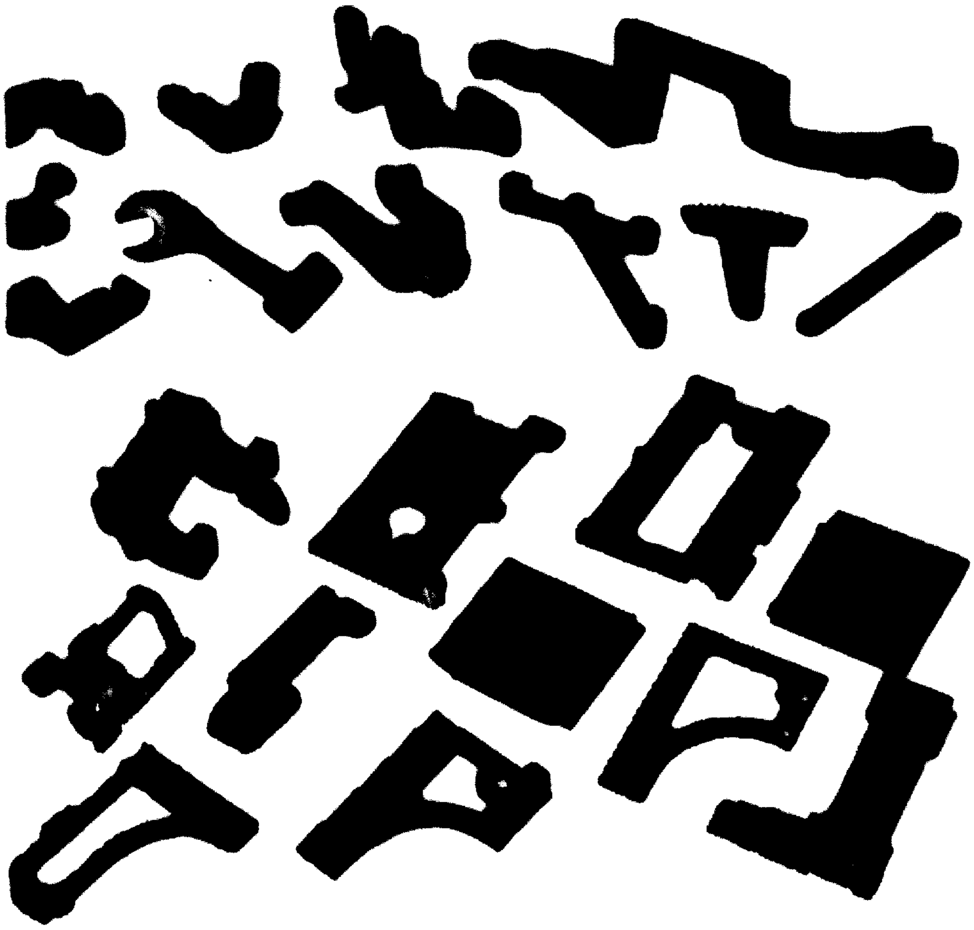


Figure 1. A selection of parts which could involve a total of 1,500 milling operations

Thus, for example, even for a large group of parts such as the brackets, levers, and plates shown in figure 1, which require milling and involve 1,500 possible part-operations, there are only 11 different types of mounting, as shown in figure 2.

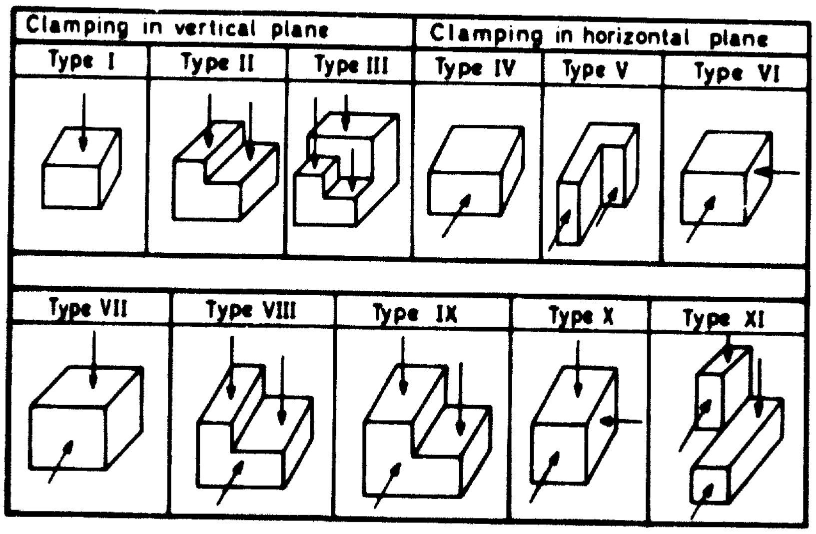


Figure 2. Methods of clamping the parts shown in figure 1 for group operations

Each of these different types represents a different design of group-adaptable jig or fixture. Thus, for mounting types I and II, a table-type, group-adaptable jig or fixture with vertically acting clamps is required. For types IV and V, normal and four-jaw pneumatic clamps are used and the jig or fixture is rotatable.

For every part-operation coming within the range of a given jig or fixture, the jig or fixture must be set up by the use of unified exchangeable components.

Examples of the design of group-adaptable jigs or fixtures for the machining of various groups of parts on metal-working machines are as follows:

Example 1

Figure 3 shows a number of parts classified for milling.

Figure 4 shows some of the parts in Group 1 of figure 3. These have all been pressure diecast. Parallel surfaces have to be machined on all of them. Previously, each part was mounted in a separate special-purpose fixture, but by assembling all these parts into a production group it has been possible to develop a group-adaptable fixture for them.

It can be seen from the diagrams of the parts shown in figure 4 that the mounting surfaces are of different sizes and are differently located with respect to each other, so that a set of exchangeable inserts is required. Figure 5 shows some varieties of such inserts.

The parallel surfaces of the group of parts in question are machined on a horizontal milling machine with two disc-type milling heads. This method of machining dictated the design of the group-adaptable fixture shown in figure 6.

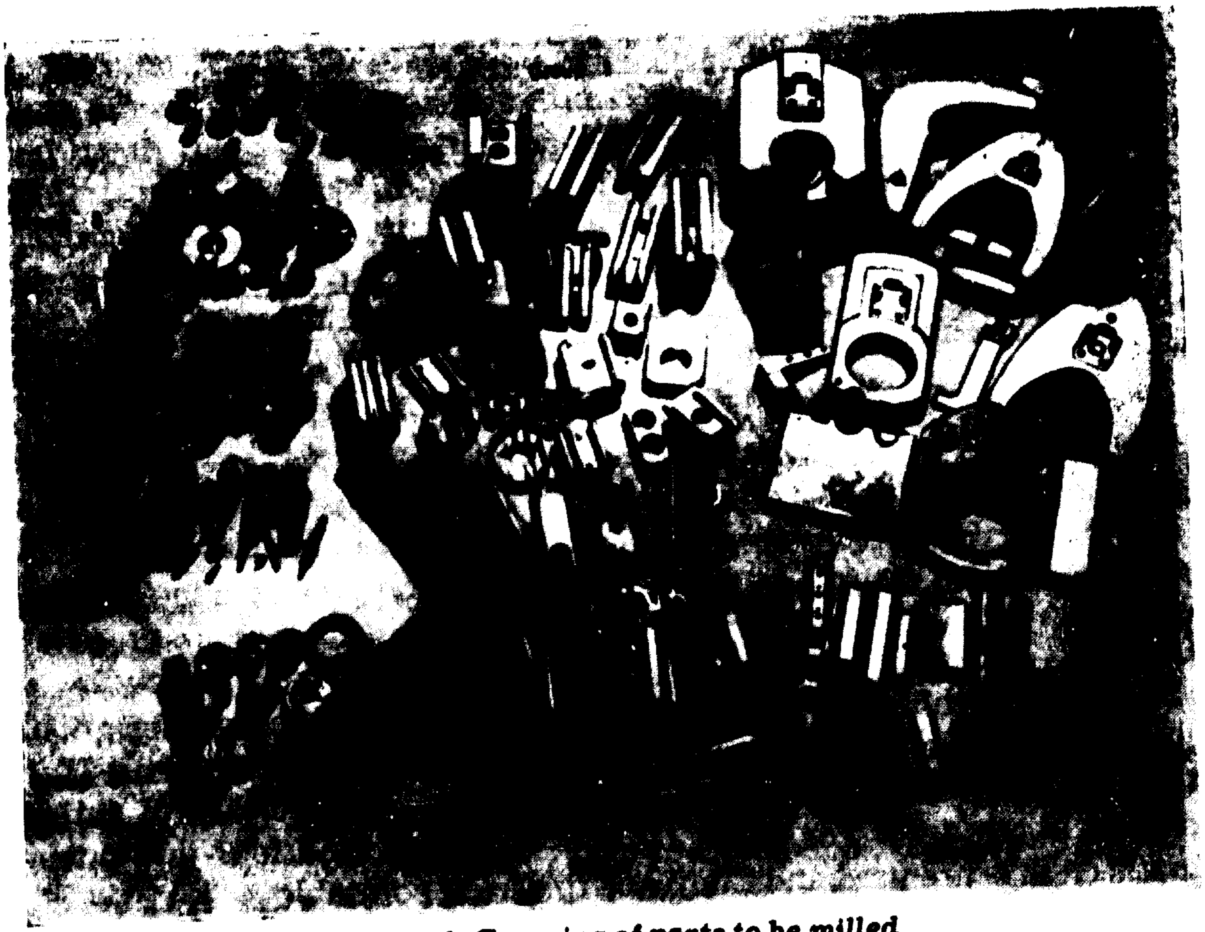


Figure 3. Grouping of parts to be milled

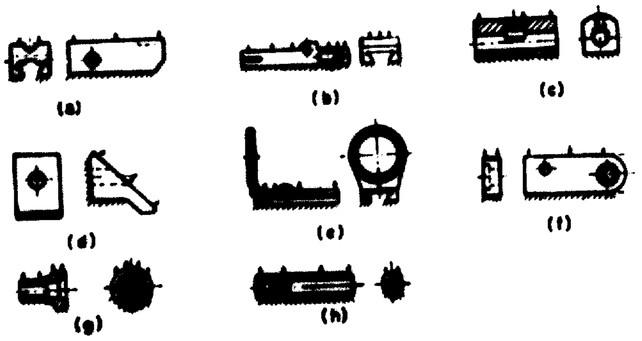


Figure 4. Pressure diecast parts from group 1 of figure 3

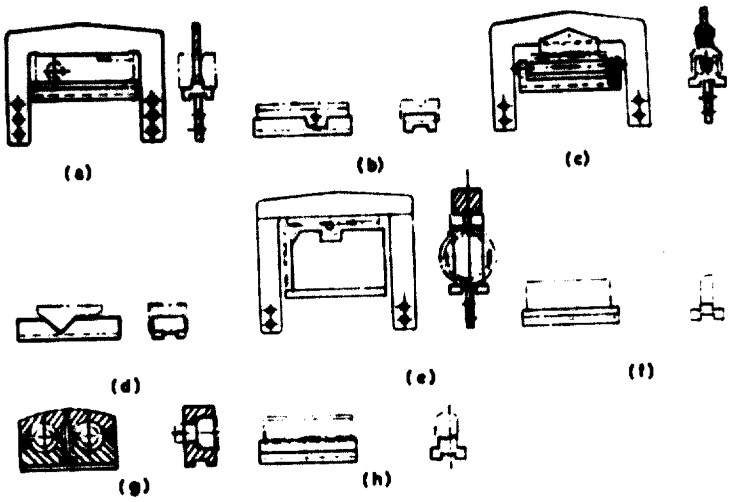


Figure 5. Various inserts used for the parts of figure 3

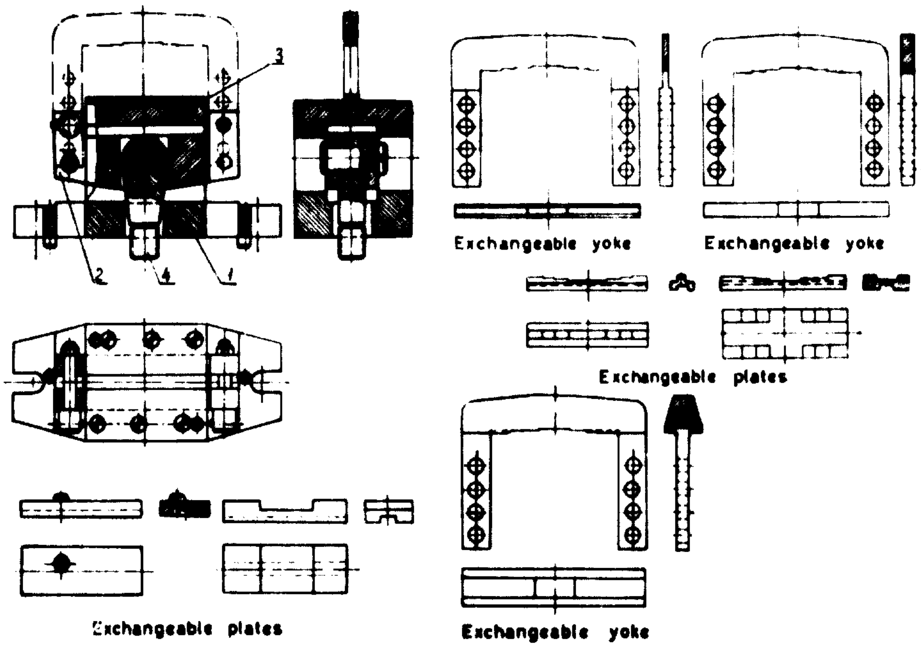


Figure 6. Group-adaptable fixtures

This fixture consists of a baseplate 1 and a yoke 2 with exchangeable clamps and exchangeable plates 3 which locate the various parts in the group.

The part to be machined, together with the appropriate exchangeable plate, is usually fixed on the base surface of the plate 3. In order to fix the part, the appropriate exchangeable clamps are selected and fixed on the yoke 2 by means of pins fitting into holes in the clamp and the yoke. The fixture is installed above a pneumatic cylinder, and when compressed air is admitted to the upper chamber of the cylinder the eye 4 is drawn down, taking with it the yoke 2 carrying the exchangeable clamp, which thus clamps the part.

Example 2

Figure 7 shows various groups of parts, classified according to the established method referred to above, which require machining on ordinary or turret lathes.

The machining of each group calls for a group-adaptable turning fixture to enable the part to be rapidly set up and fastened and the lathe to be quickly adjusted when changing over from machining one part in the group to machining another. Thus, for example, figure 8 shows a group of parts whose mounting surfaces are so located as to make their fastening on the lathe a complicated matter which previously necessitated the use of many special-purpose turning fixtures of quite complex design.

The group method of machining has made it possible, however, to develop a group-adaptable turning fixture in which any part in

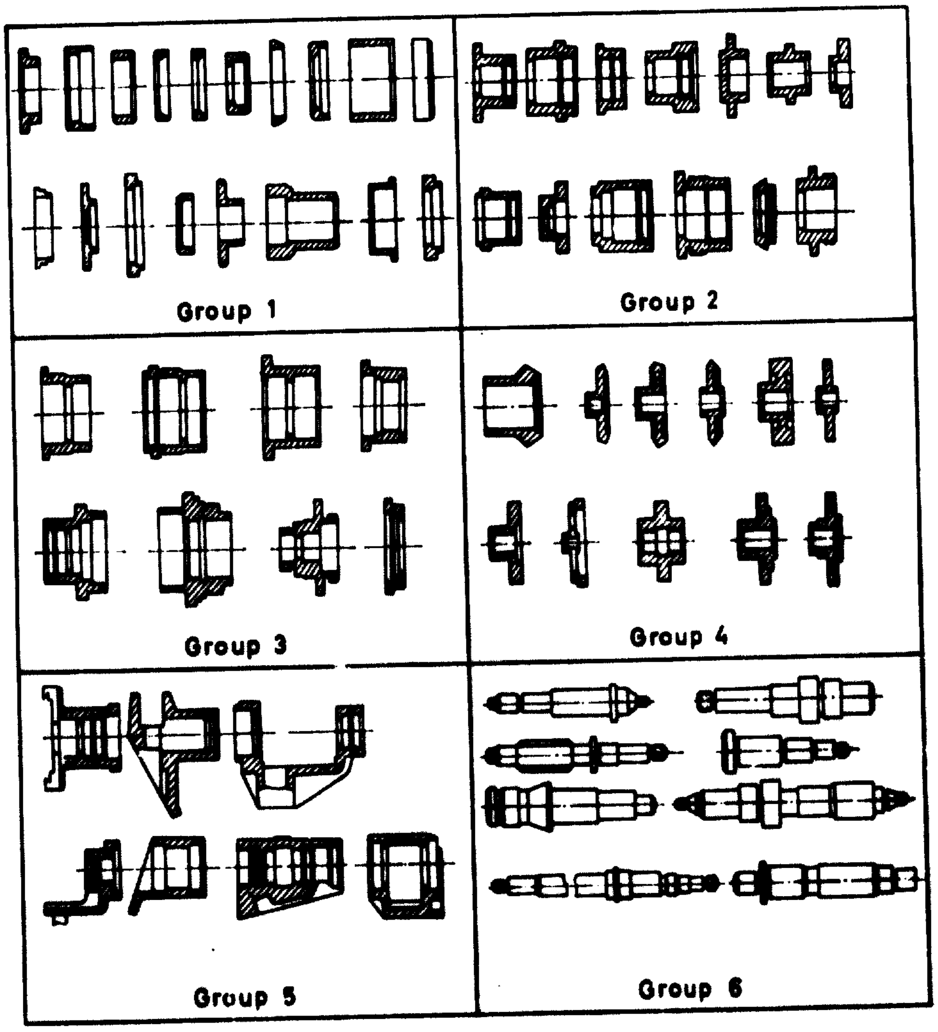


Figure 7. Parts classified for turning

the group in question can be fastened. Figure 9 shows this fixture, which is fastened to the faceplate of a turret lathe. It consists of

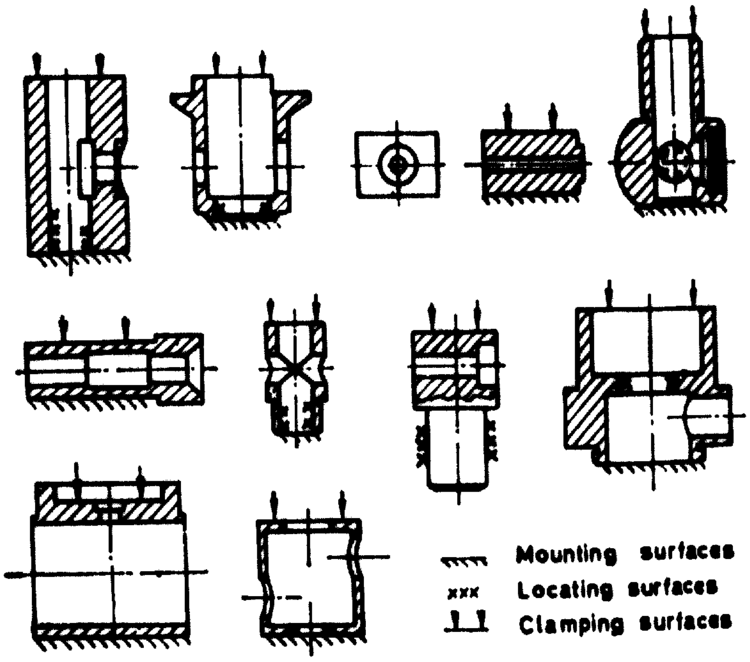


Figure 8. Parts with mounting surfaces which are difficult to fasten on a lathe

three basic parts: an angle bracket 1, on which the exchangeable insert 3 is fixed, the faceplate 2, and a clamping device consisting of a clamp 9 with a pivoted pressure plate 10. The bracket 1 and the fixed counterweight 11 are fastened to the faceplate by screws 15. A movable counterweight 4 is provided between the bracket and the fixed counterweight, so that the fixture can be accurately balanced.

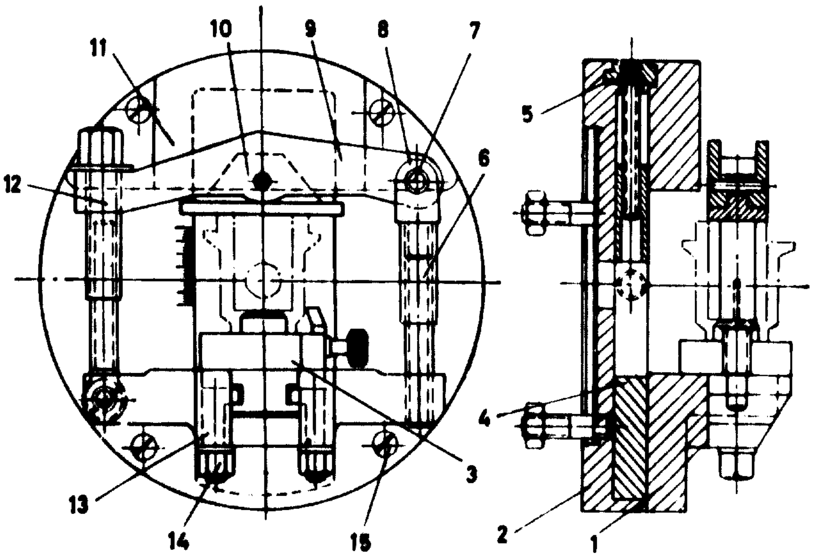


Figure 9. Group-adaptable fixture for fastening to the faceplate of a turret lathe

The turning fixture is set up as follows. An insert is selected to suit the part to be machined, and its shaped end is inserted in the groove of the bracket 1. The two pins 13 are then tightened by turning the nuts 14, thus pressing the insert against the bearing surface of the bracket.

After the part has been set up on the insert, the clamping device is adjusted to suit its height. For this purpose the eye nut 8, to which the clamp 9 is connected by a pivot pin 7, is screwed up or down the pin 6 sufficiently to clamp the part. The nut 12 is adjusted in a similar manner.

After the turning fixture has been adjusted, it is balanced by means of the movable counterweight. In order to do this, the screw 5 is turned so as to raise or lower the counterweight until a groove marked on the latter coincides with a particular graduation on the scale engraved on the faceplate (the graduation corresponding to the part to be machined is marked on the insert). The counterweight is then locked with a set screw and the setting up of the fixture is complete.

Figure 10 shows ten designs of inserts with parts fitted on them.

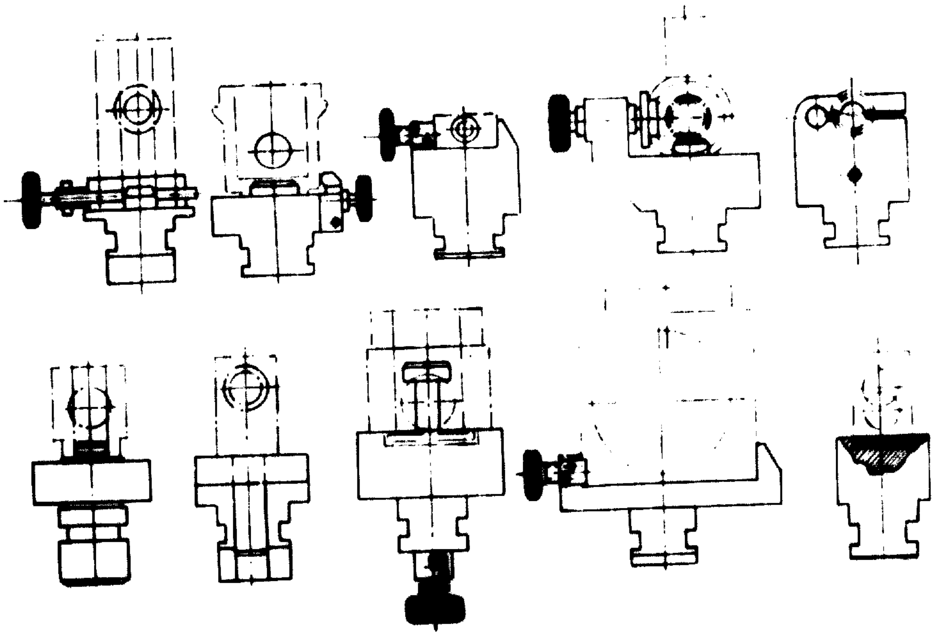
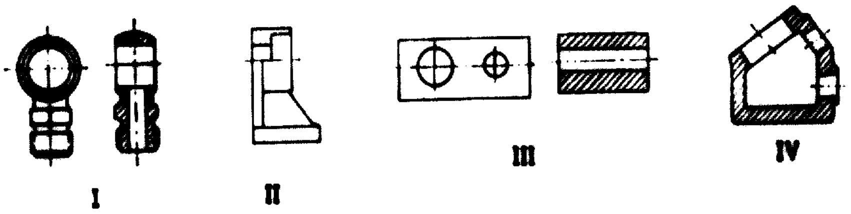
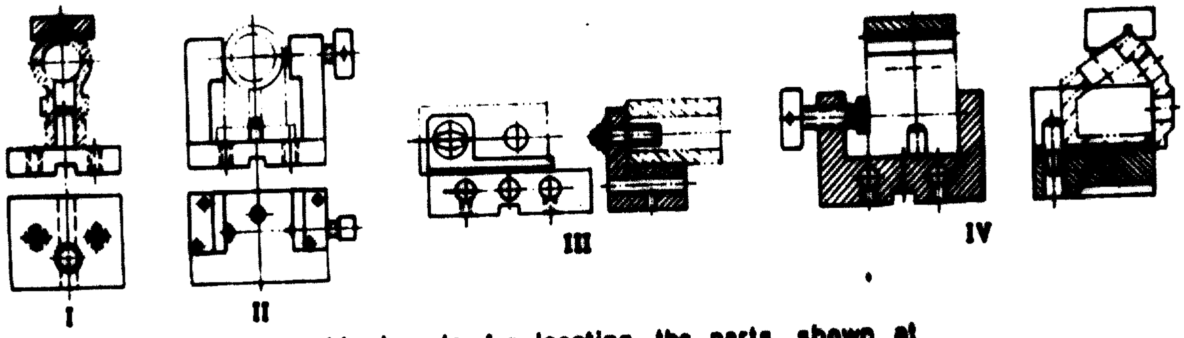


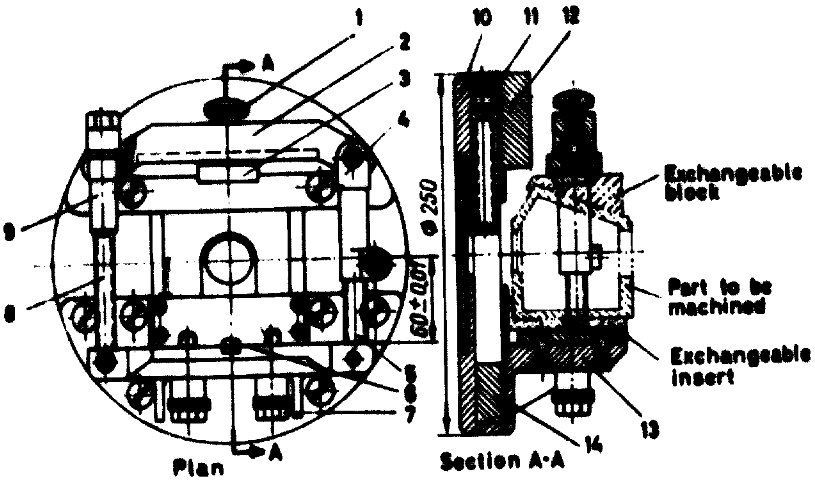
Figure 10. Inserts with parts fitted to them



Parts to be machined



Exchangeable inserts for locating the parts shown at the top of the page



Jig in which parts are machined

Figure 11. Another group-adaptable turning fixture

Example 3

Figure 11 shows the design of yet another group-adaptable turning fixture. This fixture also consists of three basic parts: a faceplate 10, an angle bracket 13 and a clamping device. The clamping device, fastened on the bracket 13, consists of a pivoted bolt 8 with a sleeve nut 9, a pivoted arm 2 with a screw 1, and a pivoted prism-shaped block 3, an eye nut 4 and a pin 5. The fixture is balanced by a fixed counterweight 12; 6 is a dowel pin.

The turning fixture is set up as follows. The exchangeable insert required for the part to be machined is installed with its longitudinal groove on the pin 6 and is fastened to the bracket by screws 7. After the part has been set up and fastened on the insert, the clamping device is adjusted to suit the height of the part. In order to do this, the eye nut 4 is screwed up or down the pin 5 sufficiently to clamp the part. The sleeve nut 9 is adjusted in a similar manner. The pivoted arm 2 is attached to the eye nut by a pivot pin. The shape of the prism-shaped block 3 installed on the arm 2 must correspond with the shape of the part to be machined.

After the fixture has been set up, it is balanced by means of the movable counterweight 14. In order to do this, the screw 11 is turned so as to raise or lower the counterweight until the groove marked on it coincides with the graduation of the scale engraved on the faceplate 10 corresponding to the part to be machined. This graduation is specified on the insert.

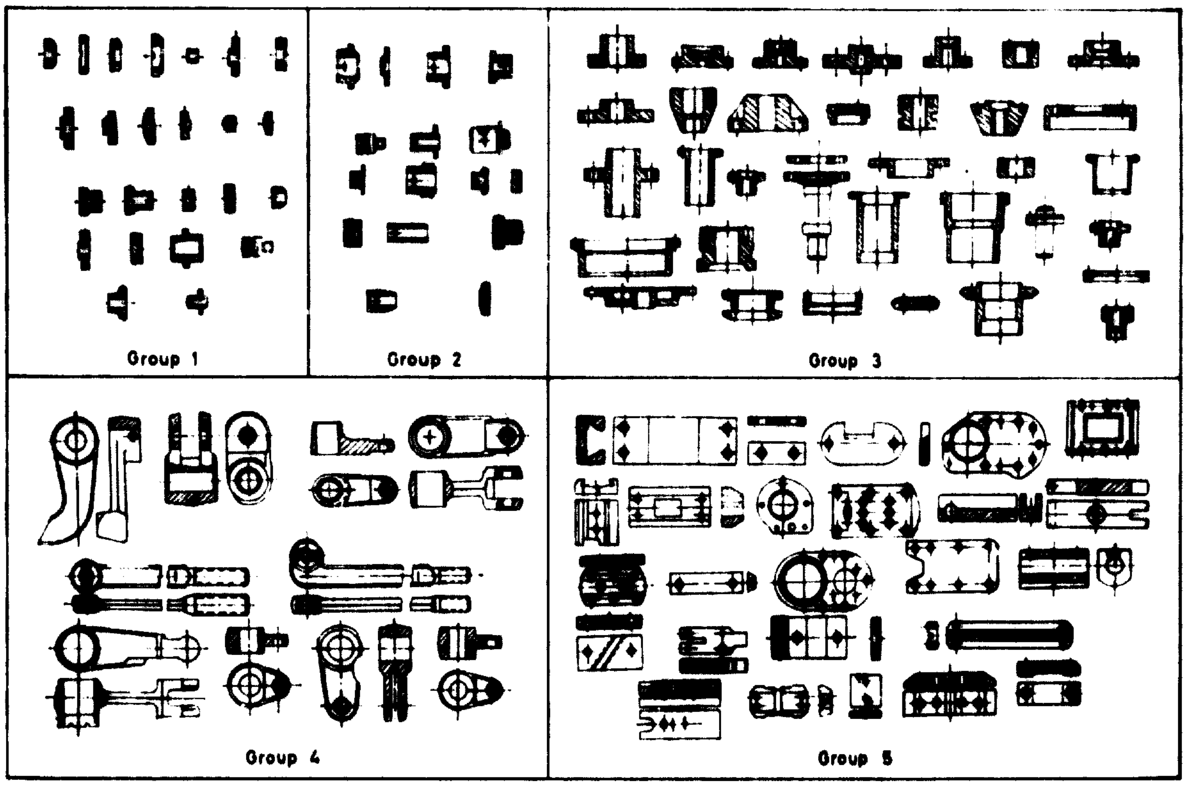


Figure 12. Classification of parts to be machined

The upper part of the figure shows some typical parts (I—IV) machined in the turning fixture. The design of the exchangeable inserts which locate the parts is shown in the lower part of the figure. Thus, for example, the part I is located by means of a pin. Part II is located by a pin in the longitudinal direction, while in the transverse direction it is located by clamping to the base surface with a set screw. Part IV is located by a pin in the longitudinal direction, while in the transverse direction it is pressed against the mounting surface of the insert with a set screw. The part is finally fastened in place by an exchangeable prism-shaped clamp.

In the group method of machining, where the parts to be machined are classified in groups (figure 12) and set up on a given machine tool, all this equipment (figure 13) is particularly widely

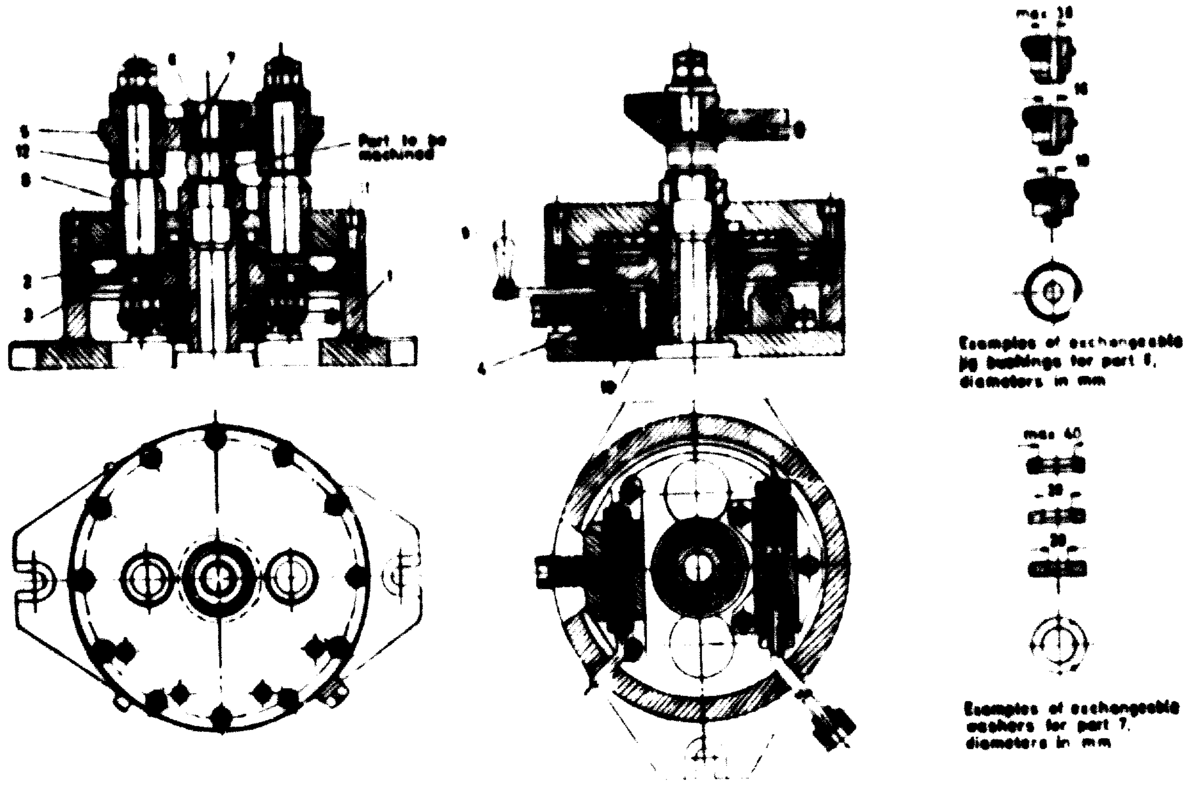


Figure 13. Group-adaptable drilling fixture with pneumatic clamping

used. Experience shows that the majority of parts can be machined with the aid of universal and group-adaptable jigs.

Example 4

Consider the machining of the parts shown in Group 4 in figure 12. These consist of levers, rocker arms and pull rods in which holes must be drilled.

The group-adaptable pneumatic drilling fixture shown in figure 13 is designed for machining parts such as these which have a boss diameter of up to 100 mm, a height of up to 80 mm and a maximum diameter of 40 mm for the hole to be machined.

The main body 1 of the fixture contains an air chamber 2 with a diaphragm 3 and an air control valve 4. The upper movable plate 5, in which the exchangeable inserts 6 and the exchangeable discs 7 are mounted, is connected by two rods 8 with the diaphragm 3.

The figure illustrates something often needed—the mounting of a part which consists of a lever with a single boss. The lever is set on the already machined surface of the boss and is centred with the exchangeable disc 7. When setting up is complete, the handle 9 is turned to deliver compressed air to the air chamber, whereupon the diaphragm 3 and the rods 8 and plate 5 connected to it are forced down and clamp the part.

When the part has been machined the air control handle is turned back, the air is exhausted by the channel 2, and the entire movable unit is raised by the spring 10, thus freeing the part.

When changing over the fixture to accept other parts, it is necessary to select and install a supporting bush 11 which has an orifice that is smaller than the external diameter of the boss, but larger than the diameter of the hole which is to be drilled in it. An appropriate exchangeable washer 7, which incorporates a conical recess to centre the boss of the part, must also be fitted. The requisite exchangeable bushing 6, which guides the drill during the machining operation, is selected and fitted in the plate 5, and the height of the plate is adjusted to suit the height of the boss of the part to be machined by means of the exchangeable discs 12.

This drilling fixture can also be designed with a cam or quick-acting screw-thread clamping device if pneumatic means are not available.

MULTI-PURPOSE DIES AND MOULDS

CLASSIFICATION OF PARTS FOR COLD STAMPING IN MULTI-PURPOSE DIES

The group method of cold stamping is based on the classification of parts into groups for the manufacture of which group-adaptable (universal) die assemblies with exchangeable working parts can be used on versatile presses.

Group stamping can be used both for individual operations and in the manufacture of groups of parts involving a sequence of operations. This latter fact creates favourable conditions for the use of group-adaptable automatic lines.

One-off or batch production of cold stamped parts can be arranged in two ways:

(*a*) By preparing universal and simplified dies;

(*b*) By preparing group-adaptable (universal) die assemblies with exchangeable punch and die sets.

In conditions of one-off and short-run production stamping, operations can advantageously be done one at a time, using universal punches and dies and a dial press. Stamping by this system is also recommended where there are frequent changes in the design of parts, as such design changes do not then necessitate changes in the universal punches and dies.

It is usually most advantageous to use group-adaptable (universal) die assemblies with exchangeable punch and die sets in short-run and series production, although they can also be used sometimes in mass production.

When the group method is used, the parts must first be classified, a group manufacturing process must be developed, group-adaptable tooling must be designed. In the group method, the parts are classified according to the way they are manufactured: i. e. distinctions are drawn between parts which are manufactured by cutting, bending, drawing, moulding, and pressing in dies on stamping equipment (see figure 14).

The main objective of this classification is to define the groups of parts which can be manufactured on a single machine with a single set of production equipment.

In classifying parts, account must be taken of their shape and dimensions, their method of manufacture, the required accuracy and surface finish, the need for economy in laying out the stock strip, and the number of parts to be made.

At the same time, the most efficient type of equipment and design of tool must be selected. Thus, for example, in grouping flat parts which are to be stamped with punch and die sets fastened in group-adaptable (universal) die assemblies, the main feature as far as classification is concerned will be the dimensions of the parts, which determine the size of the die sets and the strength of the press required for stamping. In this particular case, the shape of the parts will not be significant.

Figure 15 shows group operations with the parts classified according to their diemensions, their method of manufacture, and the nature of the blank used. The figure also gives details of the universal group-adaptable blocks used in the stamping of parts in each group.

In stamping one operation at a time with universal exchangeable-component dies, it is necessary to single out as grouping features those operations which are to be carried out on a single press fitted with either a fixed die set or with a group-adaptable base with exchangeable punch and die sets.

In stamping one operation at a time on a dial press, the grouping features are those characteristics of the part which determine the

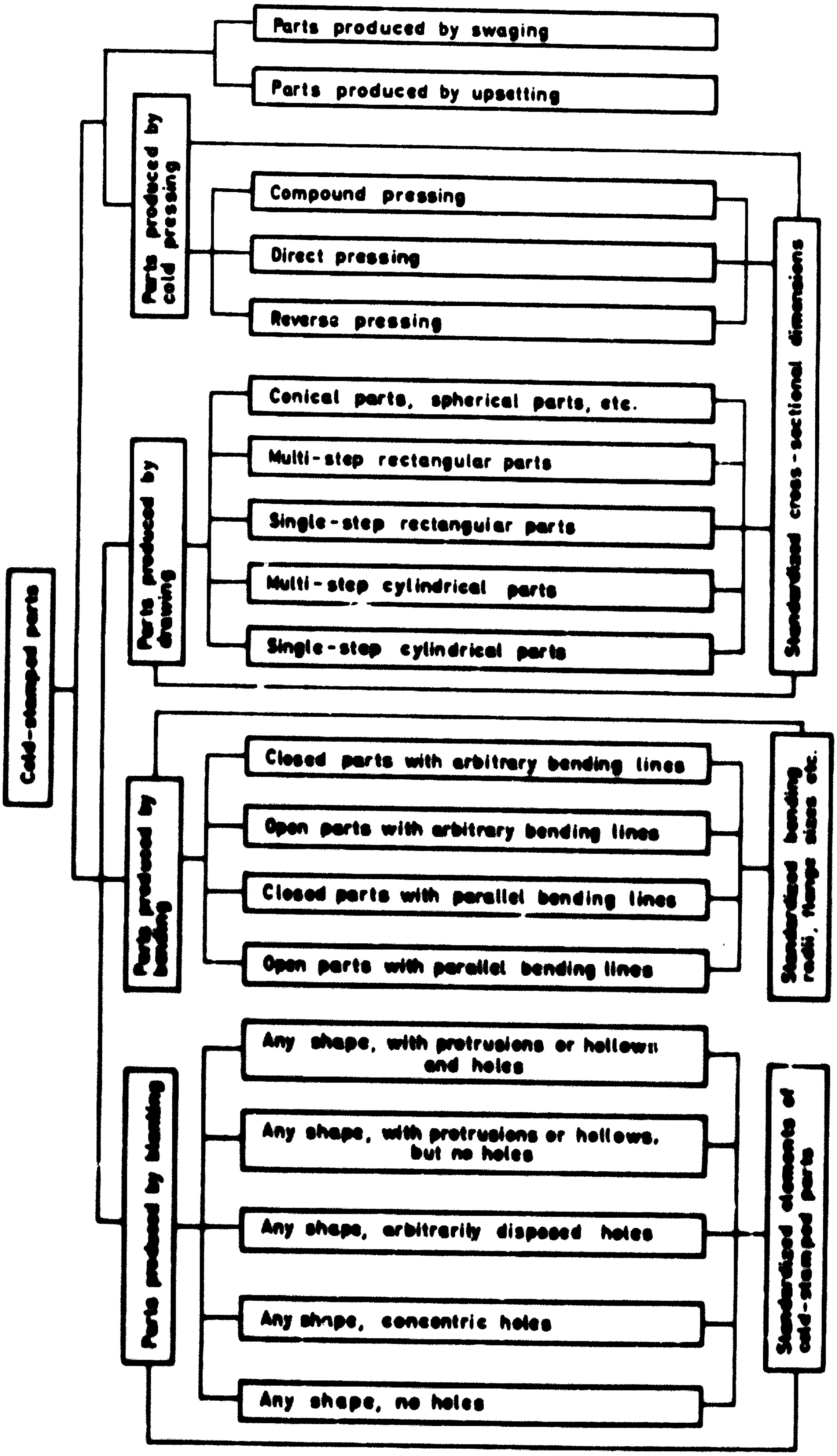
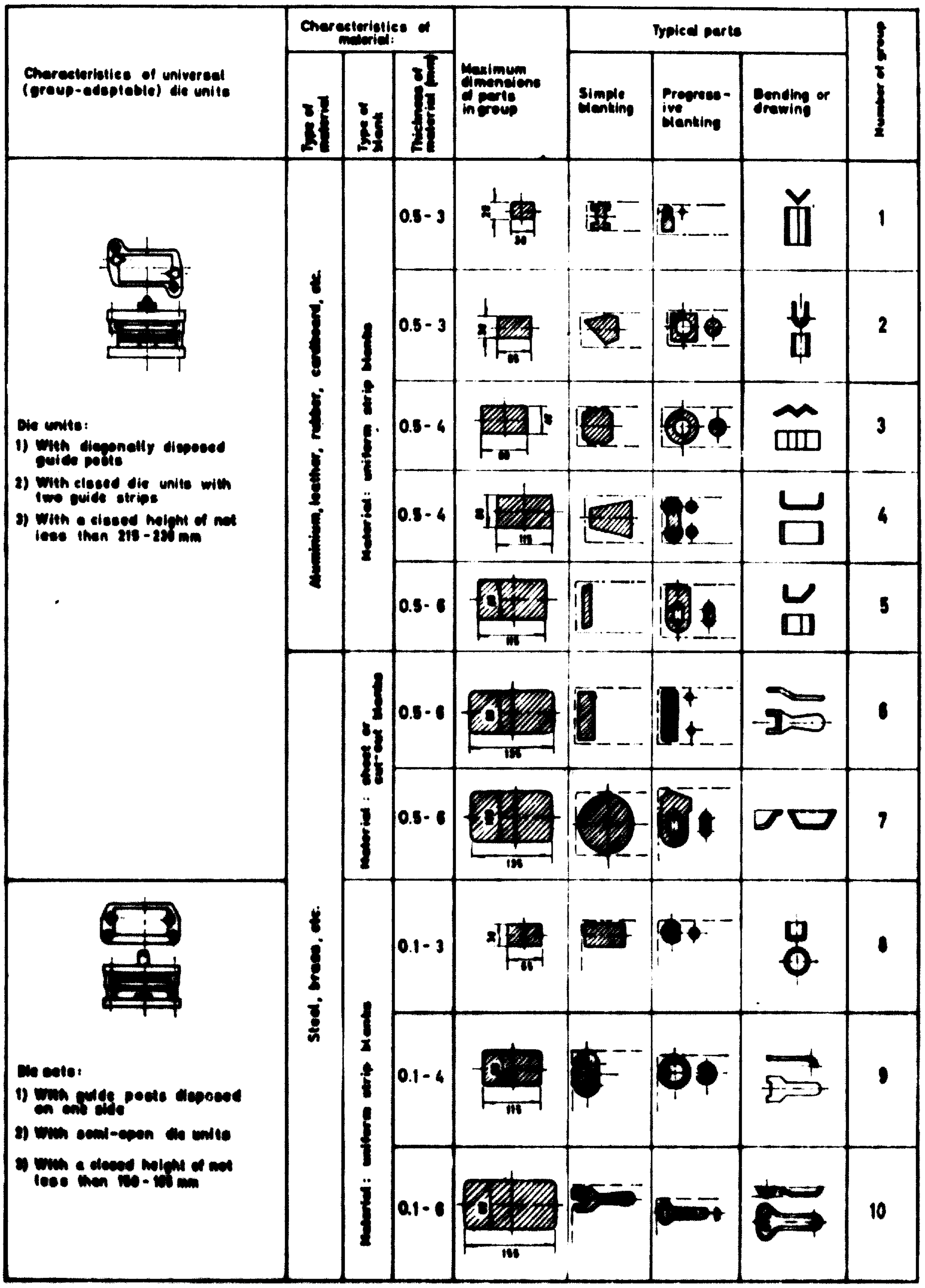


Figure 14. Classification of parts for cutting, bending, drawing, moulding or pressing

CLASSIFICATION OF PARTS COLD-STAMPED FROM SHEET

Type of production equipment used	*Means of adaptation of equipment*	*Grouping features*	*Differentiating features and limitations*
Fixed dies	Exchangeable punches	Parts are of identical dimensions and outside shape	Different numbers of holes
Universal (group-adaptable) die sets	Exchangeable punches and dies	Dimensions and thickness of material of parts are within certain limits for a given die set	Parts of any shape with over-all dimensions up to 250 mm
Universally adaptable dies	Adjustable and exchangeable stops	Parts have similar stamped elements, the dimensions of which must be within certain limits for a given die	Parts of any shape with dimensions over 70 mm
Universal (group-adaptable) bases	Exchangeable die sets and adjustable stops	Parts have identical stamped elements (holes, grooves)	Parts of any shape, provided that the holes to be punched are located more than 1.5 *t* from the edge of the blank where *t* is the thickness of the blank
Dial blocks (dial presses)	Exchangeable tool units and displacement of the blank in given directions	Parts have identical stamped elements or else elements which can be stamped without re-tooling the dial head	Parts of any size and shape for the stamping of holes, or parts with a maximum diameter of 70 mm for cutting out



Characteristics of universal (group-adaptable) die units	Characteristics of material: Type of material	Type of blank	Thickness of material (mm)	Maximum dimensions of parts in group	Typical parts: Simple blanking	Progressive blanking	Bending or drawing	Number of group
Die units: 1) With diagonally disposed guide posts 2) With closed die units with two guide strips 3) With a closed height of not less than 215 - 230 mm	Aluminium, leather, rubber, cardboard, etc.	Material: uniform strip blanks	0.5 - 3					1
			0.5 - 3					2
			0.5 - 4					3
			0.5 - 4					4
			0.5 - 6					5
	Steel, brass, etc.	Material: sheet or cut-out blanks	0.5 - 6					6
			0.5 - 6					7
Die sets: 1) With guide posts disposed on one side 2) With semi-open die units 3) With a closed height of not less than 160 - 165 mm		Material: uniform strip blanks	0.1 - 3					8
			0.1 - 4					9
			0.1 - 6					10

Figure 15. Classification of banking, punching, bending and drawing operations

selection of tools fitted in a single setting to the dial head. When changing over from the manufacture of one batch of parts to another, it is sufficient to change the master pattern or programme (when the press is fitted with a programme device), which takes much less time than re-setting the tool.

Grouping is somewhat more difficult in this type of stamping, as the number of types and dimensions of the elements of all the parts making up the group must not exceed the number of stations on the dial head.

It is typical of stamping one operation at a time that there are few stable groups, not only as far as the whole manufacturing process is concerned, but also in the separate operations. Usually small batches of parts are manufactured in this way, and some of these parts are not repeated at all (experimental parts), while others are repeated only infrequently, say once a quarter. The groups must therefore be reviewed each month, according to the types of parts to be produced under the monthly production programme.

As grouping must involve the minimum of re-setting of the dies (or of the tools in the dial head of the press), it can most advantageously be carried out with a computer into which punched cards with coded information on the grouping features are fed, or else by a manual punched card system.

Figure 15 shows that different types of production unit must be used for manufacturing different groups of parts and that the parts must be classified with this in view.

One of the main conditions for effectiveness in the use of universal dies is the unification of the stamped parts and their design elements. Work on unification should therefore be carried out side by side with the classification of parts. The elements of stamped parts (holes, grooves, radii, curves) must be standardized in order to reduce the number of varieties.

The correct choice of the geometrical forms of design elements in this standardization process creates the most favourable conditions for the effective use of production processes involving the minimum amount of equipment.

The successful introduction of the group method of stamping and its further improvement through mechanization and automation depend to a considerable extent on the level of unification and standardization achieved.

GROUP-ADAPTABLE DIES FOR COLD STAMPING

One of the most important conditions for the effective use of the group method in stamping is the correct selection of types and designs of dies.

Group-adaptable dies must be simple in design, universal in application, safe and convenient in operation, and capable of ensuring an adequate level of productivity in stamping.

In selecting types and designs of dies, it is necessary to take account of the volume of production and the length of each production run, the production capabilities of the enterprise, the features of the equipment, the plan of operations for the group process, and the special features of the parts making up the group.

Group-adaptable (universal) dies impose on the designer more complicated requirements than do special-purpose (individual) dies. Group-adaptable (universal) dies are designed after analysing the design and manufacturing characteristics of the parts making up the group, the range of dimensions, and the nature of the mounting surfaces and fastenings of the parts.

The basic data for design are:

(a) Drawings of all the parts in the group, a card index of the drawings, and comprehensive tables of the standardized geometrical shapes of the design elements of the parts which are to be stamped;
(b) An outline or details of the production process to be used;
(c) Details of the press for which the group-adaptable die is being designed; and
(d) Details of the existing designs of dies and their production capabilities.

Universal dies must be designed to be as simple as possible in their setting up and adjustment. They must also be versatile in use, have a long life, minimum cost, be convenient to service, and they must use as many standard die components as possible.

More details are given below on the design and use of *(a)* universal (group-adaptable) die sets with exchangeable punches and dies, *(b)* universal exchangeable-component dies, *(c)* dial-plate dies, *(d)* dial presses, and *(e)* group-adaptable automatic lines, used for the cold stamping of various groups of parts.

(a) Universal (group-adaptable) die sets with exchangeable punches and dies

This equipment is widely used for short runs and series production. Three types of die set are used, differing in the method of fixing the exchangeable punch and die. The fastening methods for punch and die may be:

(i) Mechanical,
(ii) Electromagnetic,
(iii) Combined electromagnetic and mechanical.

The most widely used die sets are those with mechanical fastening of the punch and die (see figure 10). The advantages of these sets are their simplicity of construction, and their universality. They can also be used for stamping parts with a wide range of dimensions and thicknesses, using all types of stamping operations. They enable various arrangements for the mechanization of the

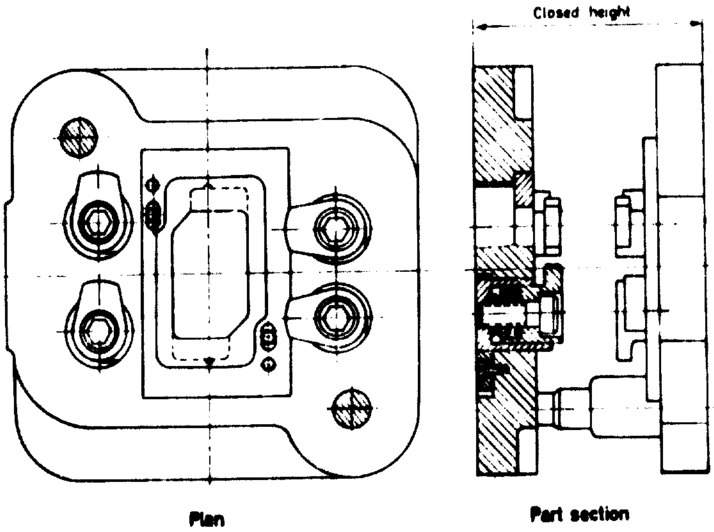


Figure 16. Die set with mechanically fastened punch and die

stamping process to be used, without requiring any special equipment on the press.

The punch and die units installed in group-adaptable die sets with mechanical fastening are essentially ordinary blanking, progressive or combined units without any means of connexion with the press (punch holder and die holder), locating means (such as guide posts and bushes) or punch shank. Where the material to be cut is not very thick (up to 1 mm), punch and die units have their own additional fittings for locating the working parts relative to each other, but with thick materials such location is carried out by the die set.

Some varieties of punch and die units for die sets with mechanical fastening are shown in figure 17. The simple blanking punch and

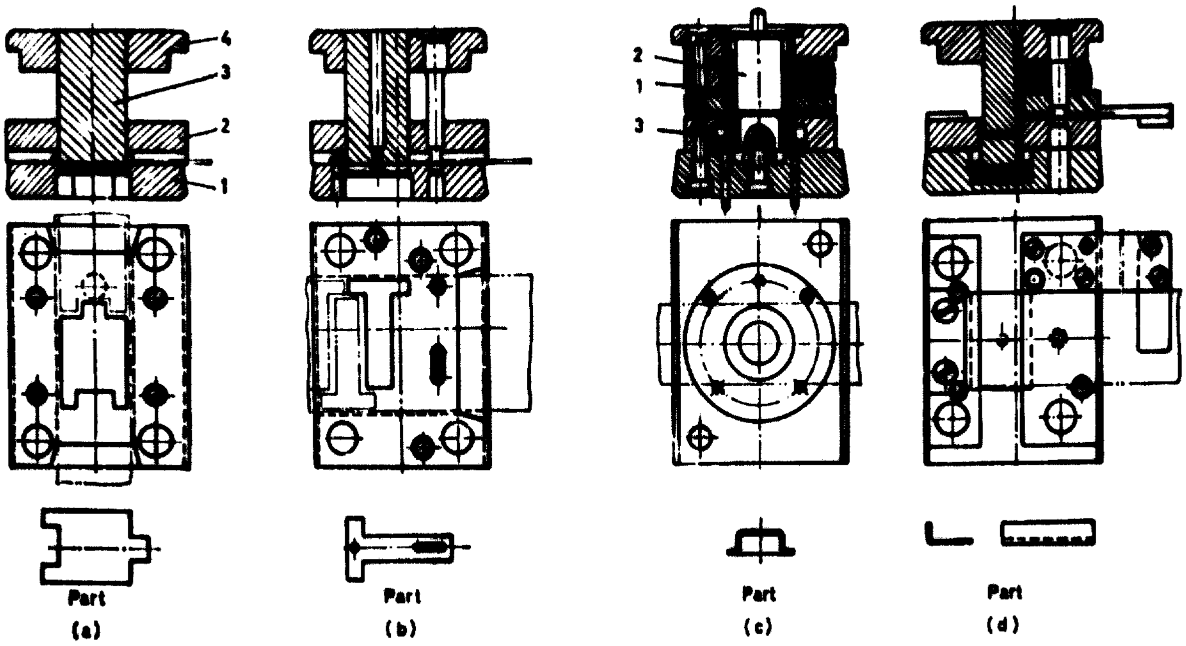


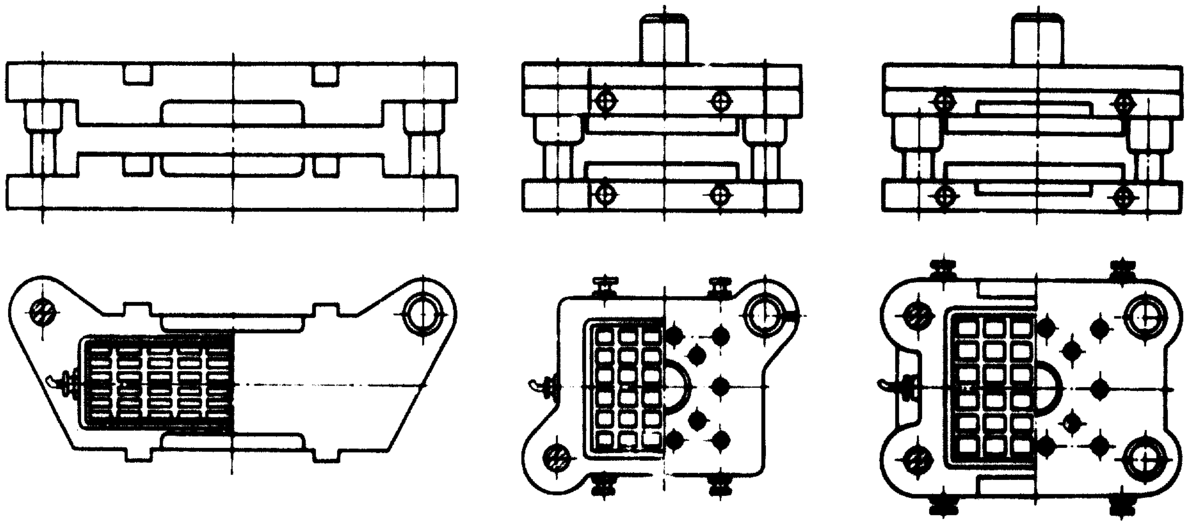
Figure 17. Punch and die sets with mechanically fastened die

die unit with a solid stripper plate, shown in figure 17a, consists of a die 1 with a stripper plate 2 fastened to it by screws and pins. The punch 3 is pressed into the punch holder 4.

The design of the progressive-action blanking die unit, shown in figure 17b, is in no way different from that of an ordinary die. The design of the compound die unit for blanking and drawing, shown in figure 17c, is also identical in its main principles with the basic design. In order, however, to release the part from the drawing die 1 by the knockout 2, and to return the lower pusher 3 to its original position, there are devices in the upper and lower parts of the group-adaptable block which are actuated by the slide and the lower buffer of the press, respectively.

Another design of a compound die unit for the cutting and bending of parts is shown in figure 17d. The provision, in the lower unit, of a resilient ejector working independently of the die set, makes the set more versatile and facilitates the setting up of the exchangeable dies.

Universal blocks with electromagnetic fastening of the punch and die units, as shown in Figure 18, offer some possibilities. They are used for the cutting, perforating, simple bending and shallow drawing of sheet metal parts (up to 3 to 4 mm thick). Their main advantage is the fact that they can incorporate units of simple design which can be installed quickly in the die set without the use of additional locating devices (by the straightforward matching-up of the cutting parts of the punch and die). This makes it possible to locate the punch and the die with high accuracy relative to each other, which is particularly important in cutting or perforating thin materials. Plate-type single or compound dies are used for electromagnetic die sets. The first type of die carries out one stamping



Type I

Type II

Type III

Figure 18. Universal blocks with electromagnetic fastening of the punch and die units

operation (such as blanking) for each stroke of the punch, while the second simultaneously carries out several different operations (such as blanking and perforation for a single stroke of the punch).

Die sets with electromagnetic or mechanical fastening of the die units, such as those shown in figure 19, offer considerable possibilities. They can be used with advantage for various types of stamping of both small and large parts out of thin or thick material.

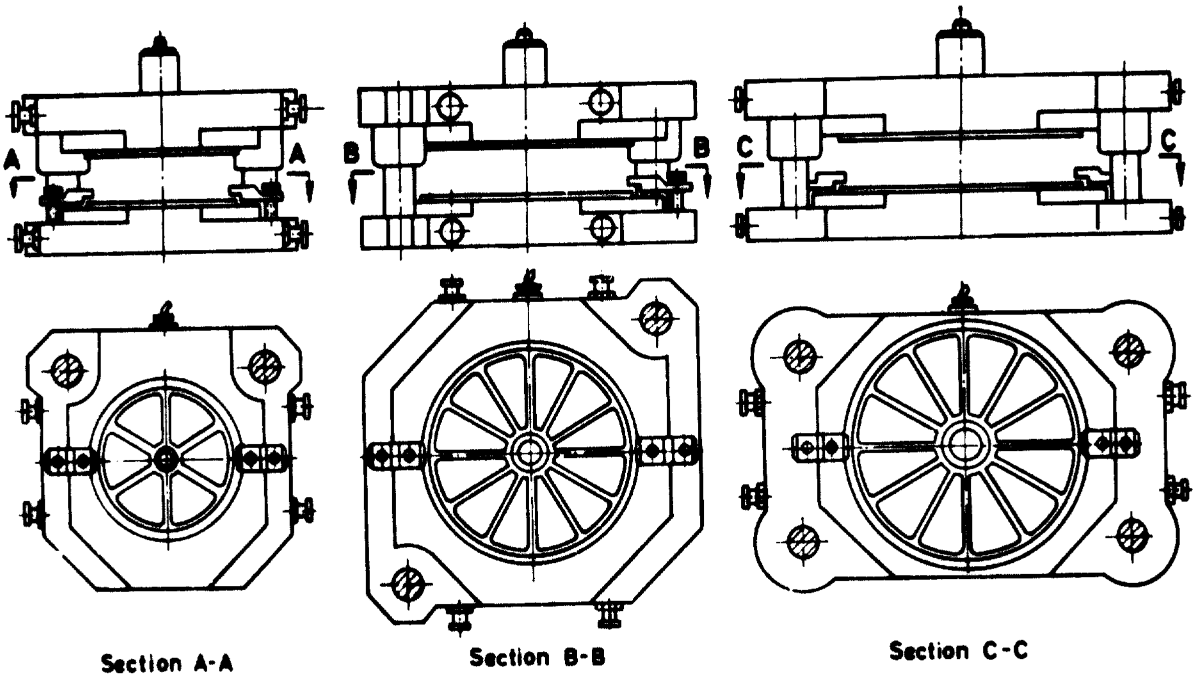


Figure 19. Die sets with mechanically fastened die units

(b) *Universal exchangeable-component dies*

These dies are intended for the stamping of parts by elements; various operations can be carried out by them.

(c) *Dial-plate dies*

These are being used more and more widely for group stamping by elements. They can be used most advantageously for punching holes of various shapes in flat parts such as plates, or panels, of dimensions up to 300 mm, as well as for blanking parts not larger than the die-holder aperture.

Dial-plate dies are divided into two types:

(a) Those mounted on a single axis with discs (with solid connexion of the upper and lower discs); and

(b) Those located in a C-shaped body in the die set (in this case, the upper and lower discs of the dial plate are not solidly connected to each other).

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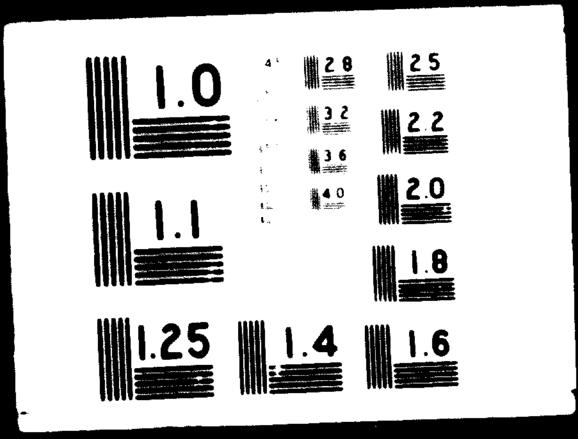


Dies of the first type are used for stamping parts out of strip up to 120 mm wide. The wider production abilities of dies of the second type, which have separate fastening of the upper and lower discs of the dial plate, enable them to be used for punching holes in sheet blanks up to 300 mm wide at a single setting.

Vernier tables are used to line up the blanks with the axis of the punch when the latter is in its working position.

(d) Dial presses

Dial presses are useful for short runs; they are one of the most vivid illustrations of the principle of the concentration of operations in cold stamping. A dial press can take the place of a line of several universal presses with exchangeable-component dies in the stamping of parts by elements.

The concentration of stamping operations and the wide possibilities in the group method reduce the cost of stamping operations and raise productivity.

Depending on the design of the press, from 16 to 36 exchangeable sets of tools can be installed on the dial plate of a press at the same time.

The presses are equipped with vernier tables on which the sheet blanks are fastened. The blank can be lined up with the set of exchangeable tools, when the latter is in the working position, by the following methods:

(i) Establishment of given co-ordinates on the reading scale with a vernier or optical micrometer;
(ii) Lining up of the blank with a template; or
(iii) Lining up of the blank automatically in accordance with a given programme.

Dial presses are used for producing sheet-metal parts such as panels, plates and frames with dimensions up to 700 × 1,000 mm. An accuracy within ± 0.1 mm can be achieved in the dimensions between the hole centres.

The maximum diameter of a part which is cut out, or a hole which is punched with a single stroke, varies from 50 to 100 mm, depending on the design of the press.

In order to cut down the time needed for auxiliary operations, some designs of press are equipped with automatic remote control of the rotation and locking of the dial plate.

(e) Group-adaptable automatic lines

The group working method opens up wide possibilities for the automation of cold stamping. Thus, example parts, from a number of groups which are manufactured by cutting out or perforation, can be produced by means of single or progressive dies with automatic feed of the material. The presses on which these dies are used, if provided with special equipment, can be substantially equivalent to a straightforward automatic line.

For production processes involving a number of operations it is worth considering whether to set up special automatic lines which can produce parts belonging to a given group with only a small amount of time for re-setting.

Special automatic machines with quickly-exchangeable components and multipurpose group-adaptable automatic lines are being used more and more widely in industry.

CLASSIFICATION OF PARTS FOR PRESSURE DIECASTING IN MULTI-PURPOSE DIES OR MOULDS

The development of a group-adaptable pressure diecasting process is divided into two stages:

(a) The classification of castings and the establishment of groups;
(b) The development of suitable designs of die or mould units and inserts for each group.

In the classification of pressure-cast parts, the main factors determining the groups to which the parts belong are:

(a) The break or parting line of the die or mould for making the casting;
(b) The ejector system in the die or mould used for making the casting;
(c) The location of the casting cavity in the die or mould (i. e., in the movable half of the die or mould, in the fixed half, or in both halves);
(d) The design of the injection system;
(e) The presence of side holes in the casting;
(f) The over-all dimension of the cast part.

In practice, the break or parting line of the die or mould determines the design of the die or mould unit, the location of the casting in it, and the ejector system used. The break or parting line may be located either at one end of the casting, along its section of maximum dimensions, or along its axis of symmetry.

When a break or parting line running across one end of the casting is selected, the part is located entirely in one half of the die or mould. When the break or parting line runs along the line of maximum dimensions of the part, or along its axis of symmetry, the part is cast in both die or mould halves.

The system used for ejecting the casting determines the design of a group-adaptable die or mould unit. Such systems can be of two types: ejection by a stripper plate or by ejectors.

Stripping is by means of a stripper plate when the outside contours of the casting are formed in a fixed half-die or mould. When the internal cores are large, however, the use of a stripper plate is undesirable, and it is better to use ejectors.

When the part is cast in a movable half-die or mould or in a cavity which is made in two parts, stripping is by ejectors.

Castings made in group-adaptable units can be side-injected, or centre-injected.

In selecting the injection point, the following factors must be borne in mind:

(*a*) Centre-injection of the molten metal is preferable, as it reduces the dimensions of the die or mould assembly.

(*b*) The injection system must be designed with a view to ensuring that the stream of metal entering the die or mould progressively drives out the air from the spaces within the cavity towards the break or parting line.

(*c*) Injection should preferably be aimed at a surface of the casting which it is intended to machine later.

(*d*) The thickness of the feeder used in making the casting should be from 25 to 30 per cent of the wall thickness of the cast part (for cast parts up to 6 to 7 mm thick).

The dimensions of the casting influence the choice of the group to which it should belong, as the area of a projection of the casting in the plane of the break or parting line is basic to the selection of the type of diecasting machine to be used. The dimensions of the

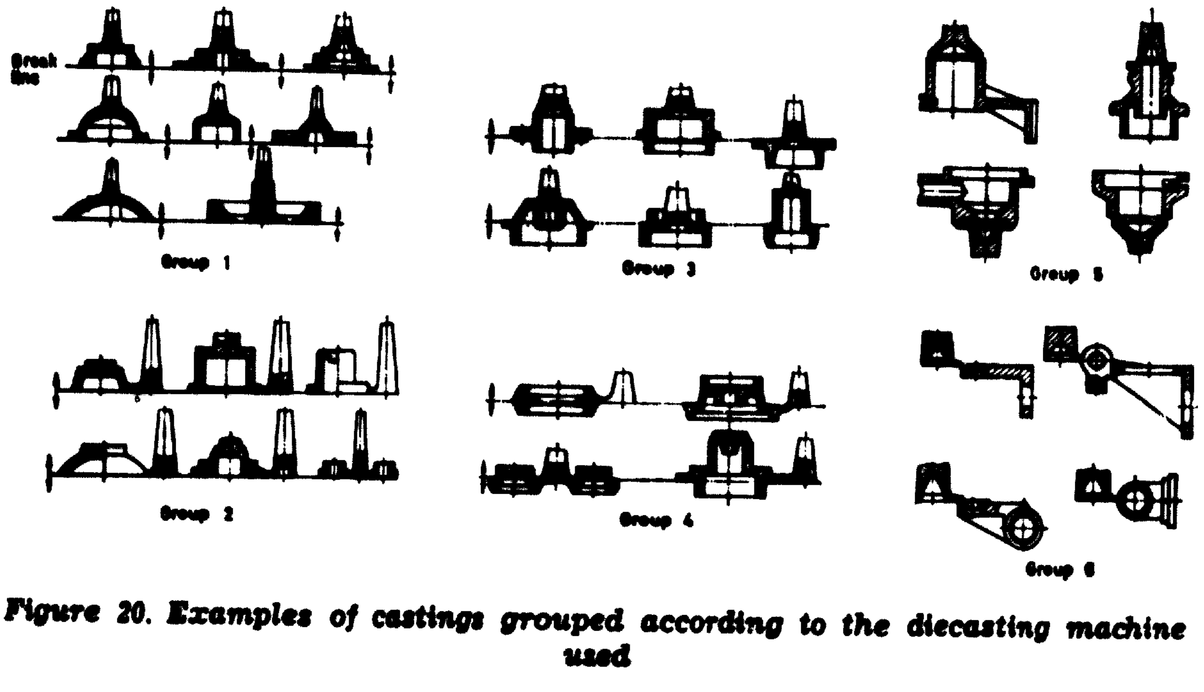


Figure 20. Examples of castings grouped according to the diecasting machine used

casting do not affect the basic design of the die or mould assembly, apart from its dimensions. Examples of castings grouped on this basis are shown in figure 20.

Group 1 consists of parts where the break or parting-line surface is a plane coinciding with the end of the part. The outer surface of the part is formed in the fixed section of the die or mould, the part is removed from the core by a stripper plate, and centre injection is used in the casting process.

Group 2 differs from Group 1 only in that side injection is used.

Group 3 consists of parts where the break or parting-line surface is located in the plane of greatest cross-sectional area. The part may be formed in both the movable and fixed parts of the die or mould; or possibly only in the movable part. The finished casting is removed by means of ejectors, and centre injection is used in casting.

Group 4 differs from Group 3 only in that side injection is used during casting.

Group 5 consists of parts which have the same features as those in Group 3, but the castings have from one to three side apertures in three mutually perpendicular directions.

Group 6 differs from Group 5 only in that side injection is used during casting.

Group-adaptable die or mould units and inserts for pressure die casting

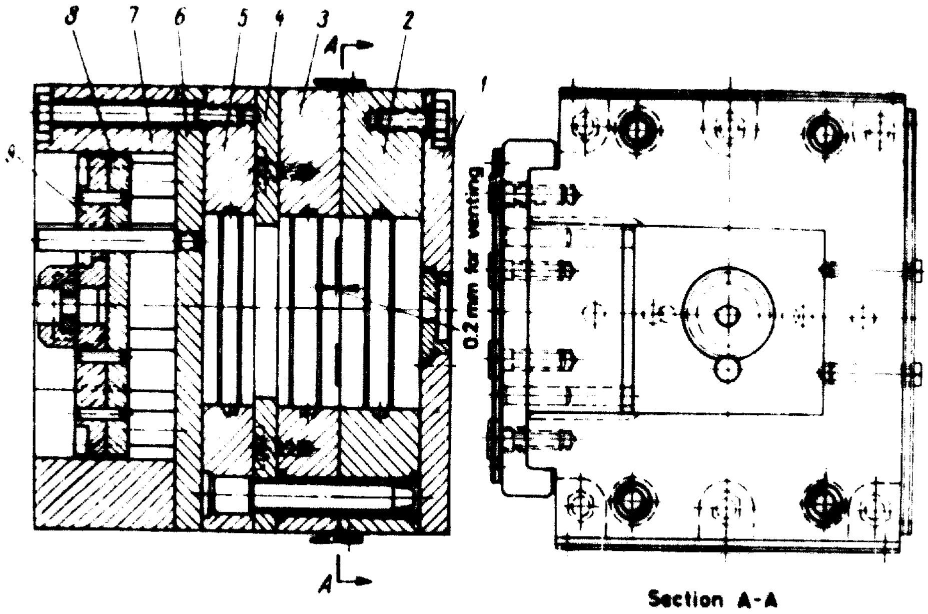
The basic principle of the design of such group-adaptable die or mould assemblies is that of the use of exchangeable inserts to form the part. Every effort must be made to ensure that such inserts can be changed without removing the die or mould unit from the diecasting machine and in the shortest possible time.

The most effective system of fastening the die or mould inserts is the slide-in system, which enables the inserts to be changed without taking the die or mould unit out of the machine.

Each unit is in two parts. The fixed part is fastened to the stationary part of the machine, while the movable part (together with the stripper devices) is fastened to the movable part of the machine.

The dimensions of the parts to be cast determine the type of machine, and consequently also the dimensions of the seats of the die or mould units. Depending on the dimensions of the castings making up the group, die or mould units may be of different dimensions, although identical in design.

By way of example, let us consider in greater detail one of the designs of group-adaptable units used to produce the castings in group 1 of figure 20. The parts are actually formed in the fixed part of the die or mould, as the break or parting line coincides with the end face of the part. Centre injection is used and the cores are stripped by a stripper plate. The die or mould units are designed for use on Polak 408 and Polak 600 die casting machines.



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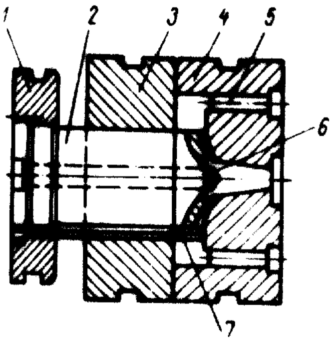


Exchangeable insert

Figure 21. Group-adaptable die or mould unit

The group-adaptable die or mould unit (shown in figure 21) consists of two parts: a fixed part and a movable part. The two halves of the die or mould are mated by means of four guide posts and bushes which positively locate them during operation. The fixed part consists of a plate 1 fastened by screws to the beam or platten carrying the fixed die or mould 2, while the movable half of the die or mould, which incorporates the mechanism for ejecting the part, consists of four plates 3, 4, 8 and 9 fastened together in two sets which can be displaced relative to the plates 5, 6 and 7 by means of a hydraulic mechanism.

Both halves have recesses in them in which the exchangeable die or mould components are held by screw clamps.

Figure 21 also shows the design of an exchangeable die or mould insert designed for this type of unit. The insert consists of plates 3 and 4, moulding cores 2, 5 and 7, a stripper 6, and a plate 1 for the fastening of cores 2 and 7.

The die or mould shown has a centre-injecting system located directly in the insert.

The die or mould inserts can be changed without removing the die or mould unit from the machine. To change the inserts it is necessary only to remove the pressure strips, take out the inserts from the movable and fixed parts of the unit, and replace them with the new ones needed to produce another type of part in the same group.

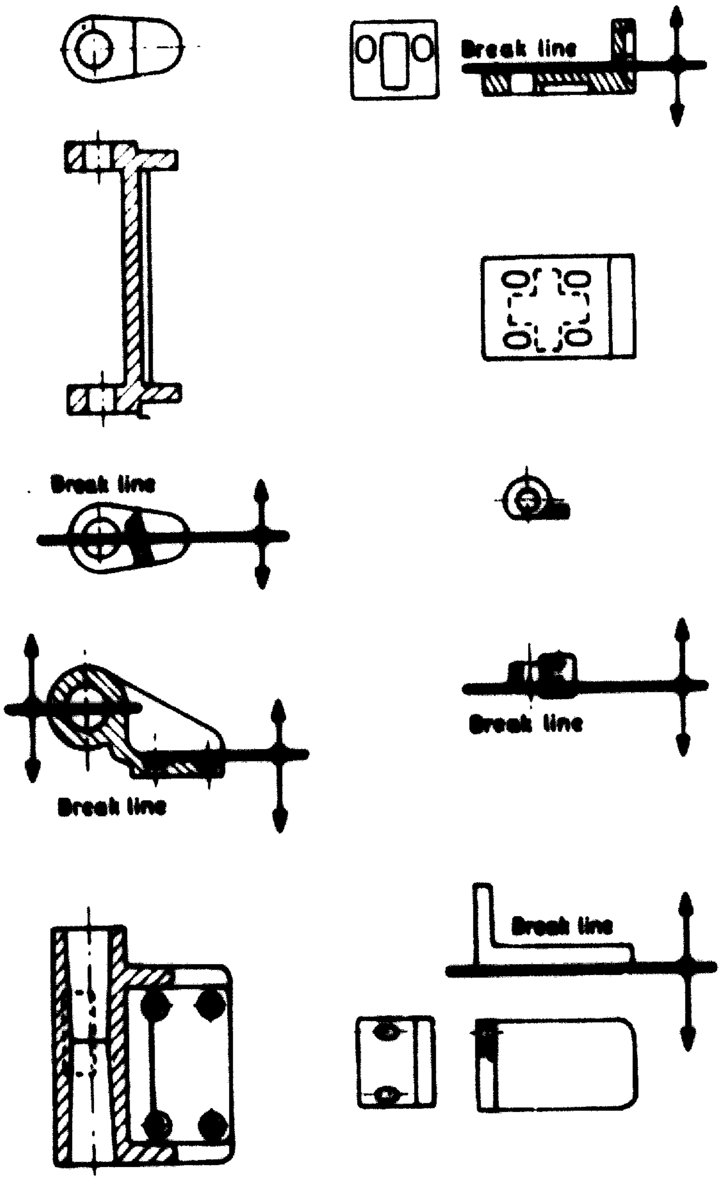


Figure 22. Castings with their parting surface running through their plane of greatest area

Figure 22 shows a group of parts made up of castings whose break line or parting surface runs through their plane of greatest area and which are formed in both the movable and the fixed parts of the die or mould inserts.

The parts in the group all have co-axial side apertures. The finished parts are stripped from the die or mould by ejectors, and side injection is used for casting.

A group-adaptable mould is shown in figure 23a. The unit consists of a fixed plate 1 with wedges 7 which serve to maintain in a fixed position the movable blocks 6 which have shafts 5 connecting them to hydraulic cylinders mounted in the unit. These cylinders actuate the cores which form the hollow spaces in the casting (items 6 and 7 in figure 23b).

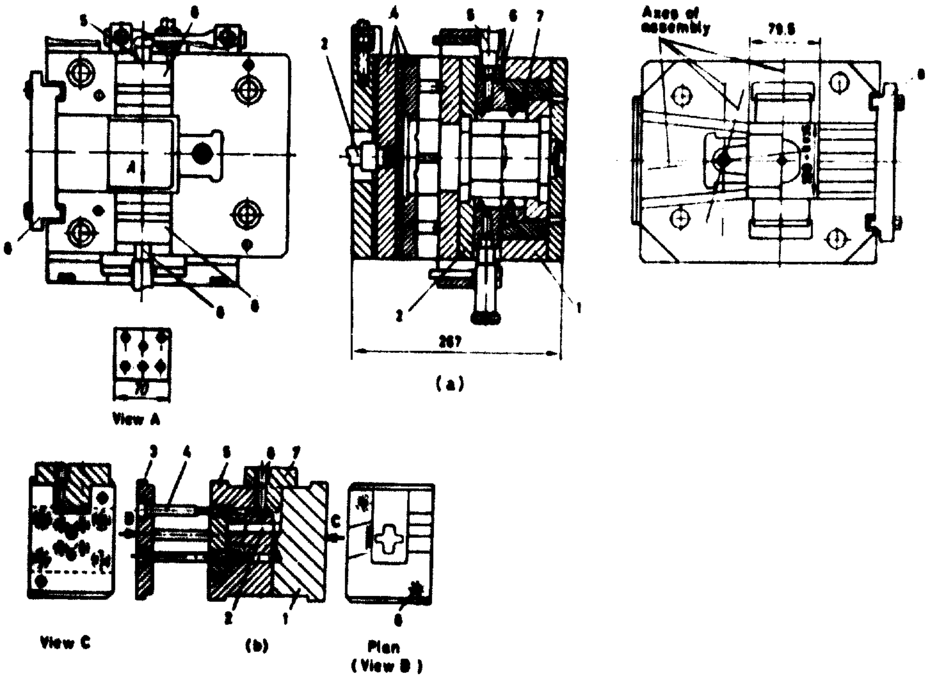


Figure 23. Group-adaptable mould

The movable part of the unit shown in figure 23a consists of a plate 2 with slots to guide the blocks 6 and a system of plates 4 carrying the ejectors, which are fitted with shafts 3 connected to the hydraulic equipment and which strip the cast part from the hollows in the die or mould inserts.

Figure 23b shows the design of the remaining die or mould inserts. These inserts consist of a fixed die or mould 1 with guide posts 8, a movable die or mould 5 with cores 6 and 7 which are connected with the movable block 6 of the die or mould assembly (Figure 23a), and a punch 2 and ejector 4 mounted on a plate 3.

CLASSIFICATION OF PARTS TO BE MADE OUT OF PLASTIC

Group operations for the production of parts from plastics are carried out in two stages:

(a) The classification of the parts and the formation of groups.

(b) The development, for each group of parts, of designs for group-adaptable mould units with exchangeable mould inserts.

Parts which are to be manufactured out of plastics must be classified with an eye to the design and production features of the parts, as well as to the design of the moulds. The main features determining the group to which a part belongs are:

(a) The type of materials and the dimensional accuracy required for the part;

(b) Its over-all dimensions;

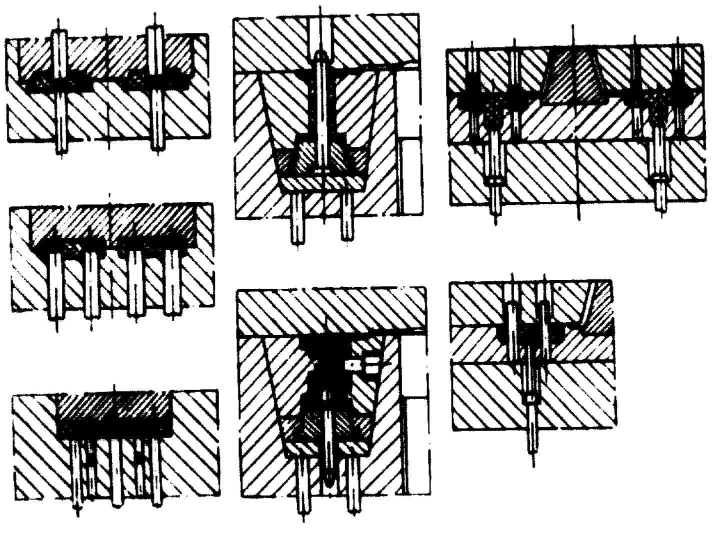
(c) The means of moulding, taking into account the process features of the material;

(d) The means of ejection and the location of the ejectors in the mould;

(e) The number and location of the break or parting lines of the mould;

(f) The number of inserted fittings, their shape and the way they are laid out in the part.

Examples of the classification of parts into groups according to these features will now be considered.



(a) Moulds with a single break line

(b) Moulds with horizontal and vertical break lines

(c) Moulds with one break line, the casting is ejected upwards

Figure 24. Possible layouts of parts in moulds

Figure 24 shows several possible layouts of parts in moulds which determine the group to which the part belongs.

Group 1: single horizontal break or parting line in mould; part ejected from the die, i. e. lower half of mould; inserted fittings can be moulded in the part only if placed in the die; accuracy of dimensions perpendicular to the plane of the break or parting line cannot be higher than the fifth class of accuracy; this group may include parts such as plates, blocks, panels, handles.

Figure 24a shows examples of parts in Group 1 produced in a mould with a single break or parting line; the bottom drawing shows a part with a moulded-in insert which is located in the die (bottom part of the mould) before moulding.

In Group 2 the moulds have two or more break or parting lines (one of them vertical and the remainder permitting the removal of the mould inserts in a horizontal direction); after the removal of the mould inserts in the horizontal plane, the parts remain in the inserts until they are removed from them outside the press; parts can be manufactured with any moulded-in fittings which do not hinder the dismantling of the mould inserts; this group includes parts such as spools, shells, plugs with moulded-in fittings, and so on.

Figure 24b shows examples of the manufacture of parts in Group 2 where both horizontal and vertical mould break or parting lines are required. In this case, a tapered split mould insert is used, the parts are produced by transfer moulding, and the locking force is downwards.

In Group 3 the mould has one horizontal break or parting line; ejection of parts from the die is upwards; parts with moulded-in fittings running right through them can be produced; the accuracy of dimensions perpendicular to the break or parting line is not higher than the fourth class of accuracy.

Figure 24c shows examples of parts in Group 3 such as blocks and plates, incorporating a large number of moulded-in fittings located both in the lower and the upper half of the mould. This means that it is necessary to use transfer moulding and to design the moulds accordingly.

Group-adaptable moulds and inserts for compression moulding, transfer moulding and injection moulding

The basis of the design of group-adaptable moulds is to produce a standard group-adaptable (universal) mould unit with exchangeable mould inserts.

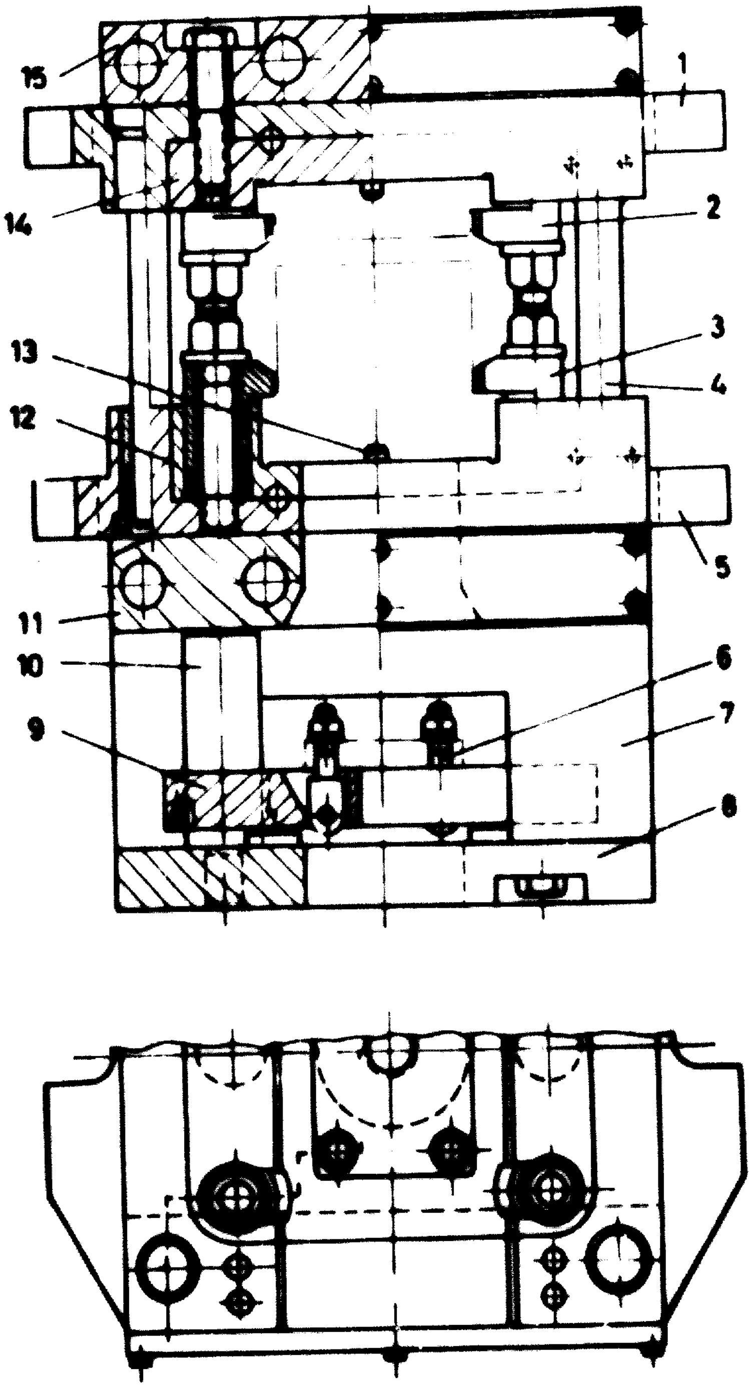
The first step in the design of a mould consists of the determination of its main operating characteristics:

(a) The method of moulding the parts;
(b) The layout of parts giving the most efficient moulding operation;
(c) The number and direction of break or parting lines needed;
(d) The method of operation of the mould (whether it is to be a fixed or removable mould);
(e) The method of ejecting the finished part and the location of the ejectors;

(*f*) The type of feed chamber to be used;
(*g*) The number of sockets or cavities;
(*h*) The layout of the feed system (if transfer or injection moulding is to be used).

A very wide variety of designs of group-adaptable (universal) mould units are now in use, because of the different means of moulding and the insufficient standardization done so far.

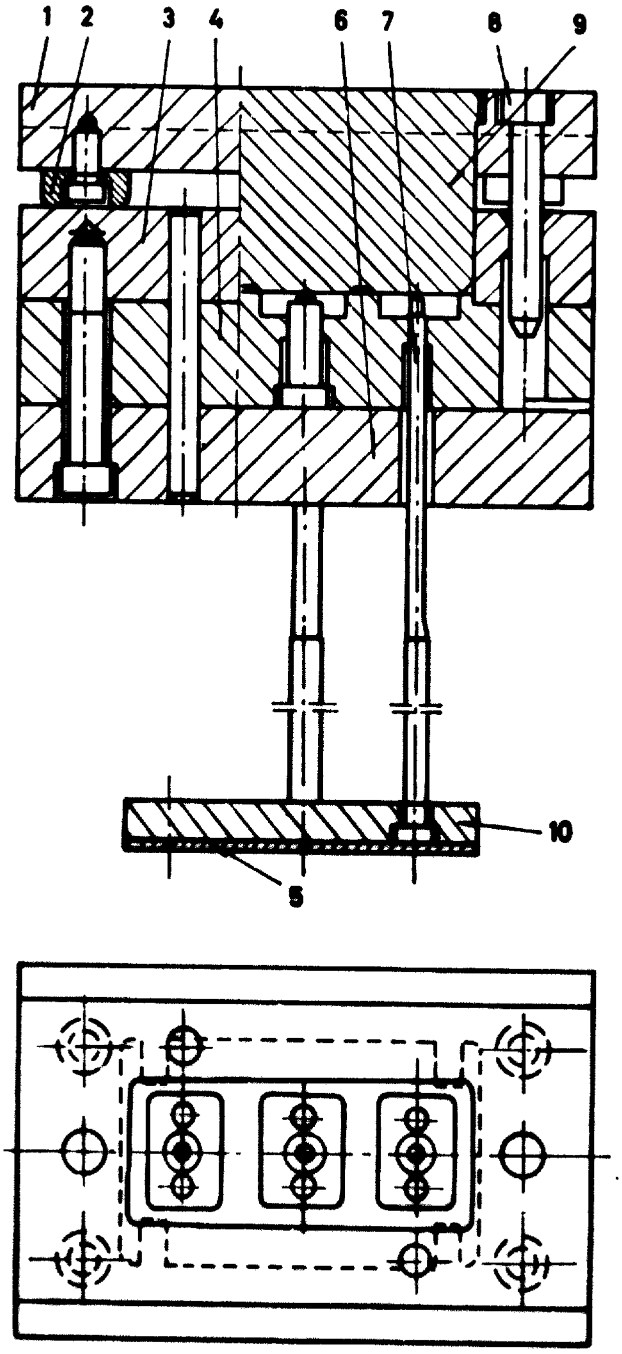
Below are some examples of group-adaptable mould units and inserts for (*a*) compression moulding, (*b*) transfer moulding, and



Part plan

Figure 25. Group-adaptable unit for compression-moulding with exchangeable mould inserts

(*c*) injection moulding. Methods (*a*) and (*b*) apply only to thermosets, and method (*c*) only to thermoplastics.



Plan

Figure 26. Exchangeable mould inserts for the unit in figure 25

(*a*) *Group-adaptable moulds and inserts for compression moulding*

Groups including parts such as panels, plates, rings, and so forth, can be produced from thermosetting plastic materials by compression moulding in a mould with a single horizontal break or parting line. The finished part is then ejected from the mould by the ejectors.

Figure 25 shows the design of a group-adaptable unit for compression moulding with exchangeable mould inserts. The unit consists of two parts: a lower part and an upper part; the lower part is fastened to the bottom table or bolster plate of a hydraulic press, while the upper part is fastened to the ram.

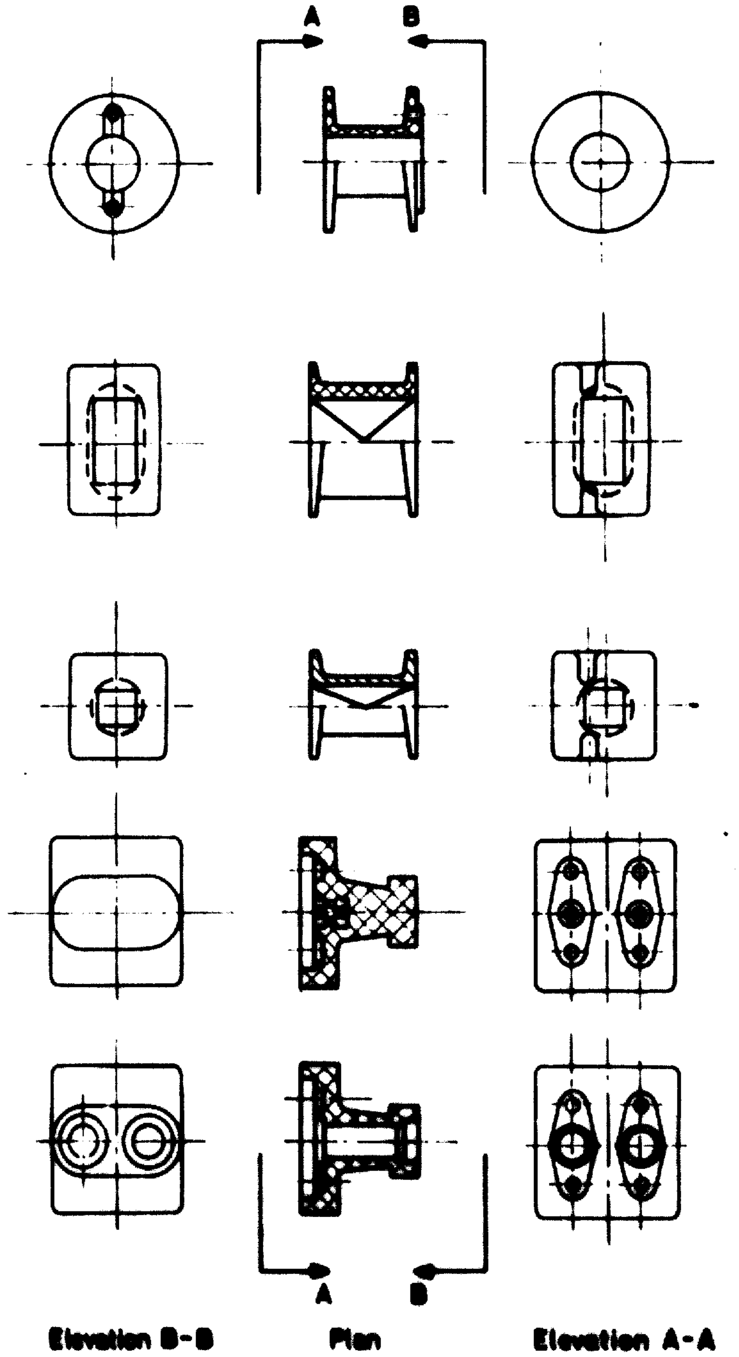


Figure 27. Castings with vertical and horizontal break lines

The upper part consists of a punch holder 1 running on guide posts 4, a heating plate 15, clamps 2 and a top bolster 14. The lower part consists of the die holder 5 with clamps 3 and a bottom bolster 12; a heating plate 11 is mounted on spacing blocks 7, a bed plate 8 and an ejection mechanism 9 which moves on pillars 10 and has a threaded hole over the press ejector.

The unit uses the slide-in system of fastening the mould inserts, so that the inserts can be changed without taking the unit out of the press. Both parts of the unit have rectangular grooves cut in them in which the exchangeable mould inserts are slid up to the stops 13 and are then fastened with the clamping lugs 2 and 3. The insert plates are connected with the ejectors by pivoted links 6 mounted on the ejector plate 9 which is connected by a shaft with the corresponding mechanism on the press. The exchangeable mould inserts for this unit are shown in figure 26.

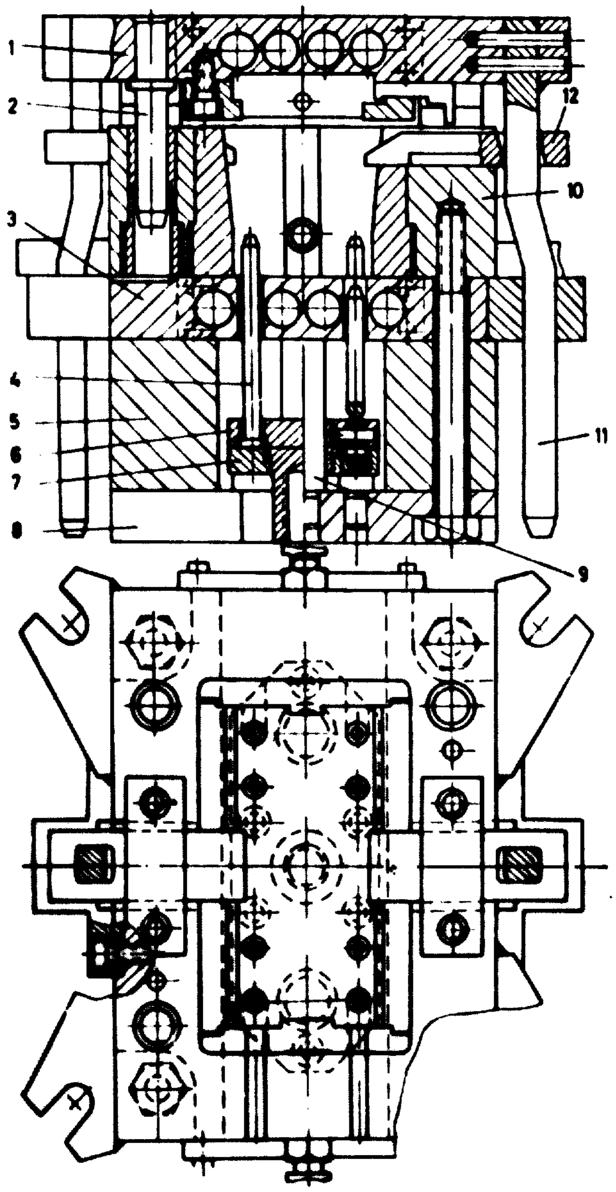


Figure 28. Group-adaptable tapered and split unit for casting the parts shown in figure 27

The mould insert consists of an upper plate 1 with a punch 9, pressure pads 2, guide posts 8, a lower plate with a feed chamber 3, the die 4 with the moulding cavity cut in it, a base plate 6 and plates 10 and 5 carrying the ejectors 7.

In the case under consideration, because of the small dimensions of the parts, the mould inserts are inserted in the slide-in components.

For large parts, however, the mould inserts may be of the same dimensions and shape as the slide-in components, and may replace them.

The advantage of this design is that the unit itself is not taken out of the press and therefore does not cool down; therefore the mould inserts can quickly be changed and work can proceed on the manufacture of other parts of the same group.

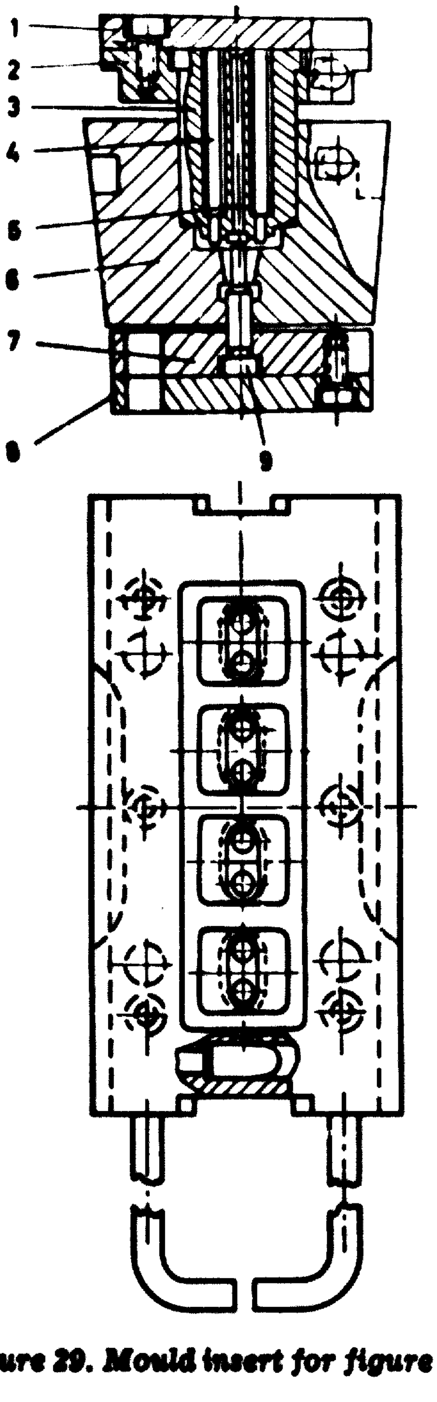


Figure 29. Mould insert for figure 28

A different design of unit is used for moulding the group of parts shown in figure 27, where both vertical and horizontal break or parting lines are required in the mould inserts. Figure 28 shows a general view of such a group-adaptable tapered and split unit, while figure 29 shows a mould insert for it.

The unit in figure 28 consists of a foundation bar 8, punch pins 4, basic frame 5, heating plates 1 and 3, a surrounding plate 10, guide posts 2, pin-holding plate 6 and pin-supporting plate 7, which slide on posts 9 and have threaded holes over the ejector of the press. The mould insert (figure 29) consists of a base 7 with a plate 8, locating pins 9, tapered half-moulds 6, a punch-holder 2 with a plate 1 and a punch 3, and punch pins 4 and 5.

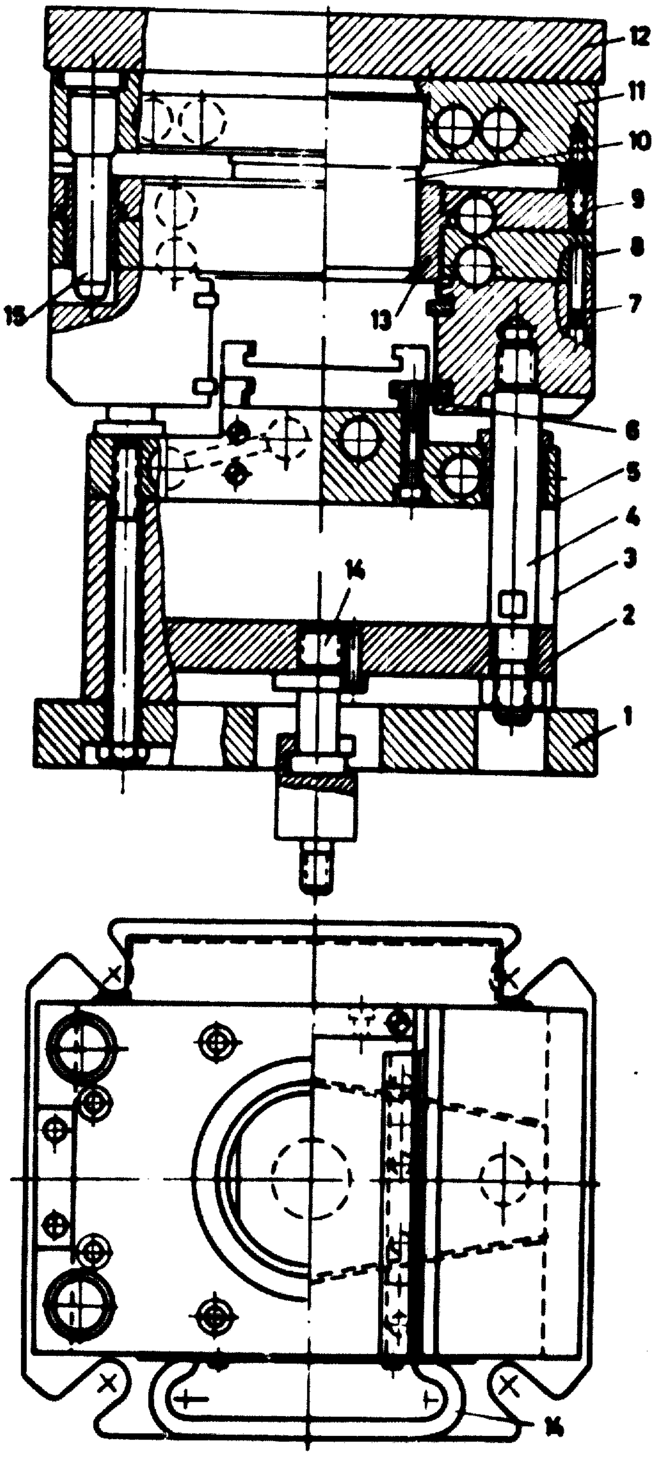


Figure 30. Transfer-mould unit with one or two horizontal break lines

In figure 28 the mould inserts are attached to the unit in the following manner: the upper part of the mould insert is inserted in a groove in the punch holder of the unit and fastened there, while the lower part of the mould insert is fastened in the die holder of the unit. In the manufacture of the parts, the loading of the material to be moulded and the moulding operations themselves are done in the normal manner, the locating fingers 12 of the unit mating with grooves in the half-moulds under the action of the cam bars 11.

(b) Group-adaptable moulds and inserts for transfer moulding

Transfer moulding must be used where *(i)* the parts to be manufactured have moulded inserts or core pins running right through them and located in both halves of the mould; *(ii)* when the shape of the castings necessitates additional dismantling of the mould inserts; and *(iii)* when the dimensions of the parts in a plane perpendicular to the break or parting line of the mould must be of high accuracy (up to the fourth class).

Group-adaptable transfer moulds are divided into moulds with working pressure from below and those with working pressure from above. Moulds with working pressure from below can have tapered split moulds inserts with vertical break or parting lines.

Figure 30 shows the design of a transfer-mould unit incorporating mould inserts with one or two horizontal break or parting lines (two or three insert plates). The design of the unit enables the mould inserts to be separated, using the force of the lower cylinder, without the use of additional pressing-out equipment.

The lower part of the unit consists of a plate 1, two spacers 3, a heating plate 5 lying on the spacers, and two guides 6. The middle part of the unit consists of the feed chamber or pot 13 located within the plates 8 and 9 which are screwed to the two beams 7, two tension rods 4 and a movable plate 2 with a shaft 14 actuated by the lower cylinder of the press. The upper part of the unit consists of a plate 12, the plunger holder 11, the plunger 10 and the guide posts 15.

This design of transfer unit can be used for moulding parts up to 35 mm high, using moulds of minimum weight. The feed holes can be located anywhere in the area of the feed chamber or pot, so that the feed channels can be of minimum length, thus improving the quality of the moulded parts. Moreover, with such a design two mould inserts can be used and they can quickly be exchanged for different ones. By using such a design of mould unit, it is possible to do without splitters (splitting jigs) and emptying equipment, thus freeing a considerable production area.

A typical mould insert for this transfer-moulding unit is shown in figure 31. Depending on the design, shape and dimensions of the part to be moulded, the mould inserts can be of various designs and have different numbers of sockets or cavities, but their over-all dimensions and shape must fit the mould unit.

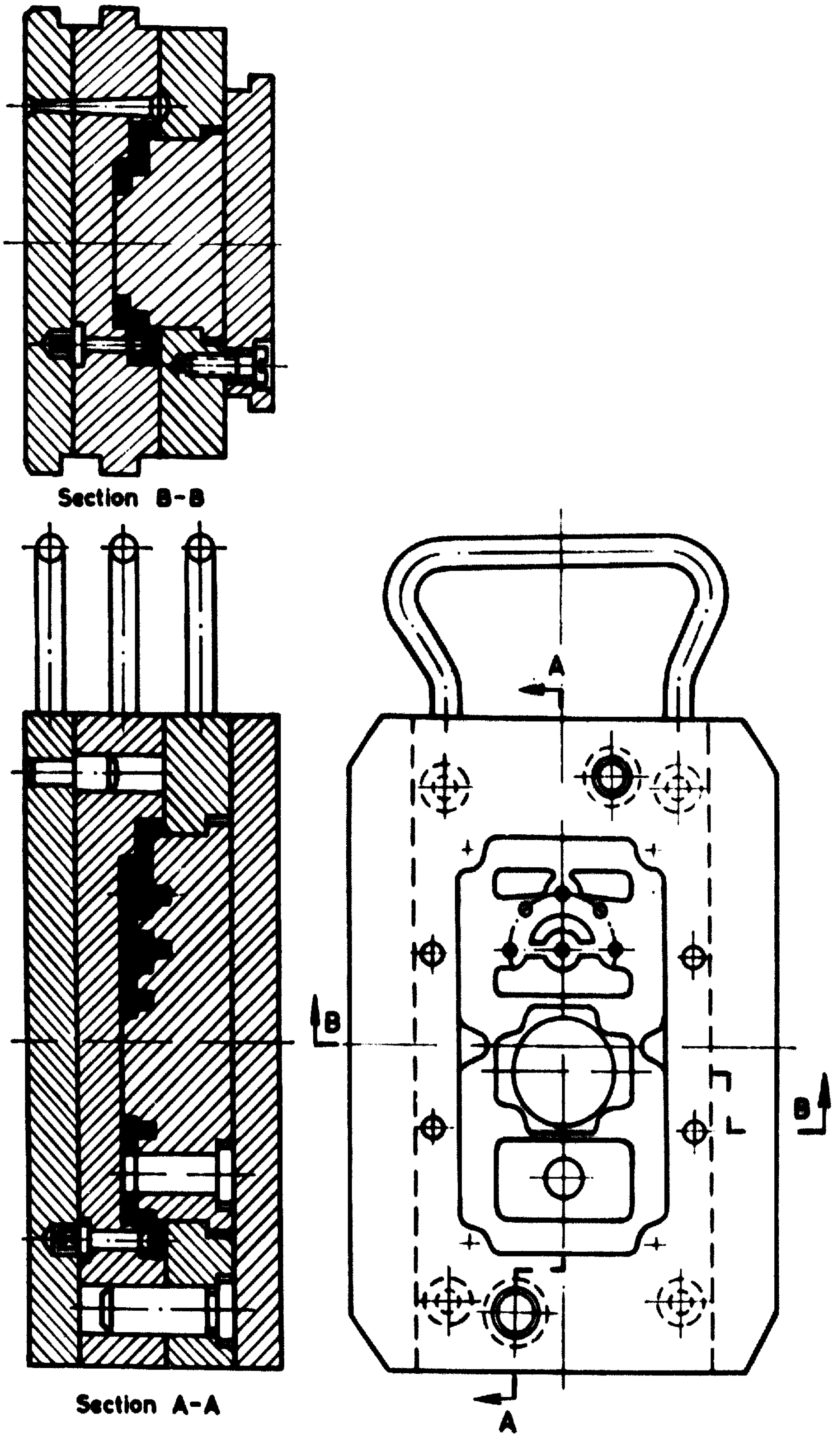


Figure 31. Mould insert for transfer mould unit of figure 30

(c) *Group-adaptable moulds and inserts for injection moulding*

Group-adaptable units for the injection moulding of parts from thermoplastics in injection moulding machines are usually of the fixed type.

Figure 32 shows an injection mould. The unit consists of a fixed plate 5 with a sprue bush, guide posts 4 which locate the mould inserts precisely, and a movable plate 1 with guides 3. The mould inserts are set up by moving them along the guides to the stop 2, and they can be changed without moving the unit.

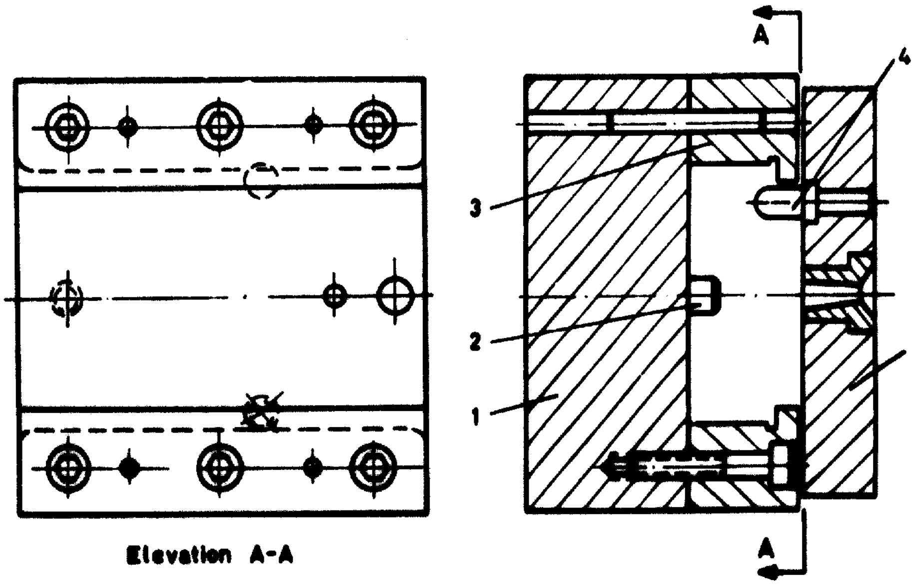


Figure 32. Injection mould

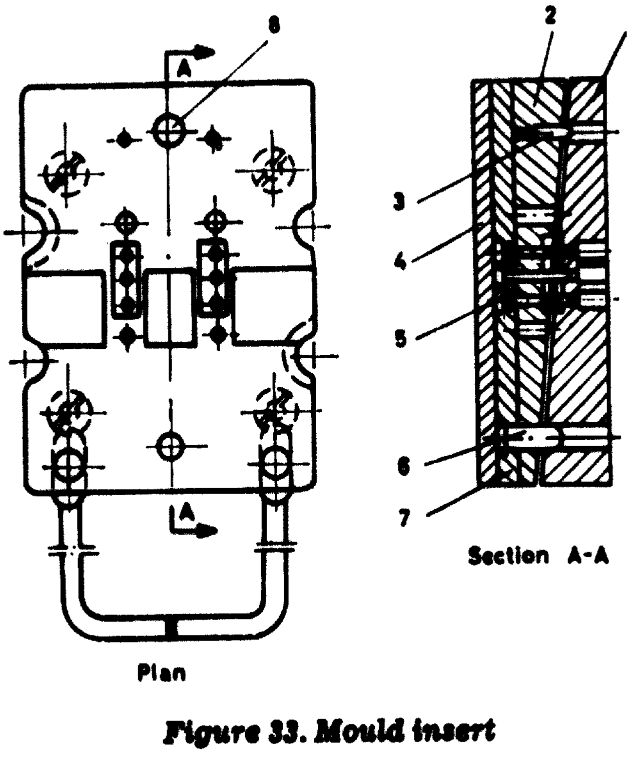


Figure 33. Mould insert

The mould insert shown in figure 33 consists of mould halves 1 and 2, a pressure plate 4, and a plate 7 with locating pins 5. The accurate mating of the mould halves is ensured by the guide posts 8 and 6. The plate which forms the base for the parts is located by the pin 3 and is sealed without danger of leakage when the machine is closed. Side cuts are made in the moulds and plate for the purpose of opening the mould.

Dismantling is carried out on the bolster plate in the following manner: the upper mould half is removed first, then the lower mould half, from which the part is ejected by means of suitable equipment.

ECONOMICS OF MULTI-PURPOSE EQUIPMENT

The economic effect of a unit of equipment is the saving per part, determined by comparing the cost of manufacturing the equipment with the savings in direct wage payments (through reduction of auxiliary, make-ready and clean-up labour) which can be achieved with the equipment.

The reduction, e', in the labour required for one part-operation is given by the formula:

$$e' = E_1 - E_2 \qquad (1)$$

where:

E_1 = amount of labour required for one part-operation before the use of the new equipment, and

E_2 = amount of labour required for the same part-operation using the new equipment.

When one type of equipment is replaced with another more efficient type, the amount of labour required is determined similarly.

Savings, e, in direct wage payments per part, achieved with the new equipment are expressed by:

$$e = E_1R_1 - E_2R_2 \qquad (2)$$

where:

R_1 and R_2 = piece-work rates for the operation in question before and after the use of the new equipment.

The yearly savings obtained with the new equipment can be expressed as follows:

$$P \geq DN \qquad (3)$$

where:

P = yearly cost of operating one item of equipment;

D = economic effect of the use of the new equipment, and

N = number of parts produced in a year.

It is assumed in this case that the same basic production machinery is used both before and after introduction of the new equipment.

If the amount of money spent on making the new equipment is the same as the savings achieved by using it for making the parts scheduled in the annual production programme, we have the equation:

$$P = DN \tag{4}$$

This equation states the maximum permissible annual expenditure on the manufacture of the new equipment for the production programme.

It follows from this that the minimum production schedule N_{min} at which the expenditure on the manufacture of the equipment will be covered, will be:

$$N_{min} = \frac{P}{D} \tag{5}$$

Accordingly, the economic effect of the equipment in the manufacture of the part in question is:

$$D = \frac{P}{N_{min}} \tag{6}$$

The total economic effect D_{tot} which will be derived from the introduction of one piece of equipment of this type will therefore be equal to:

$$D_{tot} = D\,(N_{s} - N_{min}) \tag{7}$$

where:

N_{s} = actual annual production schedule.

Where it is necessary to compare two types of equipment which differ in effectiveness and cost, the following formula can be used:

$$N_{K} = \frac{P'' - P'}{D'' - D'} \tag{8}$$

where:

P', D' = cost and savings for the less expensive type of equipment;

P'', D'' = cost and savings for the more expensive equipment; and

N_{K} = critical production schedule for which the types of equipment being compared have the same economic effect.

For an annual production schedule greater than N_{K} the use of the more expensive type of equipment will be more advantageous.

Figure 34 shows curves comparing cost and savings. The critical production schedule N_{K} corresponds to the point of intersection of the curves A and A' representing the total economy for the two types of equipment being compared. Curve A shows the saving achieved with the equipment which is lower in first cost, but which is less efficient in use, while curve A' represents the saving achieved with the more expensive equipment.

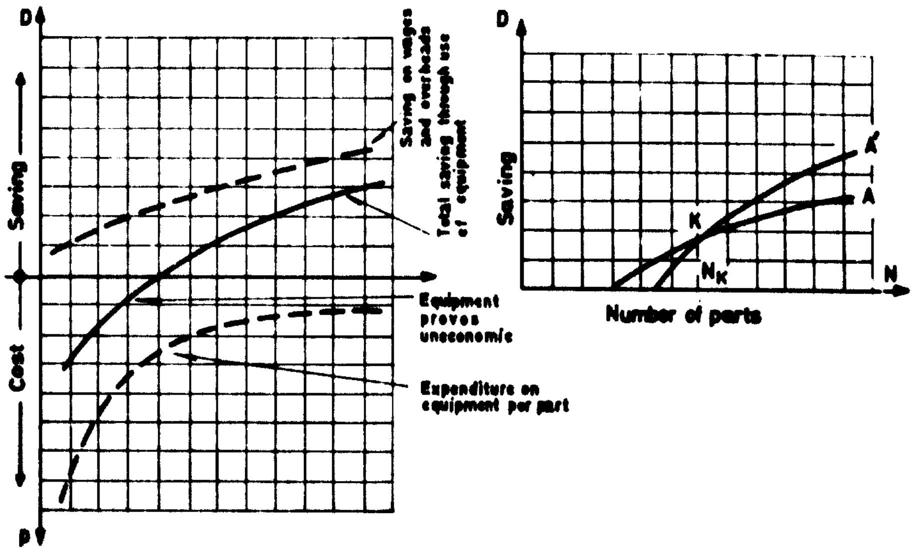


Figure 34. Curves comparing cost and savings

To determine the effectiveness of equipment, a nomogram such as that in figure 35 may be used for solving the following problems:

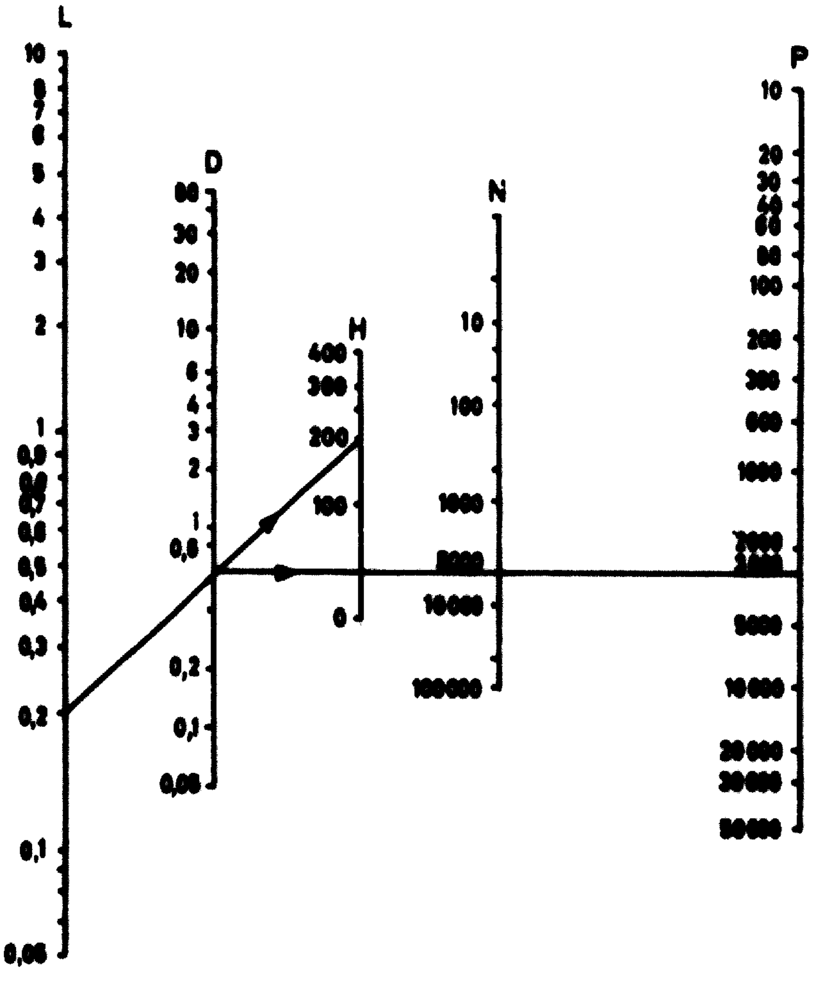


Figure 35. Nomogram for determining cost effectiveness of production equipment

L H D
or
D N P
or
P D N

L = direct wage payments
D = saving
H = overhead costs
N = number of parts
P = cost of equipment

1. Determination of the maximum permissible annual expenditure on a single type of equipment, as a function of the savings it achieves;
2. Calculation of the economic effect of using a given type of equipment, for a known annual expenditure on such equipment and a given volume of production;
3. Determination of the minimum saving on direct wage payments through the use of a given type of equipment if the annual expenditure on the equipment, the production schedule, and the level of overhead expenses, are known; and
4. Calculation of the production schedule for a given part which will cover expenses on equipment and will bring about a given saving in direct wage payments.

The amount of labour needed to produce parts with different equipment can be determined by the standardization of operations.

When group production methods, which permit the use of group-adaptable (GPN) and universal (UNP) exchangeable-component equipment, are used in a plant, the savings made with the equipment must be calculated.

A group may contain different kinds of parts which are produced in different numbers, and it may be profitable to use special equipment for making some parts. It is therefore necessary to establish whether or not it would then be preferable to use group-adaptable equipment.

The solution of this problem amounts basically to a comparison between the economic results of the use of special equipment and the results achieved by replacing it with group-adaptable or universal equipment with special exchangeable components. The following inequality may be used for this calculation:

$$\left\{D_{gr} - \left[(A^{a}_{gr} + A^{D}_{gr})\, S_{gr} + (A^{a}_{N} + A^{D}_{N}) \sum_{1}^{m} S \quad \right]\right\} \gtrless \left\{D_S - (A^{a}_{S} + A^{D}_{S}) \sum^{m} S_S\right\} \tag{9}$$

where:

D_{gr} = total economic effect of producing an entire group of parts with group-adaptable equipment;

A^{a}_{gr}, A^{D}_{gr}, A^{a}_{S} and A^{D}_{S} = annual depreciation allowance and the cost of production corresponding to group-adaptable and special equipment;

A^{a}_{N}, A^{D}_{N} = annual depreciation allowance and the cost of production of the exchangeable components;

S_{gr} = cost of group-adaptable equipment;

S_N = cost of a single exchangeable component;

D_S = total economic effect achieved with the use of special equipment for the production of the entire given number of parts; and

S_S = cost of a single item of special equipment.

In this instance, each of the three expressions:

$$(A^a_{gr} + A^D_{gr})\, S_{gr};\quad (A^a_N + A^D_N) \sum_1^m S_N;\quad (A^a_S + A^D_S) \sum_1^m S_S \qquad (10)$$

represents the total of the corresponding expenditure for one year of operation.

The values of the coefficients A^a and A^D must be determined on the basis of practical factory experience.

For short runs, there is no advantage in preparing complicated special equipment. Parts are therefore frequently manufactured either with universal equipment or with the use of simple mounting and clamping elements such as clamps, blocks, etc. In such conditions, however, the use of group-adaptable equipment would be much more advantageous, because it is specifically designed for the production of a whole group of parts rather than one batch of identical parts.

In the case in question, the total yearly production schedule N will consist of the outputs N_1, N_2, etc. of each part in the group:

$$N = \sum_1^m N_n \qquad (11)$$

In the graph shown in Figure 36, the cost of special-purpose equipment for a single part in a given production schedule is represented by a straight line parallel to the horizontal axis of the graph. If such parts are manufactured with group-adaptable equipment with exchangeable components, however, the picture changes.

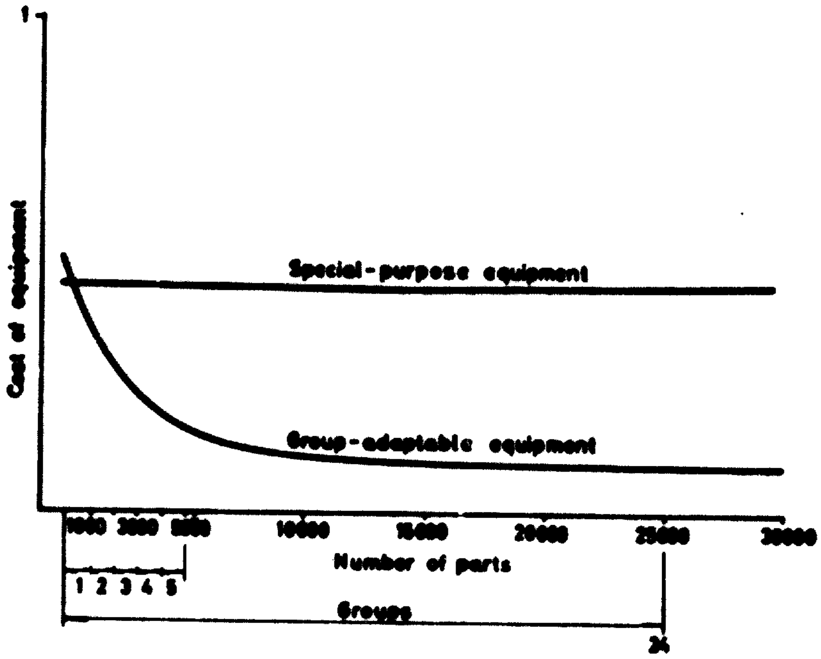


Figure 36. Graph of cost of group-adaptable equipment against number of parts and number of savings

When a large number of types of parts, and consequently also a larger quantity of parts are to be produced, the cost of group-adaptable equipment will amount, for each individual part, to:

$$P_{gr} = \frac{S_{gr} + \sum_{1}^{m} S_N}{N_{tot}} \tag{12}$$

where:

P_{gr} = annual cost of group-adaptable exchangeable-component equipment per individual part;

S_{gr} = cost of the group-adaptable equipment; and

S_N = cost of individual exchangeable components.

Figure 36 clearly shows how expenditure on group-adaptable equipment varies with increase in the total production schedule of all types of parts in a group.

In introducing group-adaptable equipment its throughput capacity should be also taken into account. If a group contains a considerable number of types of parts, it is sometimes necessary to put into operation not just one, but several duplicate items of equipment.

Furthermore, in order to unify the equipment, it is necessary to standardize the basic (fixed) components of group-adaptable equipment. If this is done, such standardized components can be made in batch production. This not only considerably reduces the cost of the components, but also reduces the amount of time and money needed to start production of the parts which the equipment is designed to manufacture.

THE SELECTION OF THE BEST METHOD OF GROUP STAMPING

When two or more otherwise equally attractive stamping methods are available, the one selected is usually that which gives the lowest production cost. The following formula is used for calculating the production cost C_T:

$$C_T = M + Z + O + Y + E \tag{13}$$

where:

M = cost of the material from which the part is made, including waste;

Z = wages of the stamping operatives and (if necessary) other production operatives, with additional payments and deductions;

O = expenditure on the operation and amortization of the punches and dies and other equipment;

Y = expenditure on the setting up and adaptation of presses and dies;

E = expenditure on the operation of the presses (overhaul of presses and cost of electric power).

This formula can be used for separate operations, for several operations together, or for a whole production cycle. All the components of the formula refer to the manufacture of one part (or, if preferred, 100 parts). Their values for different methods of group stamping are determined either from generally known standard values (cost of materials, wages) or from other figures.

The cost, O, of the operation and amortization of the punches and dies is calculated from:

$$O = \frac{F + P}{N} \tag{14}$$

where:

F = cost of making the die unit;

P = expenditure on the overhaul and sharpening of the die unit;

N = number of parts manufactured with the die unit before it is written off.

The cost of making a die unit can be determined approximately from the formula:

$$F = (K_T + K_G)(A + B) + d \tag{15}$$

where:

K_T = a coefficient depending on the type of die, varying in value from 0.08 to 0.2;

K_G = a coefficient depending on the complexity of the working surface of the die, varying in value from 0.06 to 0.2;

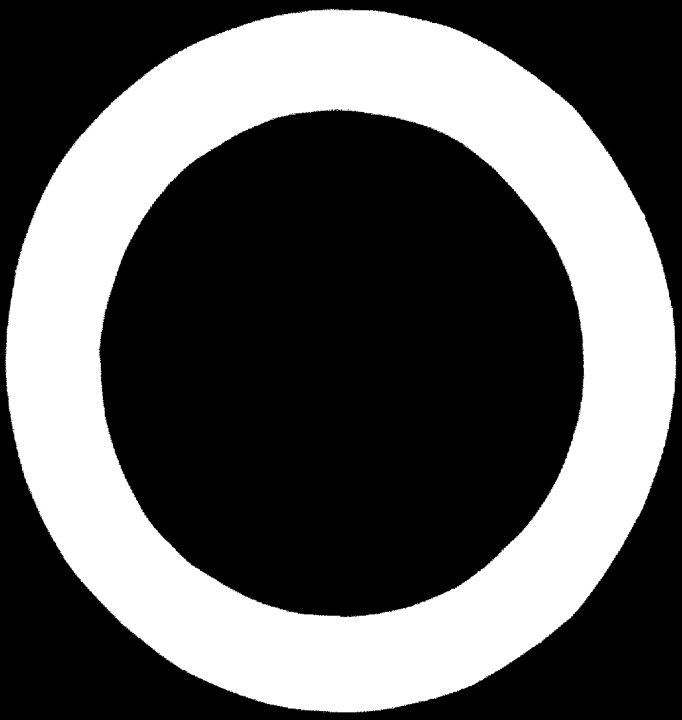
A, B = dimensions of the die and the punch in millimetres;

d = cost of the die set (for group-adaptable die units, $d = 0$).

The cost of overhauling and sharpening of a die unit generally averages 40—60 per cent of its cost of manufacture.

The number of parts which can be manufactured with a die unit before it is written off is taken as being equal either to the life, T, of the unit until it is completely worn out, or (if the number of parts required is less than T) to the number of parts which are to be manufactured with the unit in question.

From equation (13), the formula for C_T, it is possible to determine the quantitative limits for the effective use of various means of producing actual parts (the so-called "critical batch size").



THE DESIGN OF DIES FOR SMALL-SCALE PRODUCTION

E. A. Popov[*]

THE ORDINARY DIE UNIT for sheet-metal stamping in large-scale production consists of many parts.

All die parts may be divided into the following categories: the working member (punches or dies), accessories for attaching or guiding the working member, associate parts for attaching and guiding the stock sheet in the direction of the feed, ejecting mechanisms for forcing the stock out of the dies, associate parts for removing the workpieces from the die, and fixtures attaching the die to the press.

Because of the great number of parts, the accuracy necessary in assembling and operating the die unit, the amount of labour required for handling the die members, and the use of expensive materials for making die parts, dies are very costly. But their use is economic in production when they produce thousands of workpieces.

In small-scale production, however, it is advisable to use cheaper, simplified dies requiring less labour. Wide experience in the design and application of simplified dies in small-scale production has been accumulated by industry, and many types of simplified dies have been developed.

The main types of simple dies are: dies with guide plates, plate dies, banding dies, universal dies, and sheet dies (tweezers), all of which have metallic punches and dies. These dies and their technical possibilities are discussed below.

DIES WITH GUIDE PLATES

Dies equipped with a guide plate are mainly used as blanking dies; the guide plate serves also as a stripper. The most usual design is built with the upper die fitting loosely to the press slider. A die of this type is shown in figure 1. The press slider, when it is at the lowest point of its stroke, presses the punch that is attached to the

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stripper plate and is resting upon the flat stock. Because of the action of the slider, the punch enters the stock. Blanking is accomplished with the cutting edges of the punch and the die. The die unit is simple and its manufacture is not complicated. If the metal being blanked is comparatively soft, the punch and the die need not be heat treated.

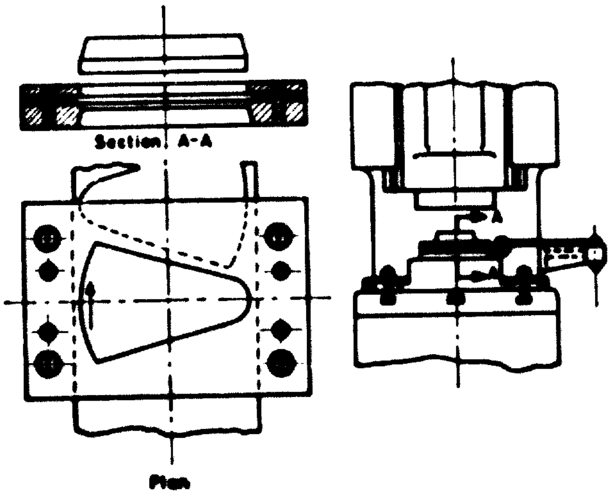


Figure 1. Die with a guide plate

This type of die may be successful in a number of instances in small-scale production. There are, however, two major disadvantages: *(a)* inaccuracy in positioning the punch with respect to the bottom die, resulting in inferior quality of the shears, and *(b)* inconvenience in handling the die caused by the difficulties in manipulating the punch.

PLATE DIES

The plate die is the type recommended for small-scale production. The working members are punches and female dies made of

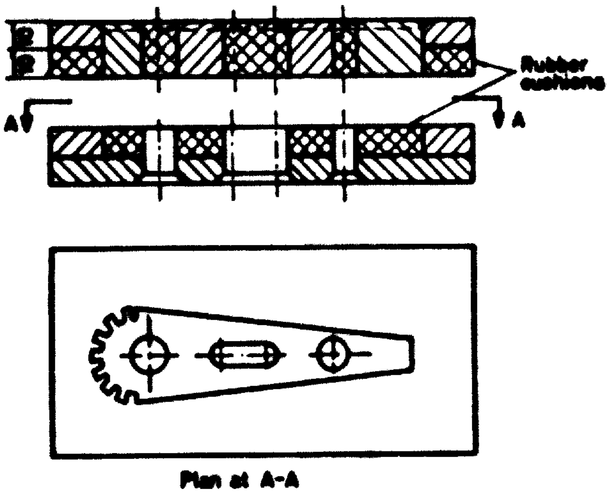


Figure 2. Plate die for simultaneous blanking and piercing

rolled steel plate. Rubber pillows are successfully used as knock-outs and strippers. Figure 2 illustrates a plate die for simultaneous blanking and piercing. As will be seen from the figure, the punches and dies are pressed into plates which serve as punch and die holders respectively.

Another modification of the working member of the plate die is shown in figure 3 (rubber strippers and knock-outs are not shown).

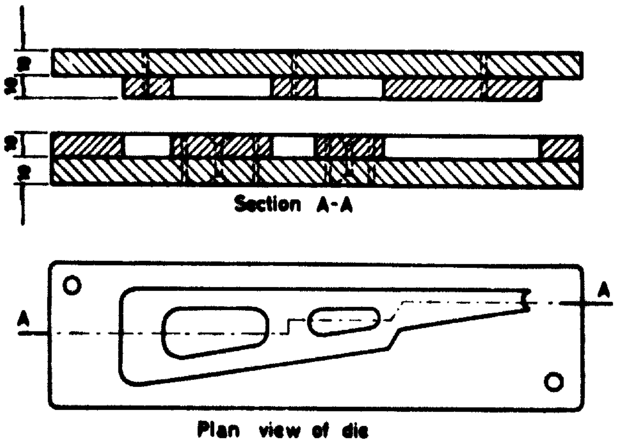


Figure 3. Modified working member of plate die

The punches and dies are riveted to the punch-holder and die-holder plates.

For stamping comparatively thin sheet material (<2 mm), the plates used for making punches, dies and punch holders may be approximately 8 to 10 mm thick.

The working part of the plate die is attached to the base plates of the die block, as shown in figure 4. The upper base plate is located by guide pins with respect to the lower base plate.

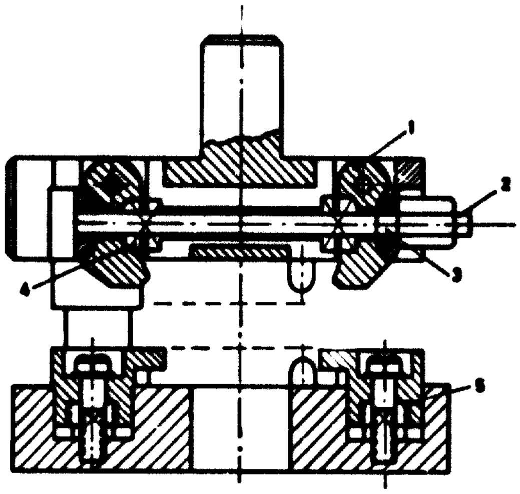


Figure 4. Attachment of the working member of a plate die in the die block

In the diagram, the upper punch-holder plate is attached to the upper base plate by cams 1 with the help of screw 2 and washer 3.

When idle, the cams are drawn apart by the spring 4. The lower die-holder plate is attached to the lower base plate by means of grippers 5. As the location of the punch and die-holder plates can be determined by guide pins attached to the base plate, it is possible to secure uniformity and some permanent circumferential clearance during stamping.

This method results in a sheared surface of high quality. When using such plate dies, the same block may be used for mounting dies for the production of many similar parts. Stamping may be accomplished on a push-through basis (the stamped part being pushed through an opening in the base plate).

More often, however, the working parts are used as shown in figures 2 and 3. The lower base plate, in this case, has no opening, and the stamped parts, at the back thrust of the slider, fall back into the strip (waste) and are removed from the die in the direction of the feed by the re-setting of the stock strip. Simple dies of this type lack guide facilities and stop pins to limit feeding steps. This necessitates an increase in the amount of allowance and, consequently, increases the amount of waste metal.

Plate dies are most often used for blanking and piercing. It is possible, however, to use these dies for other operations, such as burring, shallow forming, or drawing, provided that only a short working stroke is required.

BANDING DIES

Great hardness of the cutting edge, and sometimes simplification of die manufacture, are provided by banding dies. In these dies, the working elements of the punch and the bed die are made out of a steel strip 1 to 2 mm thick, tempered to Rockwell 45—55 hardness.

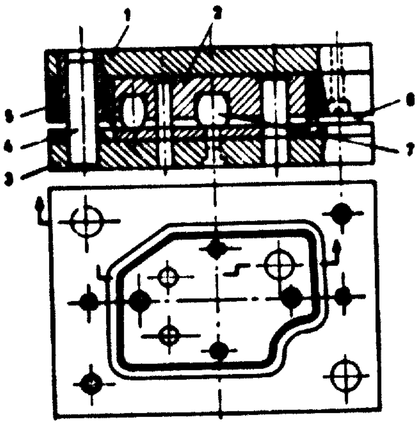


Figure 5. Typical bending die

Figure 5 illustrates a typical banding die. A knife-type female die is attached to plate 1 by a die holder 2. A blanking punch made out of steel plate is attached to base plate 3. The location of the upper member is secured by guide pins 4 and guide pin bushings 5. Stripping and knocking-out take place by rubber pillows 6 and 7.

On such dies, cutting is either by means of two opposing edges (blanking on a push-through operation, in which the blank passes into the die hole), or by means of a cutting edge against a solid surface. In the latter case, blanking takes place in the same way as in knife dies. The cutting part of the band is ground to an angle of approximately 30° and the cutting edge thickness is 0.8 of the stock thickness. Blanking on solid surfacing may take place on stocks of soft metals or non-metallic materials.

Banding dies with double cutting lips provide high quality products and permit blanking on comparatively hard materials (alloy steels) up to 5 mm thick.

One of the difficulties in the manufacture of banding dies is that of obtaining shaped contours with sharp corners which necessitate correspondingly sharp bending of the tempered band. Therefore, these dies must be limited to blanking parts of simple shape with large radii of curvature.

UNIVERSAL DIES

Universal dies are more complicated and expensive, but are, nevertheless, quite acceptable in small-scale production since they can be used for a number of different parts with some common features. These dies also consist of blocks, but these are more complicated than the blocks of plate dies. The complications result from the desire to increase versatility, safety, and accuracy in attaching the working tools in the block of the die.

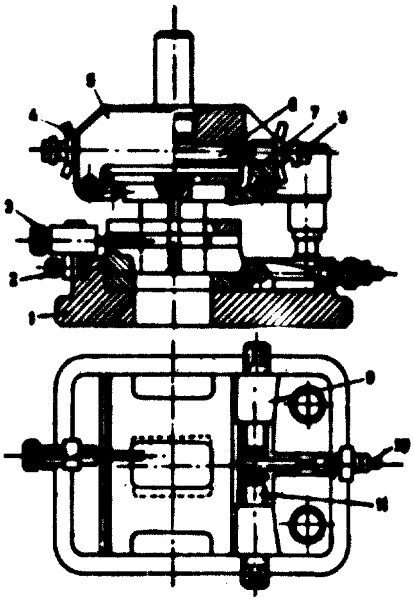


Figure 6. Block of a group-stamping die

The working members, and fixtures for them, are removable, and are designed for easy replacement and reliable attachment.

Figure 6 shows a block of a gang or group-stamping die. The upper part of the removable unit and the working tool are attached to plate 5 by means of grippers 7, screw 8, control rod 6 and counternut 4. The lower part of the unit is mounted on plate 1 with the aid of wedges 9 and the left-and-right-hand-threaded screw 11. A sprung control rod 10 holds the wedges against the solid surface.

These dies can provide blanking, piercing, shape forming, and shallow drawing operations. The die may be used also as a double-action follow die for piercing and blanking. In this case, besides the fixed-stop pin, a provisional-stop pin 3 controlled by nut 2 may be used. The block of the die is mounted on the press, and in proceeding to the handling of other workpieces, it is necessary only to replace the unit and adjust the new one on the block, which remains fixed to the press.

A somewhat more complicated design of die for group stamping is shown in figure 7. A buffering arrangement 9, 10, 11, and 12 is provided in the die so as to induce in the die the required force for holding the blank. In addition to this, in the upper part of the block, an arrangement is provided for knocking out the part by means of dowel 7 and plate 8 through shank 6. Dies of this type permit not only blanking and piercing operations, but also drawing and pressing, and simultaneous blanking and drawing as in the compound-die operations. Other parts are: 1, lower insert; 2, clamping lug; 3, guide post; 4, guide way; 5, upper plate.

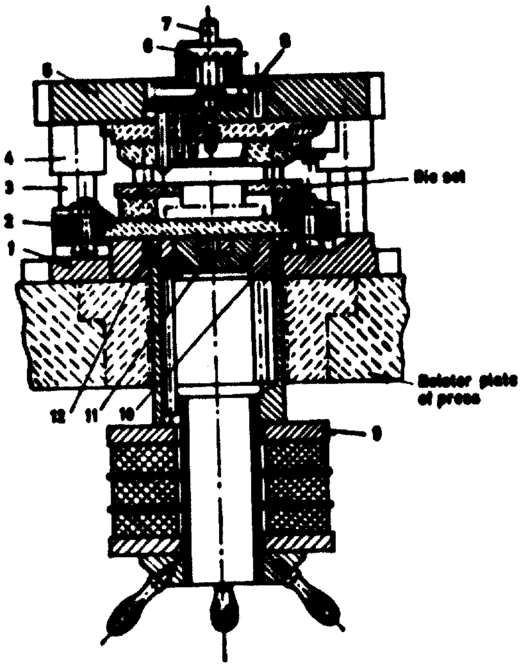


Figure 7. Another group-stamping die

Universal dies, in which the only removable part is the working tool, are most useful not only for cutting but also for shape-forming.

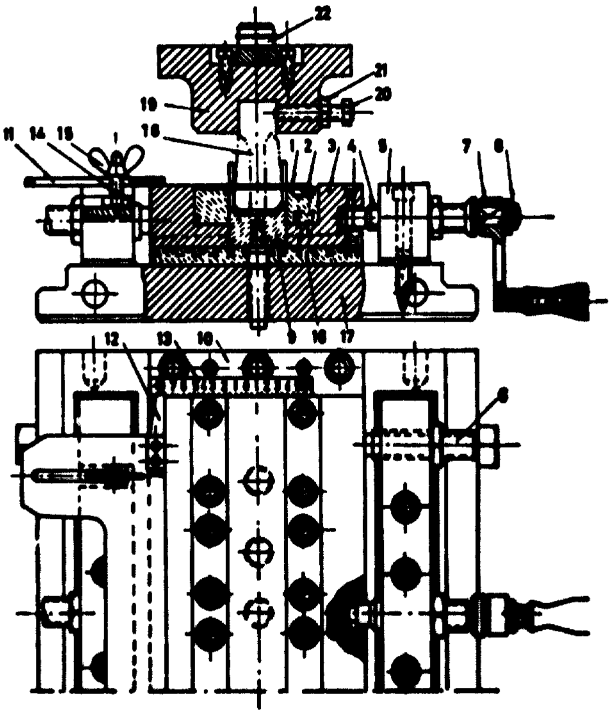


Figure 8. Universal bending die

Figure 8 shows a universal bending die developed for biaxial bending. The removable parts are a punch 18 and stripper plate 9. The space between the dies is adjusted by screws 6, which are attached by screws 14 and by wing nut 15, and aligned by the ruler 13. Other parts are: 1, die; 2, bolt; 3, die holder; 4, adjusting bolt; 5, bracket; 7, crank bearing; 8, screw; 10, plate; 11, adjustable guide; 12, pointer; 16, pad; 17, lower plate; 19, punch holder; 20, bolt; 21, locking nut; 22, precision-setting device.

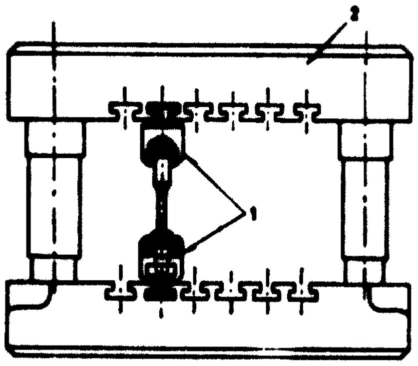


Figure 9. Block plates with punches and dies attached by grooves

Universal dies vary considerably in their design. Another use for them in small-scale production is in the manufacture of medium-sized parts which require the piercing of a number of holes or the creation of several hollows or throats.

The block plates of these universal dies are constructed so that punches and dies may be easily mounted on them at any point. Punches and dies 1 in figure 9 are attached by means of grooves ground in the plates 2 or by grippers. Plates with built-in electromagnetic blocks can also be used. A die equipped with electromagnets is shown in figure 10. Dies with working tools fixed by electromagnets are suitable for non-magnetic workpieces.

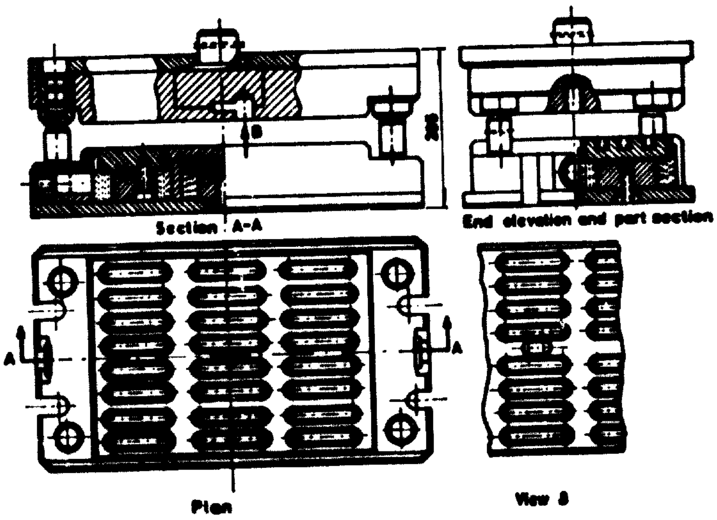


Figure 10. Die equipped with electromagnets

SHEET DIES

Sheet dies are the last design of simplified die to be discussed in this short review. These are simple, inexpensive dies made of sheet material slightly thicker than the sheet stock to be stamped. Sheet dies make it possible to obtain accurate workpieces of dimensions up to 2,000 mm × 1,000 mm, with thicknesses ranging from 0.3 mm up to 10 mm.

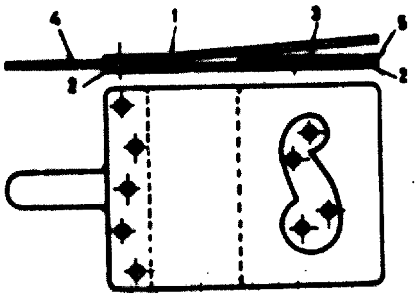


Figure 11. Sheet-blanking die

As shown in figure 11, sheet blanking dies consist of two plates welded or riveted together. One of the plates 1 (with a cut-out) is a die. The other plate 2 has a further plate 3 (which is the punch) welded, or otherwise attached, to it. The flexibility of the plates 1 and 2 provides the movement of the punch with respect to the die. To facilitate stripping the work or scrap from the punch, rubber strippers 5 are sometimes provided in the dies. For convenience in handling the die and to increase safety during stamping, a handle 4 is sometimes also provided.

The plates are made of either low-carbon steel or of chisel (high-carbon or alloy) tool steel, depending on the material to be stamped. For stamping soft sheet metal, the plates are not necessarily heat treated. For stamping hard materials, however, the plates must be heat treated. Plates of low-carbon steel are case-hardened and then tempered. Various methods of stamping by means of sheet dies are shown in figure 12.

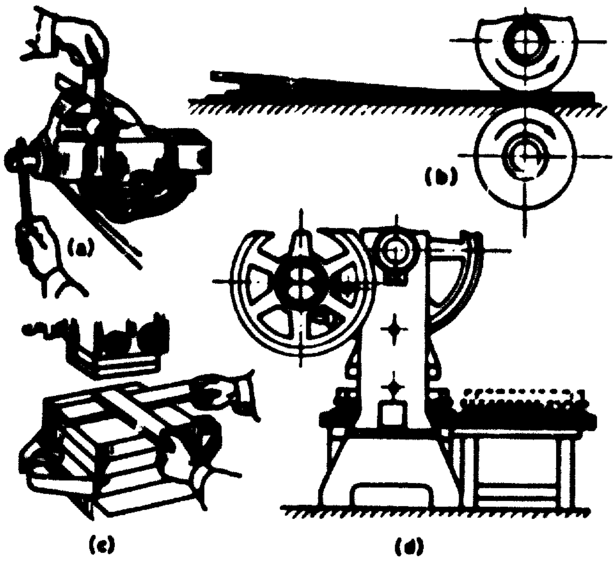


Figure 12. Various methods of stamping possible with sheet dies

As shown in figure 12 *(a)*, small, thin parts may be stamped without the use of machinery by gripping the sheet dies in a vice. For small and average-sized workpieces, the work may be stamped on an eccentric press *(c)* between the plates mounted on the table and attached to the press slider.

For stamping large workpieces (or when presses are not available) tandem rolls can be used *(b)*. The rotating rolls pull in the sheet die and blanking takes place as the punch and die pass between the rolls. In passing through rolls, the force required for blanking is considerably reduced.

Large, thick workpieces may be stamped with sheet dies of a somewhat different design, but similar to the plate die, using in this case, bigger crank presses *(d)*. Friction-screw presses and hydraulic presses may also be used.

If the design of the work is complicated, sheet dies with a compound action may be used. Blanking and piercing can then be done simultaneously. An example of such a die is shown in figure 13.

In this case, the die consists of three plates. The intermediate plate 3 is a female die. The blanking punch 2 is attached to the bottom plate 5. The punch serves also as a female die in piercing. The piercing die, 1, is attached to the upper plate 4. Figure 13 *(a)* and 13 *(b)* show the procedure for the blanking and piercing operations.

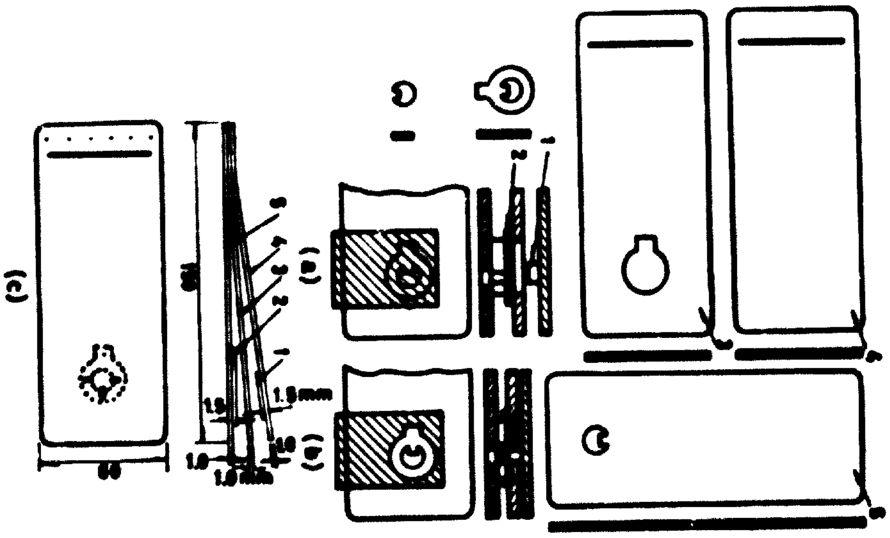


Figure 13. Sheet dies with a compound action for simultaneous blanking and piercing

Sheet dies may be used not only for stamping operations, but also for bending, forming, and shallow drawing. The sheet die shown in figure 14 is designed for drawing the component *(a)*. The original stock has previously been blanked out with a hole in its centre and is placed in the lower part of the die *(b)*. To provide alignment between the upper and lower parts, guide pins, 1, enter holes in the upper plate. The blank is located by means of the pilot, 2, which accommodates the hole in its centre.

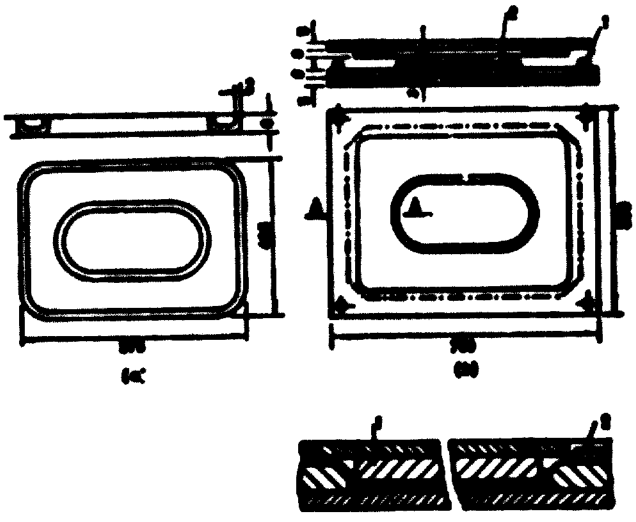


Figure 14. Simple sheet die for internal and external flanging

CONCLUSIONS

The foregoing analysis of simplified die design illustrates the opportunities for reducing the cost of stamping equipment to fit small-scale production.

The use of simplified dies, in addition to reducing the cost of the process, shortens the time needed for preliminary adjustment, eases the actual manufacture of dies, and decreases the need for complicated and expensive metal-cutting equipment. The use of these simple dies is most advantageous in developing countries.

Another factor which simplifies the manufacture of dies and reduces their cost is the substitution of new materials and processes for those which are customary in die manufacture. The new materials should cost less, be easier to handle, and stand up under repeated use. Cast dies or dies with plastic parts often meet these requirements.

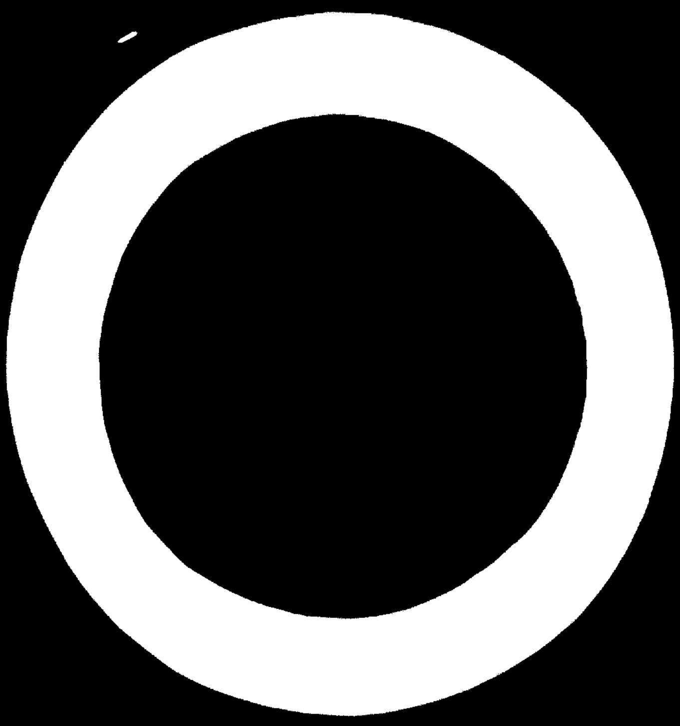
For cast dies, the working members (punches and dies) are often cast of specialized, easily-melted alloys. For stamping soft materials, zinc-base and aluminium-base alloys are often used. These alloys are fluid, their shrinkage is small, and their hardness is sufficient for small-scale production.

Precision casting, when used to produce the working members of dies, not only reduces metal costs, (the worn-out metal can be remelted), it also simplifies manufacture. The precision-cast punch or die requires little finishing, and this considerably reduces the volume of expensive machining work.

The replacement of metal by plastic in the manufacture of dies makes them lighter and simpler, and eases their assembly. The cost is also reduced if inexpensive plastic materials and polymers are available.

Cast dies are suitable for stamping average-sized and large parts. The use of plastic material for making dies may be advisable regardless of the size of the parts to be stamped.

The application of casting processes and the use of plastics in the manufacture of dies does, however, generally require additional facilities. It is therefore not always possible to make and use them in small factories.



THE ECONOMICS OF TOOLING

*I. Ham**

IN DESIGNING, selecting or buying any form of production equipment, economic aspects should not be neglected. Although the technical requirements and functional necessity of the equipment are of prime concern, its economic justification should equally be considered.

ANALYSIS OF TOOLING COSTS

In dealing with the economics of tooling, there are many types of problems, and many factors, to be considered. For a simple comparison of two different tooling setups, the saving, S, occasioned by the new improved method or tool will be

$$S = N(C_{u_1} - C_{u_2}) \qquad (1)$$

For the saving to be equal to, or larger than, the cost of the new tool

$$S \geqslant I_2,\ N \geqslant \frac{I_2}{C_{u_1} - C_{u_2}} \qquad (2)$$

where:

S = total annual saving,
N = number of pieces produced per year,
C_u = annual unit cost per piece with the old method,
C_{u_2} = annual unit cost per piece with the new method, and
I_2 = cost of the tool for the new method.

Where quantity production is involved, many other factors must be taken into account.

THE ECONOMICS OF JIGS, FIXTURES, DIES AND MOULDS

In arriving at the selling cost of any production item for which any form of special equipment has been designed and manufactured,

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* Pennsylvania State University

the costs of the special equipment must be completely amortized. This is particularly relevant to the design and manufacture of jigs, fixtures, dies and moulds. In assessing the manufacturing costs per part, allowance should be made for recovering cost out of earnings, and breaking even within the useful life of the equipment, or within the term of the production run, whichever is the shorter.

The methods of doing this can be found by applying a series of equations which answer the following questions:

1. How many pieces must be run to pay for a piece of special equipment, of given estimated cost, to show a given estimated saving in the direct labour cost per piece?
2. How much may be spent on the design and manufacture of a piece of special equipment which will show a given estimated unit saving in direct labour costs on a given number of parts?
3. How long will it take the proposed equipment, under given conditions and carrying certain fixed charges and overheads, to pay for itself?

All these questions assume that savings just balance the outlay of capital at the end of the period of amortization, reliance being placed on a higher profit margin after the expiration of this period. How to obtain a bigger profit during the period of amortization (which necessarily extends the period) is expressed by:

4. What additional profit will be earned by a piece of special equipment of given estimated cost for an estimated unit saving in direct labour cost for a given output?

If money is to be made available for the equipment, account should be taken of the loss of interest on the money which could otherwise be invested, or of the amount of interest which must be paid for its loan. Account should also be taken of the costs of insurance, upkeep (routine maintenance and repairs), depreciation, and setting up.

If, within the amortization period allowed or calculated, the special equipment ceases to be used, either because of the end of the production run, or because the equipment is being superseded by other equipment, the balance of its cost should be taken into account in subsequent calculations involving further production runs.

The first approach is to consider the break-even point at which two methods are of equal cost, or where the annual operating savings equal the total fixed charges and set-up costs for the period considered, as given by:

$$(S_d + S_o + S_p) = C_t\,(R + T + M + D) + u + E \tag{3}$$

where:

S_d = annual saving in direct labour cost;

S_o = annual saving in labour overheads;

$S_o = S_d t$ when t = rate of overheads on the labour saved;

S_p = annual saving through increased production;
S_e = saving per piece in direct labour cost;
C_t = estimated initial cost of the tool;
R = annual percentage interest rate on investment;
Y = annual percentage allowance for insurance, taxes, and so on;
M = annual percentage allowance for maintenance and repairs;
D = annual percentage depreciation allowance on a straight-line basis;
n = number of years allowed for depreciation (amortization);
u = annual cost of setups;
E = annual cost of power and supplies;
N = annual production quantity for which the equipment is to be used;
V = annual gross operating profit in excess of fixed charges.

Since:

$$S_d + S_e = NS_e(1 + t) \tag{4}$$

and in most cases for small tools both E and S_p are negligible,

$$NS_e(1 + t) = C_t\left(R + Y + M + \frac{1}{n}\right) + u, \tag{5}$$

the answers to the foregoing four questions are found from the following four basic equations:

(*a*) The number of pieces required to pay off the new investment is given by

$$N = \frac{C_t\left(R + Y + M + \frac{1}{n}\right) + u}{S_e(1 + t)} \tag{6}$$

(*b*) The initial investment to justify the expenditure is given by

$$C_t = \frac{NS_e(1 + t) - u}{R + Y + M + \frac{1}{n}} \tag{7}$$

(*c*) The number of years for pay off is given by

$$n = \frac{C_t}{NS_e(1 + t) - u - C_t(R + Y + M)} \tag{8}$$

(*d*) The annual gross operating profit over all fixed charges is given by

$$V = NS_e(1 + t) - u - C_t\left(R + Y + M + \frac{1}{n}\right) \tag{9}$$

In applying these relationships, the items R, Y, M and D (= $1/n$) are fixed by operating policy. However, n, the number of years to depreciate, should be adjusted to meet the various requirements, i. e. rapid deterioration and obsolescence of the equipment.

METHODS FOR COMPARISON AND SELECTION OF TOOLING

For almost all tooling problems, the following three basic questions must be answered:

(a) What is to be done?
(b) By what method and with what tooling can it be done?
(c) Which method is best, or most economical?

The primary problem is usually the comparison and selection of machines, equipment, tools or tooling setups in order to obtain a desired output and quality and maintain a required production rate at the lowest cost. Choice of the best alternative tooling method is made by:

(a) Comparison of two or more proposed methods on technical and functional aspects.
(b) Proposal for a new tooling method to replace the present one.
(c) Determination of the most desirable features of the selected alternative methods.
(d) Decision on whether to invest in the proposed tooling by internal manufacture or by outside purchase.
(e) Comparison of annual costs or unit costs.

COST METHOD

A comparison on the basis of annual and unit costs may be made as indicated in the following procedure:

Calculate the average annual interest and other allowance rate (r_a).

$$r_a = \frac{r}{2}\left(\frac{(n+1)}{n}\right) \tag{10}$$

where:

r = annual interest or other allowance rate per cent: $r = (R + Y + \ldots)$
n = depreciation period in years

Determine the annual percentage allowance for depreciation (D).

$$D = \frac{1}{n} \tag{11}$$

Determine the net investment, C_i.
Calculate the total annual fixed charges, C_f.

$$C_f = C_i\,(r_a + D) \tag{12}$$

Compute other costs such as maintenance and repair cost, C_r, power cost, C_p, etc., if necessary.

Determine the direct costs such as labour cost, C_d, material cost, C_m, etc.

Determine the overhead cost, C_o.

Calculate the total annual cost C_a.

$$\begin{aligned} C_a &= C_f + C_d + C_m + C_o + C_p + C_r + \ldots \\ &= C_i\,(r_a + D) + C_d + C_m + C_o + C_p + C_r + \ldots \end{aligned} \qquad (13)$$

Calculate the total annual unit cost, C_u.

$$C_u = \frac{C_a}{N} = \frac{C_i\,(r_a + D) + C_d + C_m + C_o + C_p + C_r}{N} \qquad (14)$$

Steps for the comparison of alternative methods:

Calculate the total annual cost, C_u, for the present method.

Determine the total annual cost C_{u_2}, $C_{u_3}, \ldots$ and the total investment C_{i_2}, $C_{i_3} \ldots$ for the proposed alternative methods.

Compute the gross annual savings, S_g.

$$S_g = C_{u_1} - C_{u_2} \qquad (15)$$

Determine the net annual savings, S_n.

$$S_n = S_g - C_{u_2} \qquad (16)$$

Calculate the percentage return, P_r.

$$P_r = \frac{S_n}{C_u} \qquad (17)$$

Calculate the pay-off period in years, Y_p.

$$Y_p = \frac{C_{u_2}}{S_n} \qquad (18)$$

BREAK-EVEN METHOD

A common approach for selecting processes, methods and tooling is to use a break-even model. In determining which of the two tooling set-ups is most economical, the total costs, T, which are composed of the fixed tooling costs, F, with the related variable costs, V, of the methods involved can be compared, as shown in figure 1. For example, in comparing two possible alternative tooling setups, assume that the fixed tooling costs (the initial investment for tooling) and the variable costs [(the production cost per piece)

× (number of pieces produced)] are F_1 and V_1 for method 1 (low initial tooling cost but high production cost per piece) and F_2 and V_2 for method 2 (high initial tooling cost but low production cost per piece) respectively. From figure 1, the break-even quantity (N_q) can be obtained as follows:

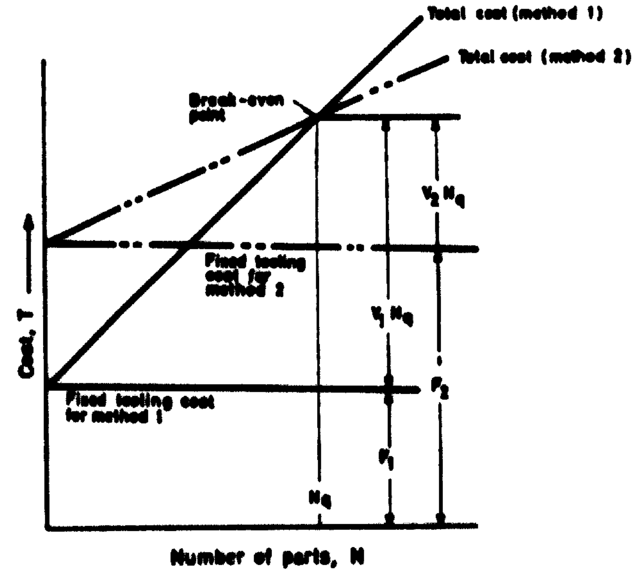

Figure 1. Break-even chart for economics of a production method

Assume

$$F_1 > F_2, \quad V_1 < V_2$$

$$T_1 = F_1 + V_1 N, \quad T_2 = F_2 + V_2 N$$

When

$$N = N_q, \quad T_1 = T_2$$

then

$$F_1 + V_1 N_q = F_2 + V_2 N_q \tag{19}$$

$$N_q = \frac{F_2 - F_1}{V_1 - V_2}$$

Also unit cost, C_u, per piece can be calculated by

$$C_{u_1} = \frac{T_1}{N_l} = \frac{F_1 + V_1 N}{N_l} \tag{20}$$

$$C_{u_2} = \frac{T_2}{N_l} = \frac{F_2 + V_2 N}{N_l}$$

where N_l = lot size (number of pieces for a single run).

This analysis with the break-even chart (figure 1) and the above computation shows that it is more economical to select method 1 if the production quantity, N, does not exceed N_q. However, for higher production quantities, when $N > N_q$, the economy lies with method 2.

MINIMUM COST METHOD

The minimum cost method is often used to obtain the lowest production cost of a given product by calculating so-called economic lot sizes or economic batch quantities for a given condition. As shown in figure 2, this minimum cost condition is satisfied when the preparation cost, P, i. e. the costs of planning, ordering, setting up, handling and tooling, equal the inventory maintenance costs. A simple model of the relationship can be written as follows:

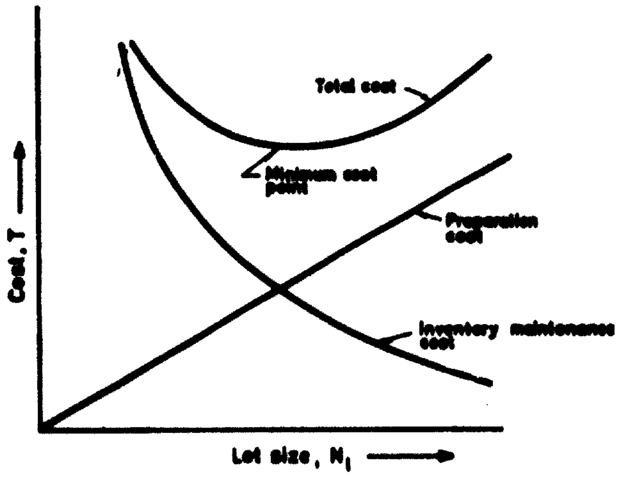

Figure 2. Minimum cost curve

$$N_l = \frac{A_p}{L_n},\ L_n = \frac{A_p}{N_l}$$

$$P = S_t L_n = \frac{S_t A_p}{N_l} \tag{21}$$

$$M = \left(\frac{A_p}{2L_n}\right) C_u H_{av} = \frac{N_l C_u H_{av}}{2}$$

where:

N_l = lot size,
A_p = annual production requirement,
L_n = number of lots per year,
S_t = setup cost,
C_u = unit cost per piece, and
H_{av} = the decimal equivalent of the average expense percentage.

Since the total annual cost (C_t) is the sum of the preparation cost and the inventory maintenance cost,

$$C_t = P + M = \frac{S_t A_p}{N_l} + \frac{N_l}{2} C_u H_{av} \tag{22}$$

Thus the optimum lot size for the minimum total annual cost is obtained by differentiating C_t with respect to N_l and equating to zero.

$$\frac{dC_t}{dN_l} = -S_t A_p N_l^{-2} + \frac{C_u H_{av}}{2} = 0 \qquad (23)$$

$$N_l = \sqrt{\frac{2S_t A_p}{C_u H_{av}}}$$

MANPOWER REQUIREMENTS AND TRAINING

J. Dillon[*]

TECHNICAL EDUCATION

SUCCESS IN UPGRADING the tool, die and metal-forming industry in developing countries will depend largely on the active participation of technical institutions, trades organizations and governmental support.

Most technical institutions are capable of producing excellent engineers, strong in engineering theory, science and research; but there is a real educational gap between the graduate engineer and the practical industrial engineer required by industry. The technician often fills the void of the industrial engineer. To suit its manufacturing needs, industry prefers to develop existing personnel rather than to hire engineering graduates, since, although educational institutions have trained these engineering graduates well in theoretical engineering, they have not been taught much of the practical application of engineering knowledge.

Co-operative engineering programmes like those operating in the United States would best fit the needs of the industrially developing nation. This is a four-year programme in which the student alternates between theoretical education at the institution and practical work under skilled managers and engineers.

The need can also be filled by providing incentives to men who have completed an apprenticeship to continue their education with programmes specializing in industry, production engineering, and industrial management.

Industrial seminars should be organized by universities or government agencies, and the material presented should originate from managers in private industry and production engineers.

In the subject of metal forming, courses should be developed with emphasis on such subjects as:

Facility loading and planning,
Production programming and control,

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[*] Ford Motor Company, Dearborn, Michigan

Plant lay-out,
Methods and works standards,
Cost analysis,
Mechanical handling.

Special instructional courses for personnel engaged in the manufacture of jigs, fixtures, dies and moulds should include:

Tool and die design,
Fundamentals of electrical discharge machining,
Fundamentals of tool steels and heat treatment.

Such a programme, through the assistance of UNIDO, would provide sufficient training, and create the necessary impetus, for developing nations which are aiming for technical equality with developed nations.

MANPOWER DEVELOPMENT

Manpower development and training has been identified as essential to the success of the toolmaking, die-making and metal-forming industry. Apprentice training, with its related technical education, is part of such a programme.

Apprenticeship can be defined as a period of learning under the tutelage of master craftsmen. For centuries, technical skills and knowledge were passed down from master to novice, often from father to son on an individual basis. Periods of apprenticeship usually lasted from seven to ten years. There were no standards regarding the skills and knowledge which an apprentice had to acquire, no instructional procedures, and no textbooks. It was commonly felt, however, that the apprentice should act as an assistant to a master. By performing all sorts of tasks, and by regular association with the master, the apprentice was expected to acquire, over a period of years, the skills and knowledge of the craft.

This method was slow but fairly effective. In those leisurely days, seven to ten years did not seem too long. The reward, the pay and prestige of a master craftsman, seemed well worth the time and effort. Today, however, neither industry nor the individual is willing to wait for such a long time to obtain results. Moreover, standards, procedures, and texts have been developed. The basic concept of "learning by doing" has not been altered, but has been supplemented by many modern teaching aids and skilled instructors.

The normal educational requirement for entry into apprenticeship training is a certificate of satisfactory completion of secondary school education. It is not unusual to find applicants and on-course apprentices with two years of college training. A high-school education is not mandatory for entry into the tool and die-making apprenticeship training, however, provided that the related educational programme is developed to suit.

An example of this deviation from normally accepted levels is the tool and die apprenticeship at the Iscar Company in Israel. Developed with the assistance of the Technion Technical University, it is a co-operative educational instruction and shop training programme.

The age of entry eligibility to the programme is fourteen years, and the training period is seven years. This programme apparently is successful and meets the needs of a flourishing and progressive company. The comparison is made merely to show that although a successful programme in a developed country may not be practicable immediately in an underdeveloped country because of its entrance requirements, these can be changed, and the end result may be equally successful.

In the United States, the programme normally has to be approved by the state. In large companies in Europe and the United States the programme is often administered by joint apprenticeship committees of union and management. Shop and educational subjects are supervised by a shop instructor or training co-ordinator.

An apprentice training programme for tool- and die-makers lasts 8,000 hours, and includes 7,424 hours of practical shop experience, with 576 hours of classroom work in related subjects. Smaller companies use accredited programmes approved by state laws involving high proficiency standards. Related training is usually co-ordinated between employer organizations and local educational institutions. This programme also consists of 8,000 hours of shop experience and related training.

Apprenticeship training programmes are being upgraded to include shop and related subject training in the new technical processes. The programmes include technical data on numerical control and electrical discharge machining.

A large US motor manufacturer commissioned a national consultant group in 1966 to study the tool and die industry at national and company levels. The purpose of the study was to improve the basic apprentice training by precisely determining the work content of jobs done by a journeyman tool- and die-maker, and was necessitated by changing techniques.

The study involved discussions and questionnaires at all levels of management and of hourly paid tool- and die-making personnel. This study included the expected levels of proficiency during the early and midpoint stages of the training. The result of the study was a change in the apprentice-shop training to include a formal pre-shop apprentice-training school.

It may be proper at this time to point out that a certain amount of loss in the apprentice programme must be expected and, in like manner, those who complete the training may elect not to remain with the company.

To acquaint the new apprentice with the programme, a training guide has been prepared and is presented to him for his use. The guide contains the following information:

The company's history,
Operating policies,
Advantages of learning the tool- and die-making trade,
Effective methods of study,
Function of the apprenticeship committee,
Union apprentice agreement,
Obligations of an apprentice to the company,
Obligations of the company to the apprentice,
Opportunities upon completion of the training programme,
Safe working habits.

Following the general orientation programme, the company tries harder to create motivation in the apprentice. The opportunity to learn a wide variety of skills is stressed. These include familiarity with new tools and die techniques, including numerical control and electrical discharge machining. Career opportunities, available within the company upon completion of the apprenticeship programme, are emphasized and include:

Supervisory positions,
Programming opportunities in numerical control,
Electrical discharge machining,
Manufacturing engineering opportunities,
Processing, tool and product design,
Jobs in training and education.

The new apprentice is then exposed to a review of the tool- and die-making trade. Educational movies and slides, including manufacturing operations, automotive assembly operations, and products manufactured by the corporation, are shown. He is made to feel that he plays a key role in this manufacturing complex.

In the pre-shop training areas, there are many visual aids, including films or slides showing:

A stamping, a metal part that is produced by a die or a series of dies;
A die as a production tool used to produce stampings;
A punch press as a power-driven machine used to shape metal under pressure or with heavy blows;
A fixture as a device used for holding work stationary during a production or machining operation.

TABLE 1. TOOL AND DIE TASKS TO BE LEARNT IN BASIC TRAINING

Learning guide number	*Task*	*Date accomplished*
9	Machine stock on a shaper	
10	Machine stock on a lathe	
11	Machine stock on a mill	
12	De-burr and stamp rough stock	
13	Drill and counterbore a hole	
14	Drill and tap a hole using either a floor drill press or a radial drill press	
15	Drill and ream a hole by using either a floor drill press or a standard drill press	
16	Barber tool or die components	
17	Spot tool or die components	
18	Stone tool or die components	
19	Using a bandsaw, safely cut a tool or die detail to lay-out line	
20	Operate an overhead crane	
21	Operate a hydra-drill	
22	Lay out die or fixture details from a sketch or blueprint	
29	Machine stock on a surface grinder	

The new apprentices are then taken on a conducted tour by their shop instructors through the stamping operations and the tool and die shop. During the course of the tour, the operations are explained in detail. The next step in the basic orientation programme is to explain the purpose of basic training, to learn basic tool and die processes as rapidly as possible, and to formulate safe working habits. The tasks which the apprentice will be expected to learn are explained in detail. The conditions under which he will learn these tasks are also explained.

An important point stressed at this time is the self-pacing concept of the programme. This means that the apprentice can have an opportunity to pace himself and to master one task before he advances to the next. The confidence developed in the apprentice by this self-pacing is one of the notable aspects of the programme. It is only after he has completed fifteen identified tasks that he achieves an efficiency rating permitting him to go on the regular apprenticeship programme. The tasks are listed in table 1.

Table 2 shows the tools and books needed by the apprentice and table 3 the apportioning of his training between various machines.

TABLE 2. TOOLS AND EQUIPMENT

At the start of his apprenticeship, the apprentice is supplied with, or expected to buy, the following basic tools and equipment:

Workshop tools

- C-Clamps, 2 in
- Inside calipers, 3 in and 6 in
- Outside calipers, 3 in and 6 in
- Calipers, 6 in hermaphrodite
- Centre gauge
- Centre punch
- Set of small chisels
- Combination square, 12 in
- Compasses
- Depth gauge
- Diemaker's square
- Dividers, 3 in and 6 in
- Set of small files
- Two 12 oz steel hammers, one ball peen
- Hammer, light, copper
- Ideal indicator
- Magnifying glass
- Micrometers, 1 in and 2 in
- Parallel clamps
- Pliers
- Prick punch
- Radius gauge
- Rule, 6 in flexible
- Rule, 6 in hook
- Rule, 6 in depth
- Scraper, three-cornered square
- Scriber
- Sliding parallel rule
- Solid square, 3 in
- Surface gauge
- Telescope gauge set
- Thickness gauge
- Thread pitch gauge
- Toolbox, 20 in × $12^{1}/_{2}$ in × $8^{1}/_{2}$ in
- Trammel heads
- Wiggler
- Wrench, crescent, single end, 8 in
- American Machinists' Handbook
- Reference tables

School supplies and equipment

- Three-hole ring binder
- Bow compasses, 3 in and 6 in
- Drawing board
- Scale, 12 in triangular engineering or 6 in or 12 in flat
- T-square
- Set square, 6 in, 45°
- Set square, 8 in, 30°
- Protractor

TABLE 3. DISTRIBUTION OF APPRENTICE TRAINING BETWEEN WORKSHOP MACHINES

Phases	*Hours*
Shaper, planner, and/or slotter	500
Lathe	500
Milling machine	800
Grinders	500
Bench — die	2,000—3,000
Bench — tool	800—1,400
Die try-out and/or model and templates .	500—1,600
Related instruction	576
Vertical lathe, profiling machines, boring machines, heavy mills, special gear, hardening techniques	optional
Total	8,000

The 31 courses are listed below, roughly in the order in which they are taken; some subjects are dealt with in two or more courses. When this is so, the number of courses is stated in parentheses after the subject title.

Shop arithmetic
Algebra
Geometry
Trigonometry (3)
Logarithms
Compound angles (2)
Blueprint fundamentals
Blueprint reading by clay models
Machine shop blueprint reading
Advanced blueprint reading (tool and die)
Elementary projection and dimensioning
Advanced projection
Manufacturing engineering standards
Detail and assembly drawing (tools)
Detail and assembly drawing (dies)
Elements of die design
Elements of tool and fixture design
Gearing
Characteristics of metals (2)
Heat treatment (2)
Elementary physics
Shop theory (4)
Shop theory (dies)

TABLE 4. TRAINING REQUIREMENTS FOR DEVELOPING

KEY:

Letter indicates location. Number indicates length of training period in months.

A = specialized establishment abroad.

C = common facility centre.

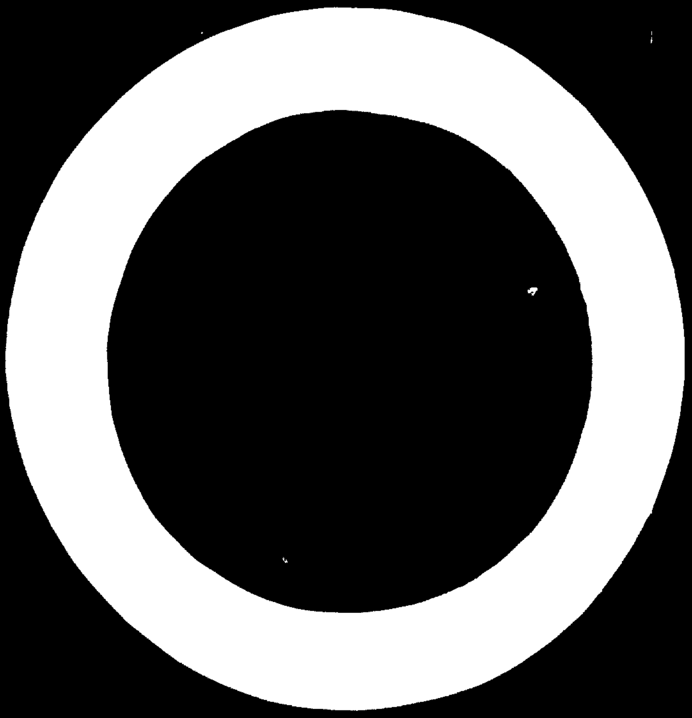
L = local factory (in-plant training).

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="7"><i>JIGS AND FIXTURES</i></th></tr>
<tr><th rowspan="2"><i>Machining jigs and fixtures for drilling, milling, turning, grinding</i></th><th rowspan="2"><i>Welding jigs and fixtures</i></th><th rowspan="2"><i>Assembly jigs and fixtures</i></th><th rowspan="2"><i>Inspection (checking) jigs</i></th><th colspan="3">PRESS WORK</th></tr>
<tr><th colspan="2"></th><th><i>Holding fixtures</i></th><th><i>Knockouts and lifiers</i></th><th><i>Feeders</i></th></tr>
<tr><td rowspan="3"><i>DESIGN</i></td><td>Tool process engineers</td><td colspan="4">A 12</td><td colspan="3">A 6</td></tr>
<tr><td>Tool designers</td><td colspan="4">A 12</td><td colspan="3">A 4</td></tr>
<tr><td>Tool draughtsmen</td><td>C 6</td><td colspan="3">C 4</td><td colspan="3">C 6</td></tr>
<tr><td rowspan="17"><i>MANUFACTURE</i></td><td>Supervisors (foreman level)</td><td>A 8</td><td colspan="2">L 4</td><td>A 4</td><td colspan="3">C 4</td></tr>
<tr><td>Layout, tracing etc.</td><td>C 4</td><td colspan="3">L 2</td><td colspan="3">C 4</td></tr>
<tr><td>Template, pattern and model making</td><td>C 3</td><td></td><td></td><td>C 3</td><td colspan="3">L 2</td></tr>
<tr><td>Tool and die welding</td><td>C 3</td><td colspan="3">C 2</td><td colspan="3">C—3</td></tr>
<tr><td>Tool and die heat treatment</td><td>C 4</td><td colspan="2">L 2</td><td>C 4</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>Toolroom horizontal and vertical lathe operators</td><td>C 4</td><td colspan="2">L 2</td><td>C 2</td><td colspan="3">L 3</td></tr>
<tr><td>Toolroom planning, shaping and slotting machine operators</td><td>C 3</td><td colspan="2">L 2</td><td>C 2</td><td colspan="3">L 3</td></tr>
<tr><td>Toolroom boring machine (other than jig boring) operators</td><td>C 4</td><td colspan="2">L 2</td><td>C 4</td><td colspan="3">L 2</td></tr>
<tr><td>Toolroom jig boring machine operators</td><td>A 3</td><td>—</td><td>L 2</td><td>A 3</td><td>L 3</td><td>—</td><td>—</td></tr>
<tr><td>Toolroom universal milling machine operators</td><td>C 4</td><td colspan="3">C 3</td><td colspan="3">L 3</td></tr>
<tr><td>Toolroom copying mill operators</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>Electrical discharge machine operators</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>Toolroom bandsaw and contour filing machine operators</td><td>C 2</td><td>—</td><td>—</td><td>L 2</td><td colspan="3">L 2</td></tr>
<tr><td>Toolroom surface, plain, internal and universal grinders</td><td>C 4</td><td colspan="2">L 3</td><td>C 4</td><td colspan="3">L 3</td></tr>
<tr><td>Toolroom contour grinding machine operator</td><td>—</td><td>—</td><td colspan="2">L 2</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>Toolroom bench finish fitters and toolmakers</td><td>A 4</td><td colspan="2">L 2</td><td>A 4</td><td colspan="3">C 4</td></tr>
<tr><td>Toolroom inspectors and testing and tryout personnel</td><td colspan="4">A 12</td><td colspan="3">C 4</td></tr>
</table>

COUNTRIES: RECOMMENDED LOCATION AND DURATION

DIES AND MOULDS										
SHEET-METAL DIES				HOT-FORGING DIES			COLD-FORGING DIES			
Through-hole work (stamping, blanking, piercing)	*Forming work (bending, cupping, drawing)*	*Spinning dies and roll-forming dies*	*Trimming dies*	*Upsetting dies*	*Drop forging and press dies*	*Trimming dies*	*High-velocity and impact-forming dies*	*Cold-heading dies*	*Pressure die casting dies (or moulds) for zinc and aluminium alloys etc.*	*Compression, transfer and injection moulding moulds for thermosetting and thermoplastics*
A 6				A 10					A 8	A 6
A 6				A 18					A 8	A 10
A 6				A 6					A 6	A 6
A 12				A 18					A 6	A 6
C 4				L 3	C 4			L 2	L 3	L 3
A 12				L 3	A 6	L 3	A 6	L 3	A 6	A 6
C 2				C 2					C 2	C 2
C 3				L 3	C 3	L 3	A 4		A 4	C 3
L 2	L 3		L 2	L 4	L 2			L 4	L 3	L 3
C 4	L 3	L 2	C 3	L 2		C 3	L 2		C 4	C 4
L 3		L 2	L 3	L 3		L 2	C 4	L 3	C 4	C 4
A 3		C 3		—	—	—	C 3	—	A 3	A 3
C 4		—	L 4	C 6		C 4	C 6	L 4	C 4	C 4
—	C 4	—	—	A 6		—	A 6		A 6	A 6
A 4		—	—	A 4		—	A 4		A 4	A 4
L 4	L 2	—	L 4	—	—	L 4	—	—	—	—
L 4	C 6	L 4		C 6		L 4	C 6		C 4	C 4
A 4		C 4	C 3	A 4		L 4	A 4		A 4	A 4
C 4	A 4	L 2	C 4	L 4	A 4	L 4	A 10	L 4	A 4	A 4
A 8		C 4		A 12					A 8	A 8

Note: **Durations recommended are only approximate, and are meant to be taken as a guide. Final decisions as to the location of the training, and its duration will depend on local conditions and many other factors prevailing at the time.**



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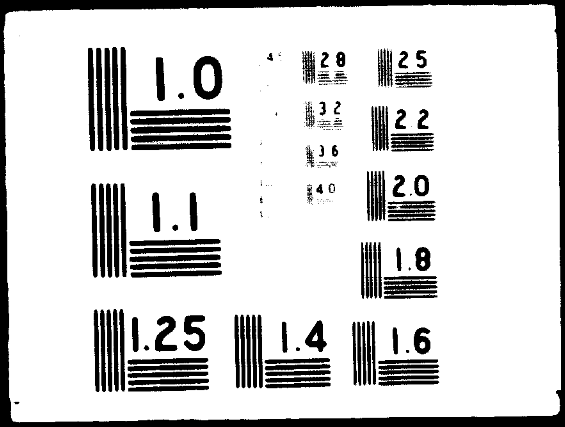

ECONOMICS AND MANAGEMENT ASPECTS OF DIE AND JIG PRODUCTION

Orvis J. Fairbanks[*]

MANAGEMENT OF DIES AND JIGS

When a problem arises with finished tools, their quality or efficiency should not at once be condemned. The tool may need replacement, should it be determined to be defective by the management's tool engineer. Some factors concerning tool problems which will need review and analysis are the following:

(a) Design
(b) Methods and application
(c) Materials
(d) Metallographic inspection
(e) Failure analysis (if failure occurs)
(f) Precision measurement of critical areas, including geometric shape
(g) History (at application)
(h) Vibration analysis (at application)
(i) Machine application review.

The author has found the numerous special-tool manufacturers most helpful in answer to a request for information or help with a particular problem. Many machine-tool manufacturers can also provide highly informative motion pictures, some with microscopic detail, or in slow motion, to allow a better understanding of the machine and tool actions, both direct and indirect, which take place while tools are working.

The American Society of Tool and Manufacturing Engineers (ASTME), 20501 Ford Road, Dearborn, Mich., 48128, and the American Society for Metals (ASM), Metals Park, Ohio, 44073, are excellent sources of technical educational materials, motion pictures, charts, standards data, and metallographic references.

The need for both short and long-range plans in a developing country cannot be overemphasized. There will be much data missing

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and estimates will be required. In every case they should be kept conservative so that the errors will at least be less costly. The main objective is to have an actual plan outlined on paper, and to discuss it at every opportunity, for example with a bank or loan agency. The plan must show a profit as well as fill a critical need. It should cover a reasonable period of elapsed time after which the project can be fully paid and perhaps continue profitably, or be ready for expansion. At this point the economists and engineers, with the statistical personnel, should review and add all pertinent facts relating to the project. Most developing countries, at least those familiar to the author, lack reliable current statistics. The economics of a project should be carefully reviewed, not only to determine that it has marketability, but also to assure its productivity.

Equipment has been known to lie idle for several years, due to lack of proper dies and tooling equipment. The original project may have required several hundred thousand dollars. Yet the small sum of ten thousand dollars could not later be raised for tools. As a result, the project remained completely idle for some considerable time.

THE ECONOMY OF DIES AND JIGS

When one is called upon to make an analysis resulting in a decision to recommend specific tools to management, for manufacture or purchase, several important factors must be considered. These are principally concerned with materials, engineering and production. All are related and overlap the above divisions. Information such as the following is needed:

(a) Size of market for the product needing tools.
(b) Suitable raw material for tools, at a satisfactory cost. Point *(b)* concerns both economics and engineering and is usually determined by engineering.
(c) Quantity of product needed per man-machine hour.
(d) Volume of product to be sold per year, determined by market study.
(e) Quantity of tools needed for the hourly production, determined by engineering.
(f) Design, manufacture and accuracy of tools, as the needs are determined for satisfactory production and assembly.

A precision tool, having a production tolerance of ± 0.002 inch, should not be made for an end product with only ± 0.010 inch tolerance. A tool having ± 0.006 to 0.007 inch tolerance will be satisfactory and much less costly than the more precise tool. Moreover, the hourly rates of pay for precision toolmakers are considerably higher than those for men working with a less precise tool.

Some raw materials will undoubtedly change with tool specifications, as the requirement loosens for a less precise tool. The main objective is to gear production to consumption or sales at the most economical cost, then to design the tool to assure suitable precision in making the end product.

The possibility of a misfit during assembly of piece parts made with a particular die or jig must be avoided. It is not economical to attempt perfection in the tool, this would only be extremely costly. Tolerances for the product must first be known. It is then possible to establish a tool working tolerance. When this is known, then the die or jig maker will know what his toolmaking requirements really are.

In all cases the cost and engineering aspects must be considered jointly. A detailed estimate must be made to arrive at the assumed cost. The beginner particularly and those who cannot afford the time and financial loss entailed in re-making tools should never try what is commonly known as a "shotgun" estimate. This practice is only for emergency or preliminary calculations. It should be attempted only by one with years of experience in the type of toolmaking under consideration. The developing country and the inexperienced are advised to avoid this type of estimate. The economist and the engineer should obtain their data from a reliable source and compute costs as follows:

(a) Cost of raw material
(b) Cost of other materials (purchased or made) such as screws, bolts, bushings, pins, and die sets,
(c) Detailed estimate of hours to manufacture all "made" items, then compute hours to arrive at a total monetary cost for the complete, assembled and "tried-out" (actually used) tool.

As experience is gained and a reservoir of information accumulated, including actual costs from previous "made" tools, the estimating time will shorten by the use of knowledge of past costs and hours. If possible, a design or good working sketch of the tool will be required. Here there are many variables to be considered, such as the following:

(a) What are production needs? An expensive tool should not be made for a very limited production.
(b) On what type of material will the tool be working?
(c) With what cutting tools, speeds and feeds?
(d) At what accuracy?
(e) Will the operators using the tool be skilled or semi-skilled?
(f) Can the tool be maintained at its home base or will it be necessary to send it elsewhere for repairs?

When the above details can be considered along with any other pertinent factors such as sufficient power, light and handling facilities, then the tool is ready for engineering and manufacture. At this point and before manufacture, the design or sketch should be approved by those responsible for its successful use. Differences can then be settled and those concerned with production will be satisfied that their contribution has been accepted.

TOOL ENGINEERING FOR DIES AND JIGS

Webster's dictionary defines tool engineering as that branch of industrial engineering which has to plan the processes of manufacture, develop the tools and machines and integrate the machinery and facilities required, for producing particular products at a minimum expenditure of materials, time and labour. In a small organization the chief engineer or even the manager may act as tool, product and plant engineer, if he is capable and has sufficient time.

A tool may be classified as a device to permit economic, efficient manufacture of a number of similar parts. With such a device, interchangeability became a reality. Tool design, as the word implies, refers mainly to production devices, the cutting tools, dies, jigs and fixtures, patterns, moulds and gauges commonly used in metalworking. A tool can be designed and engineered to encompass many functions. Some permit a better product, utilizing lower-grade machine operators and a lower quality of machine tool equipment. It should be borne in mind, however, that most tools, dies, jigs or fixtures, often require a gauge. The gauge ensures that the product can be processed through assembly and will be satisfactory to the customer.

It can be said that nearly all tools, dies, jigs and fixtures may be classified into two general categories: general purpose, and special purpose. An important phase of designing and building any tool is the selection and specification of its raw material. For without suitable chemical composition, there can be no certainty of the metallurgical qualities for a satisfactory working tool. Finding the raw material tool steel may be a real problem particularly for developing countries. Great care must be exercised to assure and secure only the most suitable of raw materials. The methods of marking and identity are poor and the many varieties of steel can be easily mixed, so that the toolmaker all too often may receive a quite unsatisfactory piece of steel for the tool. The unfortunate result is to blame the heat treatment process at the toolmaking shop. A steel maker can and will guarantee his steel, within narrow tolerances. His written guarantee should accompany the steel raw material, carefully identified, all the way to the toolmaker's workbench, and a copy of the tool-steel specification should remain on file with the toolmaker. Only in this way can he apply his knowledge and ultimately assure a satisfactory tool. The next critical step is final finishing, grinding and assembly.

The possibility of a misfit during assembly of piece parts made with a particular die or jig must be avoided. Tolerances for the product must be first known. It is then possible to establish a working tolerance for the tool. When this is known, then the die or jig maker will know what his toolmaking requirement really is.

Many expensive form-cutting tools are ruined because of incorrect grinding and grinding methods. Often tools of this type simply cannot be salvaged, and the result is a complete loss. Specific heat treatment procedures will not be discussed in this paper, since they are available in published form and bulky. Information may also be obtained from the steel maker. It should perhaps be mentioned that the so-called carbon tool steels and the more recently developed high-speed steels are both excellent steels for tools for specific purposes, but their heat treatments are entirely different. Each type of steel requires special knowledge and special furnace equipment.

Many advantages are available to the developing country which uses the technique of hard facing, since it involves no intricate heat treatment. The method is best adapted for welding a bead, or brazing a suitable strip of the various cobalt alloys to the edges or wear areas of the tool. The base of the tool can be of lower quality and tougher. Some of the advantages of these cobalt alloys are:

(a) Abrasion resistance
(b) Corrosion resistance
(c) Friction reduction
(d) Further heat treating not required
(e) Hard facing to Rockwell 65 (or higher if the carbides can be used)
(f) High heat resistance, without loss of hardness
(g) High impact resistance
(h) Fast cutting.

Several disadvantages do, however, exist in the utilization of hard facings and some of these are:

(a) They are not machinable
(b) They are difficult to grind
(c) They have a low coefficient of expansion
(d) They have less impact resistance than carbon tool and high-speed steel.

Carbide and ceramic tools have a definite place in certain applications where rigid fixing is possible and the technical knowledge and equipment are available to use them. They cannot be applied anywhere and the hazards of their application are many.

Great care and proper technical preparation are advised for all, especially the inexperienced, before applying these tools. Their value is undeniable for a special type of application, particularly on a long production run. The most suitable conditions must however be arranged, after careful analysis by a tool engineer, or an experienced technical tool specialist. Whenever applications of the carbide or ceramic tools are considered, the high-cobalt alloys should also be evaluated, since they are somewhat tougher and withstand much more shock. Although they cut faster than the carbon and high-speed steel tools, they are not so fast as carbide or ceramic tools. Should the application be one of wear only, then the ceramics and carbides are unexcelled. It must be reiterated that special grinding and working equipment are necessary, as well as special technical analysis of the application planned.

Below are listed some materials available for non-cutting purposes in such items as dies, jigs, fixtures, forms for forming light metal, and moulds for plastics:

(a) Epoxy resin compound
(b) Kirksite casting compound
(c) Hardwood
(d) Aluminium
(e) Cast iron
(f) Steel, cast or fabricated.

These materials may be especially useful for the tooling of small lots, particularly by new companies. The developing countries have much to gain by making full use of the epoxy resins, which in some types of jigs and the drawing and forming dies, have reduced tooling costs by as much as 50 to 90 per cent. Mainly this saving is brought about by the difference in additional machining time, required for the hard tool steel materials. The epoxy tool can be made in hours, or perhaps days, compared with weeks, or months, required for the tool steel die. The epoxy die can be easily repaired or modified, whereas the tool steels would require extensive time and perhaps complete re-making. It must be recognized, however, that the epoxy tool may lose hardness, shape or form more quickly than tool steel, when large quantities of a product are made.

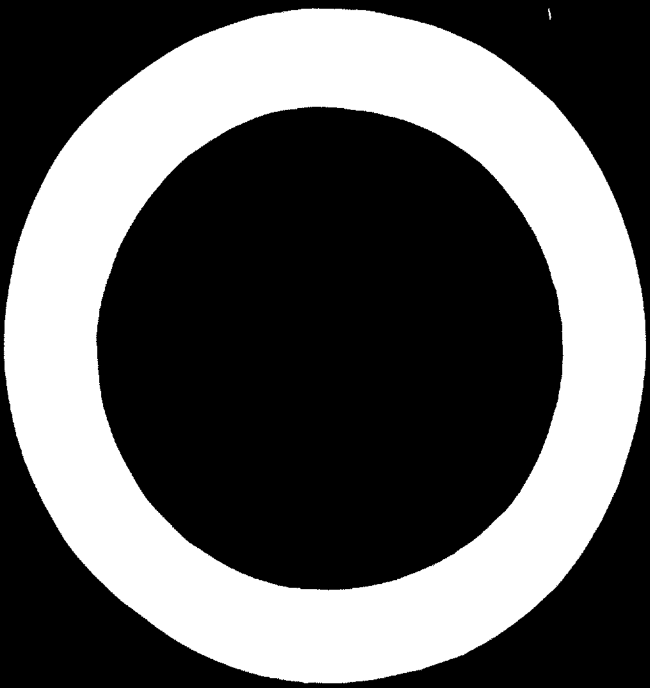
One of the most valuable assets any country can possess is its skilled men. They can recognize the qualities and limitations of the tool steels and other raw materials and turn them into efficient tools. The development of skilled manpower must expand continuously. It is the author's emphatic opinion that skills training, within the developing countries, is essential and should expand rapidly.

Without resourceful craftsmen, the making of dies, jigs, fixtures and other tools is not advised. The manager, the engineer, economist, superintendent, or other supervisory staff will all know, in a general way at least, what type of tool will be most useful. Few in this group, however, even in the developed countries, will have sufficient knowledge of toolmaking to impart specific instruction for making tools to personnel who may have a very limited background.

CARE, USE AND MAINTENANCE OF VALUABLE TOOLS

Most tools are expendable, that is, they either wear out by normal use, or simply become obsolete owing to change of product, design, or methods of fabrication or use. A tool may however be immediately ruined by misuse or neglect. Climatic conditions are important to consider, and dry storage, in a wax or plastic encasement is probably the best means of preserving the tool. Where steel drill bushes, banking blocks, landing pads, locating pins, or other critical points exist, they need to be protected. Similarly, the cutting edges of steel tools, reamer flutes, plug gauges, and so on must be carefully preserved. Tools also need continual care while in use. Working joints and locating pins and screws should be kept tight, well oiled, and not abused by hammering. The edges of a cutting die must be sharp and its surfaces smooth and clear. They must not be permitted to operate after becoming dull. During sharpening, proper clearance and rake angles must be maintained at all times if the life of the tool is to be preserved. Here proper training and skills are essential for satisfactory tool care and maintenance. It is the responsibility of management to see that capable personnel are assigned to this critical activity.

All special tools, dies, jigs, fixtures or gauges must carry a tool identification number. This should be stamped or etched upon a non-working surface, and a record and locator card should be completed and filed for future reference. All delicate tools should be boxed, crated or plastic-coated whenever they are stored.



ADVANCED TOOLMAKING TECHNIQUES FOR DEVELOPING COUNTRIES

D. N. Smith

FOR ECONOMIC REASONS, industrialized countries are using new methods to increase their production of tools and dies with fewer toolmakers. Developing countries also, which wish to expand their tooling output should adopt new techniques to maximize the productivity of their scarce skilled labour.

The successful application of computers, numerical controls and electrical machining processes by industrialized countries shows that these new methods can now ease the shortage of critical metal-working skills. The new techniques shift certain operational functions from the production floor, where job proficiency is obtained through long years of on-the-job training, to the engineering office where the appropriate skills are more speedily acquired through intensive formal technical education that is supplemented by a shorter period of on-the-job training.

NUMERICAL CONTROL IN TOOLMAKING

Numerically controlled machining is a relatively new method of machining that uses mathematical information in both design and manufacture, and thereby has introduced important technical changes. Since numerical control is a machine control method, its impact has sometimes been assessed as similar to that created by earlier machine tool controls such as the tracer device. The benefits of numerical control, however, influence every phase of toolmaking. Design, assembly, inspection, and quality control activities as well as the machining function are all directly affected. By contrast, the tracer or duplicating machine, although indeed a significant innovation for toolmaking, had only limited effects outside its machining function.

The superior performance of numerically controlled machining results from improved flexibility and longer cutting periods at

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* University of Michigan

increased precision standards. Furthermore, these machines, when properly maintained, show no ill effects from fatigue. They are equally efficient in the early morning or late afternoon, on the day or night shift, or Saturday and Sunday.

PRODUCTIVITY

When a toolmaker produces a part on a conventional machine, he must frequently refer to a drawing to find the dimensions of the part. Interruptions to adjust the machine's handwheels, and to inspect the workpiece with gauges, calipers, and micrometers are common. The machinist makes progressively smaller and slower cuts, measuring between each cut to avoid removing too much material. Such a trial-and-error process is time-consuming and susceptible to error.

Numerical control increases productivity by establishing all the machining instructions on the tape before the part is positioned on the machine tool. The interpretation of the drawing, and decisions regarding the machining sequence are made by a programmer or process planner at a desk rather than by the operator in the shop. Expensive machine tools no longer stand idle during an operation which can be performed on inexpensive equipment in the office, and the proportion of the machine's actual cutting time increases from a 10 to 30 per cent range to one of 60 to 80 per cent. Such high utilization of equipment is also made feasible because accurate estimates of machining time can actually be adhered to on the production floor. Tight schedules are maintained since the operator has relatively little control over the pace of the machining sequence.

The increased productivity of numerically controlled tools not only reduces labour costs per part but makes 24-hour operation of the tools feasible. In developing countries where skills and precision machine tools are scarce it becomes vitally important to use these scarce assets to the maximum.

Both numerical control and EDM have proved attractive for making tooling, quite apart from the reduction they achieve in machining time. For instance, the amount of benchwork and hand finishing is often halved and the need for templates, patterns, and models is greatly lessened.

ACCURACY

Even though cutting rates are accelerated with numerical control, its use often has produced double the accuracy of conventional toolmaking machines. Previous improvements in metal-cutting accuracy were usually achieved by cutting more slowly. Since numerical control usually eliminates cutter guides, errors accumulating in the design and construction of tooling aids for conventional machines are also avoided.

Because of the accuracy limitations on conventional machines and associated tooling, parts with undesirable tolerances had to be accepted because these nevertheless met the best achievable precision standards. In the less highly developed tool and die industries where both the skills and the machine tools are not as refined as those in developed countries, these undesirable tolerances can represent substantial liabilities to the metalworking industries. The users of the tooling and the product designers facing this obstacle will welcome the accuracy improvements from numerical control, since they will be able to specify shapes and dimensional tolerances previously not feasible.

The primary reason for the great improvement in accuracy is that numerical control operates from electronic commands and through a closed-loop system. The information carried by the electronic signal is also translated into machining directions with less chance for error in interpretation.

The finite numbers appearing on a drawing represent discrete values with no intended tolerance, but by the time the machinist interprets and transmits the numbers to a conventional machine tool through manual controls and checks the setting with mechanical measuring devices, errors often modify the discrete value. When a dimension is expressed by an electronic signal from a numerically controlled system, human errors cannot degrade the reproduction fidelity of the value. The command is accurate to better than 0.0001 inch and is repeatable to at least 0.0002 inch. Since the accuracy of the machine is much below that of the control unit's electronic signal, the final tolerances in the part reflect the limitations of the machine tool.

The accuracy of electronic commands and the closed-loop monitoring system, coupled with the capability of more exact duplication, have significantly improved the quality and uniformity of parts. Fewer random errors reduce the need for finished part inspection. Frequently only the first part of a given production lot need be thoroughly inspected.

Many of the aspects of numerical control which contribute to increased accuracy and flexibility also shorten lead times. Machining instructions stored on tape eliminate the need for tool guides and jig plates; therefore, the lengthy delays for their design and construction can be avoided. Programming the machining instructions with high-speed computers can also be done in a fraction of the time conventionally spent in tooling construction or part lay-out.

Besides being prepared more quickly, tapes can be easily revised to accommodate last-minute engineering design changes.

The versatility of numerically controlled equipment is especially important to the small shops in developing countries. Independent operations previously performed on separate machines can now be consolidated on a multipurpose numerically controlled machine. Some machines equipped with index fixtures and tool changers can mill, precision-bore, drill, ream, and tap on one setup of the workpiece, eliminating the need for several other machines and fixtures for previously independent operations. Such a consolidation is extremely beneficial in toolmaking where the frequent transfer of tool components between machines and work stations is not only costly, but often lowers precision standards.

The high precision achievable at increased machining rates with minimum setups has greatly reduced inspection, hand finishing, and re-work and assembly labour in the fabrication of tools and dies. In jig and fixture applications, the accuracy and repeatability of numerical control greatly simplifies assembly, and provides for substantially better performances by the jigs and fixtures when they are delivered to the customer. Consistent dimensional uniformity between die and mould components not only reduces hand fitting but also permits design modifications, thereby simplifying assembly. These advantages are extremely valuable in situations where toolmakers capable of precision benchwork are scarce.

ECONOMIC FACTORS

The advantages of numerical machining for complex, mathematically definable parts, or for medium-volume runs, if the capital and programming costs are justified, have been very attractive for highly industrialized countries where toolmakers' pay is relatively high. But if the part is small and uncomplicated, setup may be simpler and more economical with conventional machines such as the tracer or the duplicator. However, even in such applications the use of tracer equipment is declining because more skilful operators are required and the tool assembly and finishing operations are more arduous and costly.

The economic advantage of numerically controlled machines over conventional machines will often be determined by comparing the cost of making a master model for the conventional or duplicating machine with the cost of the numerically controlled tape—minus the savings in machining, finishing, and assembly labour. In some applications where right- and left-hand tooling are to be machined, cost can be reduced because only one tape need be programmed. Most numerical control systems on large milling machines provide for mirrorimage machining by simple controller adjustment. For such an application, two models would normally be required by the tracer or duplicating machine.

Until recently, the cost of defining the instructions to regulate the machining of an acceptable part has retarded the spread of numerical control. This is understandable since no problem is more central to its economic use. The creation of control tapes has generated an entirely new technology for which the necessary techniques and skills are still developing. Associated operational costs have, therefore, been high and sometimes difficult to amortize on one-of-a-kind applications. In low-to-medium volume machining jobs, however, the cost of tape preparation for mathematically definable parts is frequently less than half the cost of constructing tooling, laying out the part, or producing a pattern.

Tapes for numerical control and toolmaking are usually prepared in one of two ways. In the first, the die, mould, or other tooling surface is described by several statements of a special numerical-control language for programming parts. A manuscript of abbreviated English-like statements is prepared and converted to coded information which is processed in a computer to calculate the required cutter path. Because dies, moulds, and some other tooling often are not true geometric shapes, the value of these languages for programming parts has been limited for some toolmaking applications. Consequently, an alternative method of tape preparation has been developed.

A contour-measuring device, similar in principle to a tracer duplicating device, determines the dimensions of a three-axis model by using a mechanical proximity probe to measure and punch the values of the co-ordinates on a paper tape (digitizing). After the machining instructions have been added to the dimensions on the tape, the numerically controlled machine tool repeats the path of the probe as it reads the paper tape. Because right- and left-hand parts can usually be produced from the same tape, only one model need be digitized. The contour-measuring device has an important advantage for developing countries—tapes can be prepared by relatively unskilled workers using this technique.

RESULTS

Not only are time skills saved but the numerical processing of dies, moulds, and other tooling produces a surface with high symmetry and continuity. This is one of the reasons why a numerically processed die or mould, for example, will need only 50 per cent of the hand finishing required for conventionally produced parts.

Numerically processed tools also have smaller cusps or none at all. Cusps are the ridges of metal remaining after two parallel passes of a milling cutter. Smaller cusps result because the spacing of the machining passes of the cutter on multidimensional work is easily regulated by the control system. Where greater accuracy is required, very small cusps can be achieved by close machining passes. Wider machining passes can be used on flatter surfaces where large cusps may be readily removed by hand finishing. Machining passes also can be made perpendicular to the main flow of cuts, thereby providing a precise intersection for guidance in the finishing operations. By making the perpendicular cuts correspond to template locations of the model, the machined surface can be checked easily and with greater precision.

ACQUIRING THE SKILLS FOR NUMERICAL CONTROL

The ability, through the application of numerical control, to use semi-skilled machine operators and less tool-finishing and assembly labour, depends upon properly trained programmer and maintenance personnel; this means changes in traditional training programmes. The skill shifts and their effects upon training in the metalworking trades have been analysed in a study of the United States Department of Labor. It was recognized that although the occupations required for conventional machining, such as part designers, methods planners, tooling men, and machine-tool operators, are still needed for numerical control, many specific functions, the relative level of skill requirements, and the decision-making responsibilities, do change. The following summary of the functions performed in numerical control by the machinist, the programmer, and maintenance personnel illustrates the major skill changes that take place.

> With the machining commands on the tape, the machinist need not have several years of experience to operate numerically controlled machines. His responsibility can be restricted to setting up the machine, recognizing operational deviations, and being alert to equipment malfunctions. Thus, once the numerically controlled equipment has been installed and its operation is reliably stable, the machine operator can be a semi-skilled worker.
>
> Equipment maintenance, however, becomes more demanding —both in terms of skill requirements and responsibility. Numerically controlled equipment requires knowledge of servomechanisms, electronics, and hydraulics. Since a malfunction may be caused by one or more of these sub-systems, at least one maintenance person must be able to analyse the total system and isolate the cause.

Numerical control has created the need for part-programming skills. The programmer, whose key responsibility is managing the manufacturing process, works closely with the design engineer to assure that the design intent will be translated accurately onto the control tape; the programmer also works with the machine operator to ensure that all programming assumptions are understood for setup and machining.

A catalogue of the responsibilities of the programmer, the numerical control maintenance staff and the machine operators will provide some insight into the nature and complexity of the necessary training programmes. It will also illustrate the training requirements for developing countries.

NUMERICALLY-CONTROLLED PROGRAMMING OF PARTS

The most serious training challenge arises in developing the part-programming skills. The programming activity begins with an over-all analysis of a drawing of the part, to determine if the part can be machined efficiently on the numerically controlled equipment available.

Some of the questions which need to be answered are:

(a) Is the machine tool physically capable of carrying out all the required operations?

(b) Can the equipment, under automatic control, achieve the desired tolerances?

(c) Does the part consist of true geometric shapes which can be mathematically defined; if not, will it be feasible to use a contour measuring machine for tape preparation?

The programmer must then analyse the process details. This often involves making a sketch of the part in its setup position to determine the best fixture arrangement. Answers to the following questions must also be determined:

(a) What cutting tools are required? Sizes and shapes should be specified.

(b) Considering the workpiece and cutter materials and the configuration of the machine tool, what cutter feed and speed rates should be established?

(c) Should the workpiece be re-set to machine any areas unmachinable because of the positions of the initial fixtures?

When the tooling and methods for processing have been determined, it is necessary to establish the proper machining sequence. This is an important phase since several approaches can be used to establish the sequence of machining operations. Only one set, however, is the most efficient process; there can be a costly difference between a programmed tape which produces a part and one which produces the part in the best manner. A second review to optimize the tape often reduces the process time by 20 to 25 per cent, especially when several cutting tools are involved for drilling a large number of holes.

For each operation in the sequence, a start and an ending point are programmed, and the intermediate points collectively define the cutter path. The co-ordinate points for each segment of the cutter path are entered on a programming sheet and are supplemented by machine tool commands. Examples of this information are cutter feed rate, coolant flow, tool selection, spindle on-off, etc. Upon completion of the programming form, the complete record of the written programme is reviewed and verified. Typical questions to be raised at this point are:

(a) Are all machine-tool operations such as coolant flow, spindle movement, properly activated?

(b) Are machinability and process sequences correct?

(c) Are the cutter paths accurate?

The information on the programme manuscript is then transferred onto a control tape or fed into a computer for calculation. The computer output is then entered on the control tape. The punched tape is verified by one of several methods, for example, plotting the tape information on an X-Y plotter or a drafting machine. When the part is complex, the tape may be checked by machining the first part in wood or plastic.

Depending upon the complexity of the application, there are several approaches for organizing the skills needed for programming parts. Programming always requires three types of activity: process planning, programming the part, and transferring the proven tape to the shop.

Because the three distinct operations are easily segregated, specialization of effort is usually desirable. Such division of effort makes possible the use of more inexperienced workers and eases the training problem. It is not always necessary, however, to separate the three activities; in many smaller companies the planning, part programming, and tape-transfer operations are successfully performed by a single person. The organizational technique used by one company which pioneered the use of numercial control illustrates the effective management of these three operations and demonstrates the levels of skills required.

PROCESS PLANNING

Personnel involved in the process-planning activities establish the over-all manufacturing plan by analysing the design data and the drawing of the part. Tooling, fixturing, and cutter characteristics are specified, and a process operations sheet is prepared, defining the machine setup, the sequence of roughing and finishing operations, and the fixture and tool changes. The methods to be used in programming the part are determined, and so is the programming language. The management plan is also prepared by the process planner. It consists of the estimated cost, schedule, and equipment requirements for all production activities.

Process planners usually have at least two years of experience in tool and process design coupled with a wide background in shop mathematics. They should be qualified machinists or machining planners. Where these skills are scarce, a machinist, machine planner, or machine fixture designer may well be suitable if he has a working knowledge of geometry and trigonometry.

PROGRAMMING THE PART

The programmer works from the data and instructions provided by the planning section and therefore uses a somewhat different set of skills. The programmer analyses the blueprint, studies the tooling and cutter requirements, and evaluates the machining sequence specified on the operation sheet. Depending upon the complexity of the part, the programmer then completely defines the path of the cutting tool by developing the beginning and ending points for each segment of the tool path. The programmer codes the machining operation and records the commands on the programming form according to the conventions of the part-programming language used. Upon completion of the programming form, a tape is prepared —usually with the help of a computer. The tape is then verified.

Besides the tape, the programmer provides the machine-tool operator with a part diagram which graphically illustrates the cutter paths and fixture procedures. The diagram includes a written explanation of the machining operations; it specifies the programmed stops, the work to be performed during the stops, and the cutting-tool numbers. Descriptions of other data pertinent to the machining operation also appear on the diagram with whatever written comments may be relevant.

Provided the process has been properly designed by the process planner, no actual machine shop, machine planning, or tools design experience is required of the part programmer. The skills required of his function are much easier to meet than those of the process planner. It is important that those involved in the machine-tool industry of developing countries know of this difference in skills. Numerical control users who organize the part programming and planning activities separately, find that recent graduates of two-year colleges whose main subject is mathematics, science, or mechanical technology make excellent programming personnel after a minimum of in-house training. Classroom training introduces the former students to the programming conventions. A three-week, 120-hour indoctrination session has been adequate to familiarize new personnel with the basic conventions of even the most complex languages. Some complex languages can be mastered in a one-week period; a few as quickly as one day.

On-the-job training activities follow the classroom session. While individual productivity is slight at the outset, most programmers are proficient within one to six months.

TRANSFERRING THE TAPE TO THE SHOP

Transferring the proven tape to the machine operator is the third distinct operation of part programming. The desired qualifications of personnel who transfer the tape and communicate the processing instructions to the shop should be roughly equivalent to those of the personnel in planning. There is an important exception: liaison personnel require only a general knowledge of mathematics and computers.

The primary responsibility of the liaison personnel is to make sure that the machine operators thoroughly understand the operation plan. They explain the diagram and the operations sheet to the machinist, monitor the mounting of the fixture on the numerically controlled equipment, supervise the location of the workpiece in the fixture, and provide surveillance during the processing of the first piece. They also mark up any corrections required in the manufacturing plan or the programmed tape. Once the first part is successfully produced by the tape, the liaison personnel advise the planning personnel of any problems or suggested changes for the tape or the process plan.

The skills required by the liaison personnel are usually present in the typical machine shop. Qualified machinists who have good communication abilities often make excellent liaison personnel after some introduction to the numerical control concepts.

The major topics to be covered in part-programming training programmes are presented below. For simplicity, the process-planning and part-programming activities are assumed to be performed by one person.

(a) The programmer must be able to interpret the part drawing. From this drawing, the positioning and fixturing of the part on the machine tool are determined. The logical order

of machining operations, together with appropriate cutting tools and their feeds and speeds are specified.

(b) The programmer must be capable of determining proper machining feed and speed rates and the rotational speed of the workpiece or cutting tool—as influenced by the chip load, the durability of the machine tool, the work material, and the type of cutting tool. Many users of numerical control find that programmers with a few years of college quickly learn how to set proper machining rates from machinability charts and tables.

(c) Programming requires the proficient use of shop mathematics, including basic arithmetic, algebra, plane and solid geometry, and trigonometry. The ability to use higher mathematics, including analytic geometry, calculus, vector analysis, will improve the programmer's effectiveness.

(d) A thorough understanding of all the numerical control principles from process planning to inspection of the finished part is required. Of particular significance is the necessity for the programmer to understand thoroughly the capabilities and limitations of the machine tool and the numerical control system.

(e) Where the computer is used to aid part programming, knowledge of the following is also valuable.

  (i) The conventions, capabilities and limitations of the part-programming language.

  (ii) Vocabulary and rules for completing the programming manuscript from which the tape or the computer-data cards can be punched.

  (iii) Interpretation of the computer print-out, including the diagnostic comments an the coded statements.

The art of part programming should not be taught as theory only. Acquiring programming skill is like learning to ride a bicycle; the learning is considerably more effective if it includes practice.

With the proper structuring of part-programmer training, inexperienced personnel can be speedily taught to programme tapes for numerically controlled machine tools. The tape will machine parts with higher precision and productivity standards than can be achieved by the most experienced conventional machinists. Mistakes can be expected from the relatively inexperienced programming personnel; potentially good programmers, however, learn quickly from their errors. Although extensive training is required to programme four- and five-axis parts, some companies have successfully taught female secretaries with a good mathematics background to programme the less complex parts.

OPERATORS FOR NUMERICALLY-CONTROLLED MACHINE TOOLS

It is not advisable initially to use unskilled machine operators for numerical control. Because the first piece of automated equipment attracts considerable attention from the work force, most new users assign highly qualified machinists to assure the maximum equipment performance. As experience grows, the skills reductions can be realized by replacing the skilled operators with semi-skilled or even unskilled workers. The less qualified personnel have proven most successful where the programmed tapes have been completely verified before the operator uses them, and where the machine setup is not complex. An importants side effect occurs from using inexperienced operators: these workers do not have a store of invalid information which may lead to poor machining practices—practices which result from misinterpreted experience rather than valid metallurgical and machinability theory.

Experiences gained from the training of operators for numerical control show that certain characteristics are desirable for a proficient operator. Such a worker must be able to:

(*a*) Read and understand drawings of machine parts.
(*b*) Verify that the geometry and dimensions of the cutting tool adhere to the manufacturing plan.
(c) Load the cutting tools properly into the spindle or tool magazine.
(*d*) Be alert to the development of a metal-cutting problem.
(*e*) Install the fixture accurately on the machine and the workpiece in the fixture.
(*f*) Inspect the workpiece to determine if the operations conform to specifications.
(*g*) Communicate the symptoms of a maintenance or programming problem to supervisory personnel.

Fortunately these seven characteristics can be acquired in days or weeks as contrasted to the one to four years required to qualify a machinist on conventional equipment. The complexity of the application again influences the required length of the training programme. For experienced, but only semi-skilled machinists, a 40-hour training programme is usually adequate for even the most complex five-axis equipment. Unskilled, inexperienced workers have been trained to operate a three-axis drilling machine in less than 8 hours. In the production of some small parts, female workers also have been quickly trained to operate numerically controlled drilling machines.

The major topics to be included in an operator's training programme are:

(*a*) A detailed introduction to the basic concepts of numerical control.

(b) Operational principles of the machine tool and its control system.
(c) A review of the programming of machine parts.
(d) Conventions used to code information on the tape.
(e) Procedures for starting and operating the machine—and the emergency steps to follow when a malfunction occurs.
(f) Setup procedures including the co-ordination of the reference locations on the tape and on the machine tool.
(g) Proper use of measuring instruments for inspection of parts.

NUMERICAL-CONTROL MAINTENANCE PERSONNEL

Workers capable of repairing conventional machine tools which have some type of control apparatus can usually be trained to handle numerical control. Personnel capable of handling the mechanical and hydraulic malfunctions of conventional equipment require little additional skill to cope with these problems when they occur in numerically controlled equipment. A brief orientation programme is usually all that is required.

The maintenance of the electronic control system, however, requires more specialized training. Maintenance personnel who service conventional electric wiring consisting of electromechanical relays and circuit breakers are often bewildered by problems in the photoelectric tape readers, the transistorized control logic, the power supplies or other solid-state circuits. Fortunately, the reliability of today's control systems is so high that only a few workers must undergo the specialized training to maintain them. It is also encouraging that the new control systems with integrated circuits are at least ten times more reliable than the quite reliable earlier controls. The mean time between failures is not only longer, but when a malfunction does occur, the faulty part is more easily identified and replaced.

It is imperative that the maintenance training programme produce at least one maintenance worker who thoroughly understands the complete operating system of the machine tool and the control unit. Such a person must determine the sub-system in which a malfunction is caused, whether it be hydraulic, servomechanism, or electronic. A worker qualified to perform such a complex task will often have had a few years of college and will be familiar with the basic operational and design principles of hydraulic, mechanical, and electronic devices. When the diagnosis has been made, a maintenance technician then can be assigned to repair the equipment.

The topics shown below should be included in training programmes for numerical control maintenance personnel:

(*a*) A detailed introduction to the basic concepts of numerical control.
(*b*) Conventions used to code information on the tape.
(*c*) Capabilities of the machine-tool and control system.
(*d*) Binary arithmetic.
(*e*) Control theory in design and operation.
(*f*) Interpretation of electronic circuit drawings and diagrams.
(*g*) Step-by-step procedures for diagnosing a simple malfunction.

TOPIC OUTLINE FOR ELECTRONICS TRAINING PROGRAMME

The outline of a course for training electronic maintenance personnel used by a large numerical control user is shown below. The teaching staff for such a programme may need to be recruited from a technical university in the developing country. Since only a few people will need training at this level, it may be more efficient to send the trainees to the campus for the specially structured course.

(*a*) Screening examination
(*b*) Direct current (d. c.) theory
  Magnetism
  Current, voltage, and resistance
  Ohm's law for d. c.
  Circuits, series, parallel, complex
  Electromagnetism
  Induced electromotive force
  Inductance
  Evaluation examination
(*c*) Alternating current (a.c.) theory
  A. c. theory
  Inductance
  Capacitance
  Resonance and tuned circuits
  Transformers
  Evaluation examination
(*d*) Tube theory and circuits
  Electron emission and diodes
  Basic triode action
  Multigrid tubes
  Amplifiers power
  Coupling methods
  Wide-band amplifiers
  Audio amplifiers
  Radiofrequency amplifiers
  Oscillators
  Evaluation examination
(*e*) Transistor theory and circuits
  Semiconductor fundamentals
  Transistor fundamentals
  Bias stabilization
  Characteristic curves and charts
  Audio amplifiers
  Tuned amplifiers
  Wide-band amplifiers

Oscillators
Measurements
Evaluation examination

(*f*) Fundamentals of binary numbers and logic
Binary system
Binary arithmetic
Boolean or logical algebra
"And" operation
"Or" operation
"Nor" operation
Inverters
Boolean equations
Evaluation examination

(*g*) Logic circuits and applications
Fundamentals of pulse circuits
Multivibrators
Logic gates
Flip-flops
Counters
Delay lines
Typical application of logic functions
Evaluation examination

(*h*) Integrated and hybrid circuits

(*i*) Intermediate systems and servo-loops
Feedback fundamentals
Resolvers
Synchros and servos
Applications
Detection
Command and error signal generation
Closed-loop system
Digital to analogue conversion
Types of servo drive
Evaluation examination

(*j*) Final examination

Where the equipment is complex at least two maintenance personnel should undergo the advanced electronics training. The duration of the training period for maintenance technicians will depend upon the skill levels of the trainee and the complexity of the equipment. One very effective training programme used by a large aircraft manufacturer lasts 10 weeks or 400 hours. Trainees spend four hours each day in the classroom and four hours in laboratory work. Several companies thoroughly train one or two high-level personnel, e. g., college graduate engineers, who in turn train the maintenance technicians on the job.

SUMMARY OF SKILL SHIFTS

Clearly, beneficial skill reductions are possible through the use of numerical control. Not surprisingly, however, these potential skill reductions involve re-training so as to facilitate effective programming; some upgrading of maintenance skills must also take place. The re-alignment of skills has meant that more college trained personnel are attracted by the new opportunities available in the metalworking industry. The use of computers and numerical controls seems to awaken the interest of engineers in toolmaking. The resulting influx has lessened the shortage of scarce professional talent with mechanical skills, and as these new professionals have become proficient in their jobs, the number of machinists and tool or die finishers required for a given level of output has decreased.

THE USE OF NUMERICAL CONTROL IN TOOLMAKING BY INDUSTRIES IN DEVELOPED COUNTRIES

Although many of the foregoing examples are from American applications, industries in several other countries—England, France, Germany, Italy, Japan, and Scotland—are also making significant advances in the application of numerical control. Because of the relatively high wage rates in the United States, US industries are using numerical control for toolmaking more than similar industries in other countries.

ELECTROCHEMICAL MACHINING (ECM) IN TOOLMAKING

As rates of electrode wear and rates of metal removal increase, electrical discharge machining (EDM) in toolmaking will be used more and more. When current EDM capabilities become relatively costly, and conventional processes prove physically or economically unfeasible, electrochemical machining may be a solution.

Electrochemical machining (ECM), though only a few years old, has already produced labour savings and quality improvements similar to those achieved through EDM. In addition, ECM can achieve considerably higher removal rates with practically no electrode wear. The successful applications of this process include production of parts without burrs or mechanical stresses, the deburring of conventionally machined parts, and the production of forging dies where more than one of a kind are involved. Metal-removal rates in forging die applications have been as high as 200 cubic inches an hour —considerably above EDM's present maximum of 100 cubic inches an hour.

ECM, with its higher equipment and electrode costs, is sometimes difficult to justify for one-of-a-kind toolmaking applications. On the other hand, EDM electrode preparation is relatively simple and is therefore more likely to be economical in the machining of one-of-a-kind dies or moulds. Of particular significance to developing countries, however, is ECM's versatility. In one operation ECM can perform the mechanical equivalent of several operations and eliminate the need for turning, planing, milling, grinding, and drilling—all at one setting on one machine by one operator.

FUNDAMENTALS OF ELECTROCHEMICAL MACHINING

ECM is basically similar to EDM yet the process details differ greatly. Essentially, ECM reverses the electroplating process. A chemical reaction dissolves metal from a workpiece into an electrolyte solution. Direct current passes through the electrolyte between the negative electrode tool and the positive workpiece. The resulting action creates an electrolytic cell that causes metal removal to take place ahead of the electrode as it advances toward the workpiece. Since the electrolyte flows to the front end of the electrode into the machining gap between the tool and the workpiece and flows out around the outer part of the electrode, insulation is required outside of the electrode to prevent machining action on the sides of the tool.

The basic elements of the ECM process are:

(a) An electrically conducting electrode,
(b) An electrically conducting workpiece,
(c) An electrolyte,
(d) A current source.

Electrode

Since it affects the other elements in the electrolytic cell, the most important element in the ECM process is the electrode or the tool. The conducting electrode, apart from low electrical resistance, has certain other fundamental characteristics which are important to the success of the process:

(a) It must be chemically inert to the reaction.
(b) It must be strong and rigid.
(c) It is negatively charged.
(d) Its shape determines the shape machined in the part.

The accuracy of ECM depends upon the precision of the electrode. The shape and precision of the electrode, however, are only two of the many aspects of concern; another is its surface finish. The roughness or smoothness of the electrode surface affects the surface of the machined part. As in EDM, the ECM electrode requires skilful preparation, and can sometimes be costly. More skill is required to produce an ECM electrode than an EDM electrode since it must properly conduct the electrolyte solution—sometimes at a demanding pressure — and have adequate insulation to ward off the undesirable machining action that may occur when the ECM tool interfaces the electrolyte and the workpiece.

Once prepared, however, the ECM electrode can machine thousands of parts. The insignificant abrasion caused by the electrolyte passing over the electrode is the only wear on the ECM tool. No single material is best for all applications; brass, stainless steel, and copper have all been used successfully for ECM electrodes.

Electrolyte

For the machining of ferrous metals, sodium chloride in water is the commonest electrolyte. It has good electrical conductivity, is non-toxic, reasonably safe, and is widely available at a reasonable cost. Although sodium chloride like most electrolytes is corrosive, this limitation can be controlled with proper precautions. Sodium nitrate and, occasionally, sulphuric or hydrochloric acid, have also been used as electrolytes. The following are essential characteristics of the ECM electrolyte:

(a) It is a strongly ionized concentrated solution.
(b) It has high specific conductance.
(c) It operates under 40 to 150 psi pressure.
(d) It operates from 100°—140° F.
(e) It removes chemical reaction products from the machining zone.

The electrolyte also removes the heat generated in the ECM process. Nearly all the energy used in de-plating and pumping the solution is transferred into the electrolyte—a 10,000-amp machining operation at 18 volts can generate up to 800,000 British thermal units per hour. Since the performance of the electrolyte is affected by variations in temperature, an electrolyte cooling system often is necessary.

Electrolyte resistivity is also influenced by the presence of impurities. The sludge impurities added to the electrolyte as it carries debris from the gap must be removed from the electrolyte to maintain the proper concentration. Metal oxides or hydroxides of about 1.0 micron in size are the usual products of metal removal. Four methods have been used to filter these minute impurities from the electrolyte.

(a) The run-and-dump method — the electrolyte is used until it is too dirty to be effective; it is then discarded;
(b) Centrifugal separation;
(c) Sedimentation through a settling tank;
(d) The use of a clarifier.

Centrifugal separation has been the most commonly used method of removing the sludge. In one popular centrifugal system, a sump pump moves the contaminated electrolyte from one container into a centrifuge where it is clarified. The clean electrolyte is then drained into a storage reservoir and is subsequently passed back to the machining gap through the electrode. Many of the newer centrifuges use a self-cleaning metallic filter. The centrifuge, which must be made of stainless steel, can be quite expensive.

The run-and-dump method is still used in smaller operations. In large operations, where the ECM equipment must be shut down during the dump process, this method usually proves uneconomical and filtering instrumentation is installed. Where sedimentation is used, settling tanks may be as large as swimming pools. The large volume of electrolyte required for such a system creates an effective heat sink which helps to control the electrolyte temperature.

The clarifier, an accelerated settling system, is about twice the size of a comparable centrifuge and only half as costly.

Today, the filtration problem is not as serious a hindrance to ECM equipment as it was at first. Nevertheless, some of the cleaning equipment can be quite costly. That EDM can be used without a filtration device is another reason why EDM is more popular for toolmaking.

Electrical current source

The power source for electrochemical machining is the same type of d. c. power supply that is used for electroplating. It provides current from 500 to 10,000 amp at from 6 to 24 volts. Its response must be rapid to prevent damage to the electrode.

Workpiece

The workpiece must be a positively charged electrical conductor. The current density on the workpiece material will influence ECM's effectiveness. For example, to remove 0.1 cubic inch of metal per minute, 1,100 amp per square inch are required for iron or steel and 1,490 amp per square inch for titanium. The metal removal rate is directly proportional to the total current passing through the tool and electrolyte to the workpiece. The rate at which metal is removed from the workpiece is a function of Faraday's law, which states that for each faraday of electricity (96,500 coulombs) that passes through the electrolyte, one gram equivalent weight of matter is liberated from the anode.

As in EDM, the workpiece hardness does not affect the process characteristics; furthermore, and in contrast to EDM, the metallurgical characteristics of the workpiece remain unchanged by the process. ECM, therefore, does not cause many undesirable surface effects that can occur from the mechanical or thermal shock inherent in some conventional machining or grinding operations. ECM surfaces usually have better wear, friction, and corrosion characteristics than mechanically finished surfaces. Very little hand finishing is required since surface finishes of the order of 30 to 60 microinches can be achieved. Finishes as good as 5 to 10 microinches have been reported.

Other material properties such as the grain size also affect the surface finish. The use of ECM, on a coarse-grained structure such as cast iron, produces a rough surface finish, while a fine-grained structure, for example, heat-treated steel, receives a much smoother finish.

THE ROLES OF ECM AND EDM

At present, although EDM's metal removal rate is lower than ECM's, the added operational cost of using ECM for the production of one-of-a-kind tools and dies is often difficult to justify. At the present state of development EDM is comparatively useful for the manufacture of one-of-a-kind items while ECM is more effective where the batches are larger. ECM has been effectively applied to four types of machining operation: round or square through holes, blind holes, cavity sinking, and planing. ECM is most commonly used to machine precision parts in small lots, especially those of complex shape or of unusual hardness.

The need to develop a small-batch machining capability in a tool and die industry is demonstrated by American industry where approximately 25 per cent of the output is in very small batches of precision-machined parts. ECM produces more and more of these precision parts for customers who dislike tooling-up for such small runs. Tool and die shops with ECM equipment are ideally prepared to provide such vital support to metalworking industries.

Even though one-of-a-kind tool and die manufacture is expensive, ECM is expected to be popular in the future because the need for complex machining in small batches in some metalworking industries is even greater. So valuable is ECM in low-volume machining, that by 1970, it is expected to be more used in the United States than EDM.

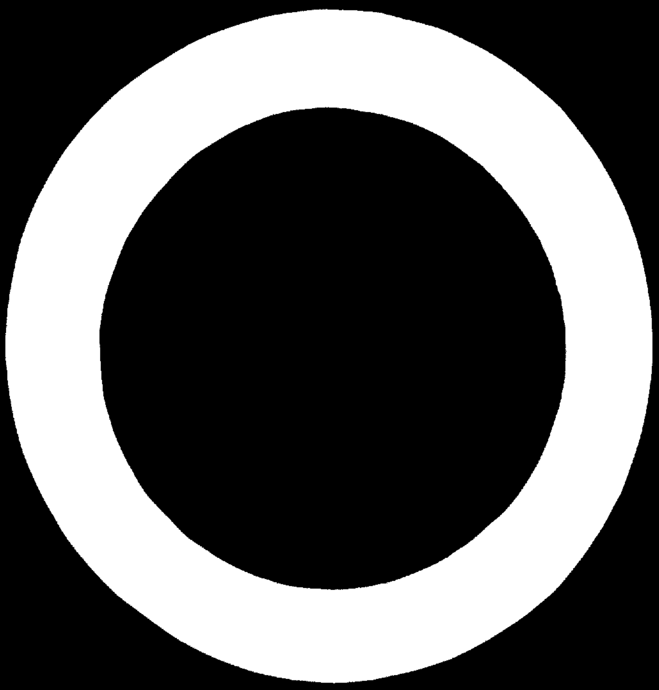
The demand for support machining services is believed to be present in most industries in developing countries—especially where mass markets are absent. It is often difficult for manufacturers with limited markets to justify the costs of preparing tooling for their small-to-medium lot sizes. These manufacturers need reliable support from the domestic tool and die industry. Manufacturing processes such as ECM, that are readily tooled-up for a small batch of precision parts, may be the key to supplying the needed support.

SKILL IMPACT

ECM provides labour savings and skill reductions similar to those achieved through EDM. ECM, however, is a more complex process, and the skills required to implement it are considerably greater than those for EDM. ECM introduces scientific phenomena which are new and quite unfamiliar to the typical metalworking environment. The effective application of ECM requires knowledge not only of electrochemical principles, but the full comprehension of their relationship to conventional metalworking concepts and practices. Even in industrialized countries, it is difficult to find engineers possessing the necessary combination of scientific education and training in both electrochemistry and metalworking.

The introduction of ECM into a developing country can be hastened by making ECM equipment available at a university or a research institute. Educators in American universities have observed that engineering students naturally become inquisitive and involved in a new or unique piece of equipment and attempt to apply it to practical problems; later they are often attracted to the industry which uses the equipment.

A resurgence of interest by graduate engineers has occurred in the United States' metalworking industries because of the excitement in becoming involved in the development and application of new technologies such as ECM and EDM, numerical control and computers. As this infusion of professional talent grows, metalworking operations become less dependent upon the skills of machinists and toolmakers.



PROPOSALS FOR SETTING UP LENDING STATIONS IN INDIA FOR HIRING OUT JIGS AND FIXTURES*

*Laszlo Dobos and K. Venkatanarayanan***

TOOLING PLAYS A major role in the development of any industry. In the metalworking industry jigs and fixtures or special tooling (or both) are used if

(a) the job cannot be done without them;
(b) the requisite accuracy for interchangeability cannot be obtained without them; and
(c) with them the products can be machined more quickly in larger quantities, and by semi-skilled labour.

In manufacturing, the judicious use of jigs and fixtures increases productivity, enhances quality and reduces cost.

It has been found in practice that 80 per cent of the chip-removing operations in the metalworking industry need jigs and fixtures. As the varieties of engineering products increase, the demand for jigs and fixtures also increases. In India, the development of tooling has not kept pace with the development of industry, especially in the small-scale sector.

TOOLING IN INDIA IN THE SMALL-SCALE SECTOR

The authorities entrusted with the development of small industries in India have recognized well in advance that the foremost condition of development is to provide means for solving the tooling problems of small units. They proceeded to solve this problem in the traditional way, both by an advisory service and by establishing common toolrooms wherever there was a concentration of small units, and by supplying tools, jigs and fixtures.

However, the problem still remains unsolved and the majority of small units are not able to use proper tooling for various reasons,

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* The paper as presented to the expert group included details of proposals for setting up lending stations.

** Small Industries Service Institute, Madras the main ones being *(a)* inordinate delays in getting tools made *(b)* high cost of tools and *(c)* lack of personnel to design both the product and the tool.

Small units often undertake job production for the large-scale sector, and invariably the delivery period is short. To get a jig or fixture made takes more time than they can afford, and they start production without the tooling.

Normally the toolroom demands a design for the tool, or at least a product design, from the unit which places the order. But the small units manufacture their products mostly from samples, and many of them do not have a draughtsman or technician who can make a drawing. This is a handicap.

The pressure on the few good units specializing in manufacture of jigs and fixtures is so great that the supply cannot be met in time, and the cost is high. As a result, the majority of small units, not resorting to jigs and fixtures, work by ordinary production, even where the use of jigs and fixtures is desirable. This ultimately becomes uneconomic, resulting in products of poor quality and low interchangeability.

The tooling problem is so varied and complicated that it will not be possible to solve it by conventional toolrooms alone; other sophisticated methods will have to be adopted to surmount this problem.

SETTING UP LENDING STATIONS IN INDIA

It is felt that the jig and fixture requirements of almost all small and medium-scale units in India can be met by lending stations, except, of course, for units engaged in mass production, where special single-purpose jigs and fixtures may be more economical, and in a few cases where the job is so specialized or complicated that it is impracticable to fabricate a suitable jig or fixture from the jig and fixture systems known as universal, or unitized elements.

In India, lending stations for hiring out jigs and fixtures can be set up which are similar to those already existing in the socialist countries with centrally planned economies, where they have proved themselves in practice. Slight modifications in the equipment stocked, and facilities offered, have to be made to suit Indian conditions. In India, for the lending station to be useful to small units, it must be equipped with a wider range of universal jigs and fixtures and special equipment than in the socialist countries. Such a wider range of equipment is necessary, because the small units in India need considerable equipment to achieve quantity and quality in production. These units cannot afford to buy equipment which is needed only periodically and which often has to be imported at considerable expense. A lending station can hire it out, at economic cost, to many units in succession.

For example, equipment such as pivoted vices, circular tables, universal angle vices, multi-spindle drill heads, are neither stocked nor hired out in the lending stations of the socialist countries. In India, many small units occasionally need such items. They are mostly imported at high cost, since they are not readily available in the home market. The small units could hire these from a lending station whenever they were needed.

Pneumatically operated jigs and fixtures are widely used in the socialist countries, but they cannot easily be used in India since the small units are not normally equipped with the necessary compressed air supply system. This is another modification to be adopted. However, later on, when the level of technology rises, these items can be included without difficulty.

To sum up, it is felt that tooling problems in India can be solved by:

(a) Standardizing the parts and elements of single-purpose jigs and fixtures and encouraging their manufacture in quantity to commercial standards for hire and sale at a reasonable price.

(b) Establishing lending stations to hire out jigs and fixtures made from the jig and fixture systems known as universal or unitized elements.

(c) Setting up conventional toolrooms to meet the demand for single- or special-purpose jigs and fixtures.

(d) Using jig-boring and numerically controlled machines in regular production. The adoption of these new techniques in India is difficult, since these expensive machine tools must be imported.

(e) Providing the existing tool designers with design aids to help them to design in a shorter time. This subject was dealt with in detail by the author in his paper presented at the All India Tool Room Seminar held at Hyderabad in 1965.

ADVANTAGES DERIVED FROM LENDING STATIONS

The advantages and benefits to the nation, and to industrial units, from adopting the lending station system for tooling are many sided.

The benefits to small industrial units are as follows:

(a) *Saving in time:* By hiring it from a lending station, the unit can get the desired tooling within weeks, or in emergency, within a day or two, whereas it may take at least 3 months

to get a tool from an ordinary toolroom. Obtaining a good jig or fixture in such a short time is a very great advantage, especially for parts that have to be made quickly.

(b) *Saving in cost:* By hiring a single-purpose jig or fixture, it can be got at 8 to 12 per cent of the first cost, depending upon the complexity of the tool. It has been found in practice that the cost of hiring is recovered by machining 1,000 pieces in mass production. Even for batch production, tooling expenses are found to be reduced by hiring, compared with the cost of a single-purpose jig or fixture.

(c) *Increase in productivity:* With the availability of a good jig or fixture in a short time and at less cost, many units will find it easy and convenient to use tooling to increase their productivity by 50 to 100 per cent. Also the quality and interchangeability of the product are enhanced. The over-all result is an increase in profits to the unit.

(d) Normally, a drawing of the tool, or at least of the product, has to be provided to get a tool made in a conventional toolroom. Many small units do not have the technical staff to design tools. This problem is eliminated if the tools are hired from the lending station. It is normally sufficient if a sample product is given to the lending station since its staff is trained to visualize the type of jig or fixture needed from this. The product itself enables them to make a sketch of the tool required, and to construct it. This is a great boon to small units.

(e) To replace a broken special-purpose jig or fixture, an assembled jig or fixture can be obtained from a lending station for emergency use until the broken one is repaired or finally replaced. This enables the unit to avoid unnecessary production stoppage. For units manufacturing prototype machines, special-purpose jigs or fixtures are uneconomical. The unit can get any number of assembled jigs or fixtures from a lending station economically.

Viewed at the national level the advantages and economy of lending stations are considerable, as indicated below:

(a) *Saving in material:* Since the materials used in this system are re-usable there is about 80 to 90 per cent saving in material over the conventional method of making a jig or fixture. This 10 to 20 per cent material requirement is for making special elements when needed.

(b) *Saving in time:* The assembly of a tool from a unitized elements jig and fixtures system takes only 5 to 15 per cent of the time required by a conventional method. The time so saved can be used for making other special tools.

(c) *Saving in machine-tool capacity:* Compared with conventional toolmaking, only about 10 per cent of the machine-tool work is involved. This 10 per cent is for making special elements or parts. The machine-tool capacity thus saved can be used for special tools or production purposes.

Some 50 to 80 per cent of the tooling needs of industrial units can be met by lending stations, and what little available toolroom facilities do exist can better be utilized for making special toolings.

(d) The low cost of hiring out a jig will enable more units to use jigs and fixtures, resulting in an over-all increase of productivity and quality of the goods. Their use will facilitate complete interchangeability of parts.

(e) Quality goods at lower cost enhance the possibility of increasing exports and of earning much-needed foreign exchange.

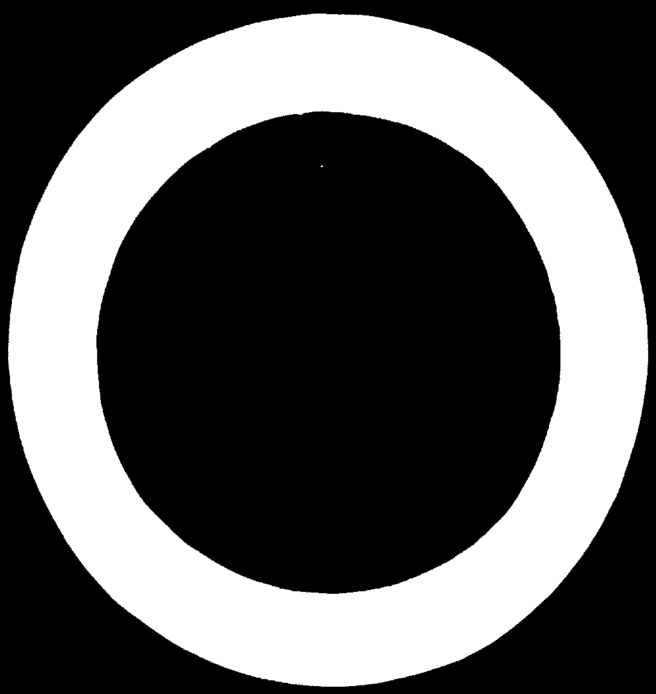
It is worth while to analyse here the advantages derived from a single lending station capable of hiring out 200 jigs and fixtures per month or 2,400 toolings per year.

(a) A jig or fixture weighs from 6 to 60 kg. Assuming an average weight of 20 kg per item, 2,400 items will need 48 tons of material, if made as single-purpose jigs or fixtures. Since there is about 90 per cent material saving in a lending station, the material saved per year works out to about 40 tons, valued at Rs. 40,000.

(b) To make one jig or fixture, about 15 to 50 hours are needed. Taking an average of 30 hours per item, 2,400 items will need 72,000 hours per year by conventional toolmaking methods. Since 5 hours is normally enough to assemble a tool in a lending station, only 12,000 hours are needed. The saving is 60,000 toolmaker hours per year valued at Rs. 60,000.

(c) To make a single-purpose jig or fixture, 3 to 30 hours of good quality machine-tool capacity are needed. Taking an average of 20 hours, 2,400 items need 48,000 hours. In a lending station two machines may be utilized full time, i. e. about 5,000 machine tool hours. Deducting this, the saving in machine-tool capacity is 43,000 hours. In terms of money this may be equivalent to Rs. 172,000.

(d) Therefore it can be seen that a single lending station can save the nation Rs. 272,000 per year. It has been found in practice that a lending station can pay off its cost within two to three years. Therefore a lending station not only supplies the needs of a developing country as a servicing centre, but is also a good financial proposition.



INTERRELATION OF PRODUCT DESIGN WITH DEVELOPMENT, DESIGN AND PRODUCTION OF DIES AND JIGS

H. Weseslindtner[*]

THE PRODUCT

THE TOOLS, the material, the machine and the shape of the product determine the order of each manufacturing process. These process conditions generally allow variability in manfucture within certain limits.

The aim of production enables one to decide to what extent the procedure is economic. Decisions about combining economic processes and about the ideal production process are based upon an understanding of each single process, and the application of equipment and tools, of dies and jigs.

The main target is the product itself and the achievement of its functions at a minimum cost.

Once these functions are determined, and divided into main and subsidiary functions, the cost of each function can be examined in order to find out about its suitability, or to find other, less expensive ways of achieving the same functions.

By so doing we imply that the apparatus or the part concerned is necessary to achieve the function. In this system two distinctive features appear:

(1) An examination of functions, and
(2) A conscious aim to cut costs.

THE VALUE OF A PRODUCT

The value of a product is not a specific quality of its manufactured parts and products, but is determined by a number of factors. In practice in order to avoid unnecessary complication, the value may be looked at as merely the sum of the costs. Value is thus

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defined as the smallest possible amount of money which has to be spent in manufacturing a product, and so includes the costs of material and production (dies and jigs), in order to produce the required usability and validity.

The full value is possibly never achieved. The extent of the value of a product depends on the effectiveness of study and application of all usable ideas, procedures, materials and methods, dies and jigs, suitable for solving the problem.

Special techniques and special knowledge help to make better combinations of materials, working procedures, dies and jigs, and to create the value of the product with less expenditure of time and money than previously.

Generally value is considered good when the product contains somewhat better combinations, ideas, working procedures, materials, and more advantageous use of tools, dies, jigs, equipment and functions, in proportion to the costs involved, than the competitor's product.

VALUE ANALYSIS

Value analysis, developed in the United States for about twenty years, is a systematic method of minimizing costs, that begins with design. It includes the function as an essential dimension which is especially stressed. Value analysis, beginning with the function asks therefore: Can the product be shaped, manufactured or acquired differently, so that the function of the product (which must be constructible) can be achieved at low cost?

A definite answer to this question must be given by means of value analysis. Thus value analysis can be applied to anything that has a function and causes costs, such as products and activities. The aim to minimize cost leads to intense co-operation among all units responsible for the product, especially the departments of design, manufacture and sales.

Suggestions for minimizing cost, after they have been examined and put into effect, will tend to bring the production cost closer to the minimum possible at that time, if a systematic search is made for alternative solutions.

The result is characteristic of the method, the particular aim of minimizing costs. Aside from the aim to minimize costs, there are additional purposes to be striven for in connexion with design and manufacture, for instance, designing the product for the most suitable manufacturing process which ensures high quality.

Value analysis results in the conscious use of alternative materials, new work procedures and in better construction of equipment, whether finished, or to be built. It calls the attention of the designer and the manufacturer to the goal of equivalent achievement at lower cost. It uses procedures which will effectively and surely lead to this goal.

MAIN STEPS IN THE ANALYSIS OF THE PRODUCT

Establishing the function

The step of establishing the function is the first task of value analysis. When the function has been established, its costs can be examined.

Evaluation of the function by comparison

The main question: does the function really occur at minimal cost? can be answered by comparisons.

The bigger and more complicated a product is, the greater will the number of necessary comparisons be in order to make the analysis comprehensive enough to find the best value for every function contained in it. This means the analysis of a series of basic functions, which is made by taking the apparatus apart into construction groups, sub-groups and parts.

In this way, the problem changes into a comparison between one material and another, between the manufacture of one part and that of its equivalent, between the application of one manufacturing process and a different process.

Development of value alternatives

In seeking and choosing alternatives, the function must always be the main consideration and not a die, a jig, or the material. It is easy to make the mistake of testing alternatives which influence the constructed function.

But the designer is the first one who should think of the dies and jigs to be used. Finding the best solution is organizing the factors: function of the product; dies and jigs.

Method of applying value analysis

Value analysis demands, first of all, that a valid answer to the following four questions should be worked out:

What is the function of the article?

What does it cost?

What alternatives could accomplish the purpose?

The completeness of the answer to the third question influences, to a great extent, the efficiency and the quality of the increased value achieved. Here too, special attention must be paid to the effect of the equipment, dies and jigs, and of the whole operation.

What would the alternatives cost?

The comparison of the costs of alternatives will lead to a decision as to which operations, which material, which dies and which jigs are to be used.

Example

There is a choice between four procedures. The first one is the traditional one, the second involves using a jig, which cuts down on incidental time. In the third procedure it is assumed that the existing die will be replaced by a top-performance die which reduces the time required for manufacture even more and, finally, using the fourth procedure, we assume that the change of construction of the product allows a further change in manufacture. This procedure requires jigs which cost C_{j4} and dies which cost C_{d4}.

The costs are defined as follows:

	Procedure			
	1	*2*	*3*	*4*
Costs of manufacture per part	C_1	C_2	C_3	C_4
Costs of jigs	—	C_{j2} =	C_{j3}	C_{j4}
Costs of dies	C_{d1}	C_{d2}	C_{d3}	C_{d4}

As can be seen from the graph (figure 1), process 1, i. e. the traditional one, is most economical up to a number of n_1 parts.

As soon as the number of parts grows larger than n_1, the construction or acquisition of a jig is recommended. Because of the use of the jig, the incidental time and the manufacturing costs are both cut.

For a number of parts exceeding n_2, the acquisition of a new die which costs C_{d3} is economical since, by cutting the actual time required, the costs of production are cut, too. Similarly, starting from n_3 parts, procedure 4 is the most economical.

We see from the foregoing that a decisive factor in the choice of procedure and in the construction and development of dies and jigs is the number of parts to be made.

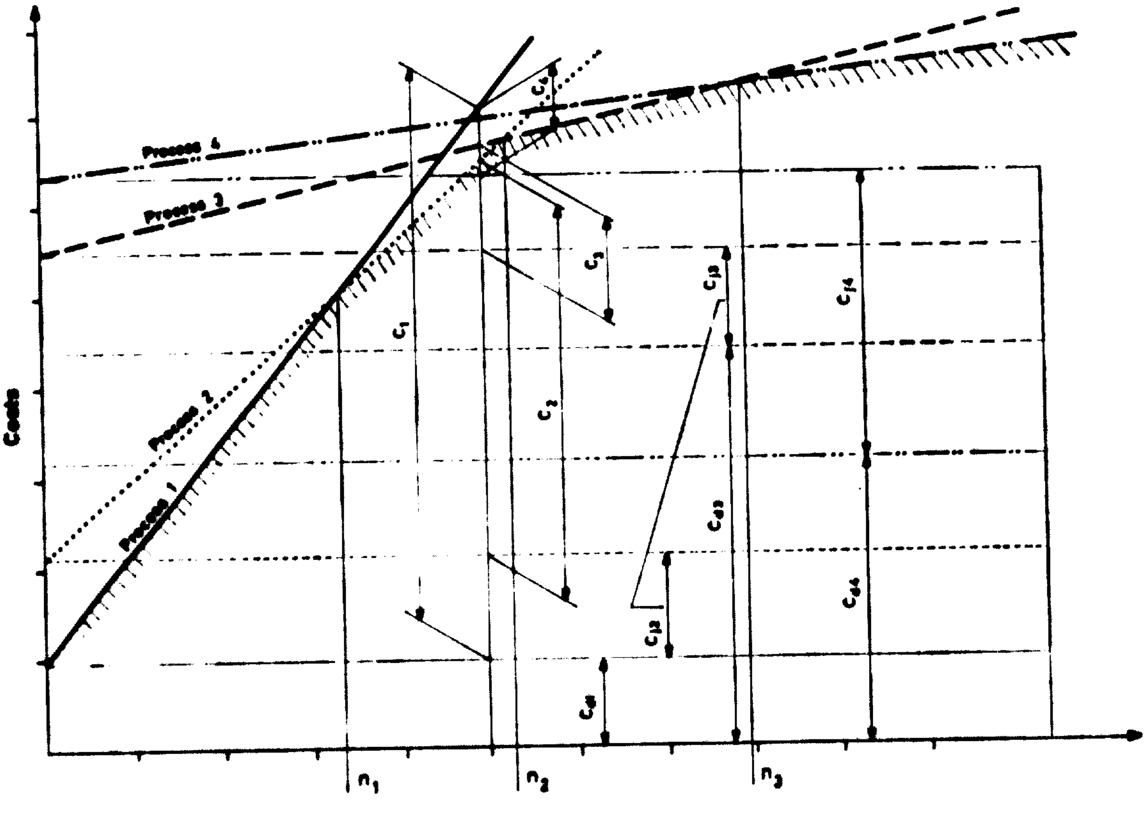

Figure 1. Costs and economic production quantities for four different processes

NUMBER OF PARTS

The number of parts to be made can decide which process is to be chosen, which equipment is to be built, and which dies applied. The number of parts to be produced in a unit of time is vital,

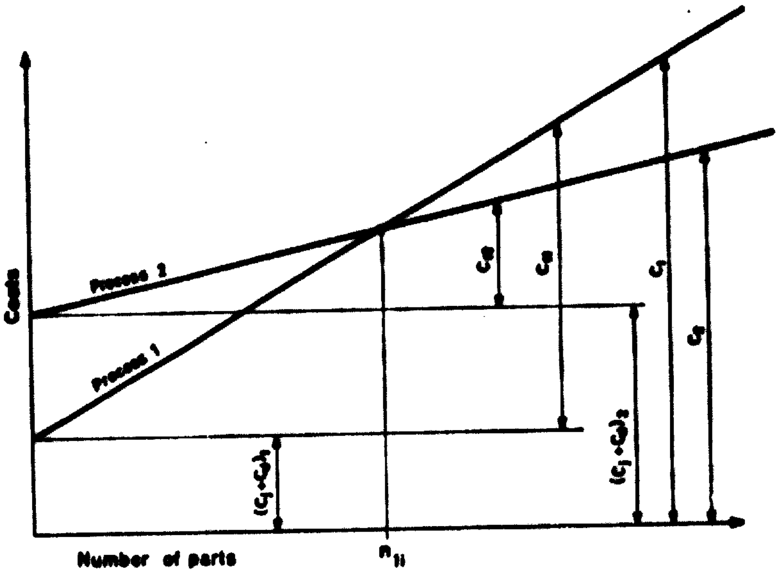

Figure 2. Breakdown of manufacturing costs per part into constant costs and variable costs

whether the unit be a week, a month or a year. In figure 2 let us have a closer mathematical look at the basic example of figure 1.

The costs C_1 of process 1 consist of the constant costs $(C_j + C_d)_1$ (jigs and dies) and the variable costs C_{f1} which increase in proportion to the number of parts produced.

Therefore $C_{f1} = nc_1$, if c_1 stands for the proportional cost per part. The same applies to the costs C_{f2} in process 2.

The graphs for C_1 and C_2 intersect in point e which determines the limit of the number of parts n_{lt}.

Below the number n_{lt} process 1 is more economical, above n_{lt} process 2 is more economical. Mathematically speaking the following is the result:

At $\qquad n_{lt}, C_1 = C_2,$

so $\qquad (C_j + C_d)_1 + n_{lt}c_1 = (C_j + C_d)_2 + n_{lt}c_2$

$$n_{lt} = \frac{(C_j + C_d)_1 - (C_j + C_d)_2}{c_2 - c_1} \tag{1}$$

The number of parts is thus a primary consideration for the choice of process and consequently essential data for deciding the easiest manufacturing method and the most advantageous disposition of dies and jigs.

THE ECONOMICS OF THE RECONDITIONING OF DIES

The reconditioning costs of a die are very important and the time between two processes of reconditioning is called the edge life of a die.

Consider the case of a die used to its limit of capacity in appropriate work. The cost of the die, C_d, per production part is found by dividing the sum of money spent on the die by the number of parts that were produced by it.

The cost consists of the first cost of the die, and the cost of maintenance, mostly sharpening.

Let us call

V_n the value of the new die,
V_r the value of the die at the end of its last edge life, called the remainder value,
n_p the average number of maintenance processes,
V_p the costs of each maintenance.

Then $V_n - V_r$ corresponds to the cost of providing the die, n_pV_p corresponds to the maintenance cost and $(V_n - V_r) + n_pV_p$ corresponds to the amount of money spent on the die.

The number of parts, n, is found by multiplying the average number of parts per edge life, n_t, by the number of edge lives, $(n_p + 1)$.

Thus $$n = n_t\,(n_p + 1).$$

So the costs of the die per production part are

$$C_d = \frac{(V_n - V_r) + n_p V_p}{n}$$

$$= \frac{(V_n - V_r) + n_p V_p}{n_t\,(n_p + 1)} \qquad (2)$$

This relation is valid no matter how many similar parts are made with the die.

If the cost of the die per edge life is C_e

$$C_e = C_d n_t = \frac{(V_n - V_r) + n_p V_p}{n_p + 1} \qquad (3)$$

If E is the edge life in minutes, and T_d the working time of the die in minutes per production part, then

$$n_t = E/T_d,$$

so that the formula can also be written

$$C_d = \frac{T_d}{E} C_e. \qquad (4)$$

If no maintenance work can be done on the die, as sometimes happens,

then $$n_p = 0$$

and $$C_d = \frac{V_n - V_r}{n_t}$$

or since $n_t = n$

$$C_d = \frac{V_n - V_r}{n} \qquad (5)$$

Extra thought is needed for dies with especially high capacity and proportionately long useful life. Does the amount of work to be done or expected completely utilize the die? This applies particularly to special dies with which only some definite production parts can be made, e. g. profile and cutting dies.

If the capacity of a tool cannot be fully utilized we must proceed as follows:

Let us call n'_p the number of maintenance operations necessary for the number m of parts demanded.

Then $$C_d = \frac{(V_n - V_r) + n'_p V_p}{m} \qquad (6)$$

We can then calculate n'_p as follows

$$\frac{n'_p + 1}{n_p + 1} = \frac{m}{n}$$

so

$$n'_p = \left[\frac{m}{n}(n_p + 1)\right] - 1 = \left[\frac{m}{n_t(n_p + 1)}(n_p + 1)\right] - 1 = \frac{m}{n_t} - 1 \qquad (7)$$

If, e. g.

$m = 220{,}000$ units

$n_t = 50{,}000$ units

then

$$n'_p = \frac{220{,}000}{50{,}000} - 1 = 3.4$$

$n'_p = 4$ because only integers are possible

Often, if different kinds of the same die can be used, it is practical to find out the highest possible number of parts it can work.

For each running hour the proportional cost, k_d, of the tool is

$$k_d = \frac{K_d}{T} \text{ if } K_d = \text{total costs}$$

V_n, for tools provided from outside, is the cost price based on the average costs of material in the factory.

If the die failures increase, this is shown up by a diminishing value of n_p and a rising value of V_p. Failures must be reduced to a minimum by appropriate construction. The value of C_d depends very much on the number n_t, which is a measurement of the edge life obtained under constant conditions.

Example

A part to be punched is being designed, and the problem is whether to make the part with a steel cutting die, case 1, or a metalloid one, case 2.

Calculation shows us that with full utilization of the dies, the die costs in case 2 are considerably lower.

Also the time for producing a part decreases, though actual production time, incidental time and distribution time are constant, since metalloid cutting dies do not have to be exchanged so often and consequently the costs of exchanging them decrease too. This saving of time, not being very great, is ignored below.

The time for producing one part, T_w, stays the same

$$T_{w1} = T_{w2}$$

The only kind of costs that must be added to c (c = production cost per part without jigs and dies), are the die costs C_d.

From figure 3 we see that the difference in costs

$$D = C_{d1} - C_{d2}.$$

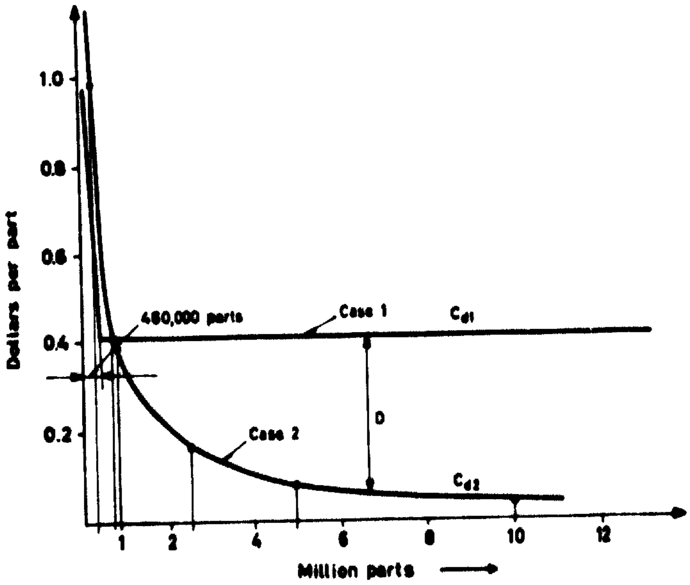

Figure 3. Relation between cost per part and number of parts produced

The following die costs refer not to 1 but 1,000 cutting processes, in order to get suitable values.

Description of cost	*Symbol*	*Unit*	*Value of cost* *Case 1*	*Value of cost* *Case 2*
Original value of die	V_n	$	80	290
Remainder value of die	V_r	$	0	0
Sharpening processes	n_p	No.	22	18
Cost per sharpening process	V_p	$	4.7	5.9
Cutting processes per edge life	n_t	No.	20,000	800,000
Die costs	1,000 C_d	$	0.405	0.026
Cutting processes per die	n	No.	460,000	15,200,000

$$n_1 = n_{t1}(n_{p1} + 1) = 20{,}000 \times (22 + 1) = 460{,}000$$
$$n_2 = n_{t2}(n_{p2} + 1) = 800{,}000 \times (18 + 1) = 15{,}200{,}000$$

Sufficient orders are usually obtained, so that C_{d1} and C_{d2} can be calculated according to the formula for C_d, equation (2).

$$C_{d2} = \frac{(V_n - V_r) + n_p V_p}{n} = \frac{(290 - 0) + (18 \times 5.9)}{15.2 \times 10}$$

$$= \$\ 0.026 \text{ per 1,000 cutting process}$$

$$C_{d1} = \frac{(80 - 0) + (22 \times 4.7)}{460{,}000}$$

$$= \$\ 0.40 \text{ per 1,000 cutting processes}$$

Sufficient orders are usually obtained so that C_d can be calculated. If the number of orders m is lower than n_2 then the following is valid e. g. for

$$m = 5{,}000{,}000$$

$$n'_{p2} = \frac{m}{n_{t2}} - 1 = \frac{5{,}000{,}000}{800{,}000} - 1 = 6$$

$$C'_{d3} = \frac{(V_n - V_r) + n'_p V_p}{m}$$

$$= \frac{290 + 6 \times 5.9}{5{,}000{,}000} = \text{\$ } 0.065 \text{ per } 1{,}000 \text{ cutting processes.}$$

Serial number	*Number of orders*	*Number of sharpening processes* Calculated	Done	*Cost of die* $	*Difference D* $
0	400,000	0	0	0.90	—0.585
1	1,000,000	0.25	1	0.396	0
2	2,500,000	2.12	3	0.158	0.247
3	5,000,000	5.25	6	0.079	0.326
4	10,000,000	11.50	12	0.039	0.366

If the costs are equal, $V_r = 0$

$$C_{d1} = \frac{(V_{n2} - V_{r2}) + n'_p V_{p2}}{m_u}$$

$$= \frac{V_{n2} + [(m_u / n_{t2}) - 1]\, V_{p2}}{m_u}$$

$$m_u = \frac{V_{n2} - V_{p2}}{C_{d1} - (V_{p2}/n_{t2})} = \frac{290 - 5.9}{0.000405 - (5.9/800{,}000)}$$

$$= 714{,}000$$

UTILIZATION OF DIES AND JIGS IN DEVELOPING COUNTRIES

M. Juza[*]

INDUSTRIALIZATION

THE WORLD OF TODAY is marked by violent social and scientific or technical activity. The revolutionary changes taking place in the organizations of the world are disclosing discords, injustices and inequalities that were long hidden. In the forefront of the interests of international institutions are the problems of developing countries. Their huge social inequalities are not only morally inconsistent with the spirit of the twentieth century, but they retard scientific and technical progress even where the objective and subjective conditions exist for it.

Developing countries are now rightly making efforts to reach or approach as closely as possible the standard of economically developed countries. An important means of achieving their economic development is by industrialization. It would be difficult indeed to find, among the world's leading economists, any who would now openly oppose the industrialization of developing countries, particularly from the point of view of their economic development.

A question which remains less clear and, to a certain extent, controversial, is the meaning of industrialization to individual economists. Also unsolved are its methods of realization, how to change the structure of the national economy so as to achieve industrialization.

The difference of opinion arises in part from the fact that everybody who now examines the problems of the development of a less highly developed or backward economy must occupy himself with industrialization to a greater or smaller extent. The present science of economics understands industrialization as a highly complex process. The scope of industrialization is frequently so wide that, for a developing country, it almost merges with the concept of economic development.

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Industry, and its establishment, are considered the foundation of industrialization, yet the concept of industrialization is sometimes identified merely with the development of industry. A more widespread opinion is that much more than industry is required if it is desired to industrialize.

While industrialization is sometimes identified with the development of processing industry, or some of its branches, another concept of industrialization emphasizes that heavy industry, above all, is the foundation of a modern economy and the key to industrialization.

The most general definition of industrialization will be found in a text accepted in May 1963 by the United Nations Committee for Industrial Development. It was worked out by a group of experts whose members were economists representing various schools of thought. This definition, in its final form, reads as follows:

> "Industrialization is a process of economic development in which a growing part of the national resources is mobilized to develop a technically up-to-date, diversified, domestic economic structure characterized by a dynamic manufacturing sector having and producing means of production and consumer goods and capable of assuring a high rate of growth for the economy as a whole and of achieving economic and social progress."

This definition, accepted by the votes of representatives of socialist, advanced capitalist and developing countries, has become a sort of official limitation of the scope and substance of industrialization in the work of the United Nations. It represents progress from the narrow concept of industrialization as a mere development of the processing or, even worse, of only the heavy processing industry. Certain objections could be raised against it, chiefly on the grounds of its general nature and the inadequate expression of the specific problems of the process of industrialization of developing countries.

It disregards at least two important points. Firstly, it does not mention that the countries concerned are agricultural, that is, their main national revenue originates from agriculture, and that it is the very purpose of industrialization to change the build-up of the national revenue in such a way that industry yields the main national revenue. Secondly, in this definition industrialization is dealt with irrespective of the position of the developing countries in the international division of work, even though, in actual fact, the very thing industrialization is expected to do in a conclusive manner is to contribute to the overcoming of economic backwardness, and to the creation of conditions for a fairer international division of work, due to which developing countries would assume a position which corresponds to their resources and possibilities.

The choice of the actual industries which would accelerate the development of the national economy is based on the possibilities of individual countries. Factors impeding the industrialization of developing countries are: a lack of skilled manpower, a lack of capital, a small market and a lack of foreign exchange. The combination of these factors is decisive for the extent, kind and scope of industrial development, also for the methods and priority of the industries to be established, and for the choice of the technology introduced in the developing countries. Most economists believe that, in these countries, it is necessary to develop, side by side, both modern, technically advanced industry with a heavy demand for capital such as a smelting works, and production with a less technically advanced industry based on the employment of a relatively large amount of human labour, such as highway construction or irrigation work.

It is, however, essential to introduce the most modern technology in developing countries, whether it requires a large number of workers or not. At the same time, it must not be forgotten that the period of introduction of a technology in these countries is longer than in advanced countries, and it thus more quickly becomes obsolete. Perhaps only in the production of consumer goods for the home market may it be permitted, for a short time, to introduce a less sophisticated method requiring many relatively unskilled workers.

One of the most important aspects of industrialization is the effectiveness of the newly established industry in connexion with the possibilities of the market. It has been shown that developing countries make efforts, during early industrialization, to replace imported foodstuffs and consumer goods by processing their own raw materials for the home market. However, any industrialization directed inwards must comparatively soon come up against the obstacle of further development, the market being small, and in the course of its progress, starts, true to economic principles, to turn outwards toward branches producing for exports. Thus the industrialization of a developing country, particularly its "strategy and tactics", during the initial period, is closely linked to the international economic position of the country. It necessitates a high productivity of labour, and cannot manage without an extension of the market towards foreign countries, and without a change in the position of economically less highly developed countries in the international division of work.

Modern engineering production is unthinkable without specialized tool shops, or independent works for the manufacture, repair and overhaul of the basic kinds of tool, such as clamping tools, gauges, cutting tools, fixtures, drop-forging dies, metal patterns, and so on. The composition and scope of the tool shops will depend in particular on the nature of the basic production, on the peculiarities of production and organization, and on the whole management structure of the tool shops in the individual works, or in the entire engineering industry. Tool manufacture makes relatively high demands on the skill of production workers, and their technical training must be provided a sufficiently long time in advance. Appreciation is therefore due to the efforts of UNIDO to make in time, and in the required direction, all the preparations for the provision of effective assistance to the developing countries in this field.

A decision concerning the construction of any plant must always be preceded by a technical-commercial feasibility study, in all three of its fundamental stages, i. e.

a guiding feasibility study,
a study prepared on the basis of data ascertained individually, and
a study of the financing.

This technical-commercial feasibility study is the result of a study of technical assumptions of production in the conditions of the country where the construction work is to be done. Its elaboration necessitates a thorough knowledge of the future trend of the national economic policy, and of the range of products of the proposed plant, as well as a thorough analysis of marketing possibilities in both the domestic and the foreign markets.

The closing study for the final decision concerning financing must contain, in addition, a detailed chapter, in which an analysis is made of the financial means which are available, or which it will be necessary and possible to provide.

These technical commercial studies unavoidably require the co-operation of foreign experts and consultants, the carrying-out of extensive laboratory and prototype tests, and a direct investigation in the country concerned. Alternatives must be prepared because various technical processes exist, and also there are several ways of siting the plant.

The process of industrialization which is taking place, and will take place, in developing countries cannot therefore be examined, arranged and planned in some general plane, regardless of the actual conditions of time and space in the various countries. Industrialization takes place under definite existing conditions, and any simplification of this fact, any disregard of many factors affecting this process, would result in a distorted picture.

It is assumed that a decision to erect a plant to make dies and jigs will be taken after a thorough investigation, and that all the peculiarities will be carefully judged in the given country, connected with its degree of industrial development, its further planned development, the specialization of industry by sectors and branches, the possibilities of team work between developing countries, and their co-operation with developed countries.

It is on the quality of this investigation that the decision on a workable plan of investment, and its efficiency in the industry and economy of the developing country, will depend.

CHOICE OF PROJECT

In this connexion, there are important principles which will greatly influence the investment decisions made after the investigation.

First of all, it will be necessary to consider for the industrial region or country under investigation: (1) the most suitable types of works to be proposed for the production of dies and jigs; (2) the regional and country-wide organization of the erection of these works; (3) the possibilities of domestic, as well as international team work; and (4) the need for assistance from developed countries. These are discussed below.

TYPES OF WORKS CONSIDERED FOR PRODUCTION OF DIES AND JIGS

There are four types of works:

(*a*) Those specializing in a definite industrial sector and method, located near an industrial centre for the sector, and with an optimum size of 800 to 1,200 employees.

(*b*) General works for several industrial sectors such as heavy mechanical engineering, each works located near an appropriate industrial centre, and with an optimum size of 1,000 to 1,200 employees.

(*c*) Works specializing in a definite industrial sector, with several specialized units in separate localities, and an optimum number of employees of 300, with central management at the most important production unit, preferably in an industrial and commercial centre. The optimum total number of employees is 1,500 to 2,000. The subordinate production units with special programmes would be located in appropriate industrial regions.

(*d*) General works for several industrial sectors, with several production units and an optimum number of employees of 300, specialized according to industry, and located near the industrial regions, having this specialization. They would be managed by a directing board of a corporation established at the most important production unit, preferably situated in the commercial centre of the country.

Production units, specialized or general, with fewer than 300 employees, are not recommended. Smaller units are not profitable because of the overhead expenses of the directing superstructure, the costs of maintaining the application of modern methods, and effective use of the technical equipment of the production unit.

The project involves detailed consideration, particularly for general production units and corporations, of the diverse production techniques for tools and fixtures, and a suitable general directing organization will therefore be necessary to make production as economical and efficient as possible. This is essential because in each industry different activities predominate. For example:

Electronics involves stamping, forming, and cold extrusion,

Precision engineering involves precise measurements, precision casting, grinding and machining,

General engineering involves cold forming, hot forming, and machining,

Heavy mechanical engineering involves forging, casting, heavy-duty machining.

The lay-out of production, its management, and the technical equipment of the proposed corporation for the production of dies and jigs must therefore always correspond to the structure of all the industries in a given industrial region or in the country concerned. Only then will it be possible to satisfy, flexibly and quickly the requirements of these industries.

REGIONAL AND COUNTRY-WIDE CONSTRUCTION OF WORKS FOR MAKING DIES AND JIGS

It is important to have co-ordination between the general build-up of the national industry and the works proposed for the manufacture of fixtures.

Steps must be taken to avoid duplicate or unprofitable production capacities. The obsolete idea that every industrial establishment, however small, must make its own fixtures and tools results in small tool shops, of 50 to 100 employees, which produce very unfavourably and expensively. This small tool shop depends on the close co-operation of other establishments, both for power machining and for deliveries of parts. At the same time a situation often arises in which the capacity of these small tool shops is insufficient when new production items are being introduced, and remains excessive, even for considerable periods, after the new items are in production.

It is therefore clear beyond doubt that the most favourable solution is to build independent works for making new dies and jigs, in full co-ordination with the capacities and specializations of the individual industrial sectors.

It is necessary, however, to build tool shops and tool grinding shops (even with few employees) at industrial establishments for the purpose of maintaining and repairing dies and jigs. To organize this activity separately from industrial establishments is unprofitable, and not flexible enough for the needs of industry. The whole concept of the organization of regional or government works for making fixtures must not only fit harmoniously into the over-all industrial production, but must also ensure that the works for the manufacture of fixtures and tools can assume the commercial initiative. This means that they must react sensitively to the needs of industry, and adapt their production possibilities in such a way that modernized and new products will appear in the market as quickly as possible.

INTERNATIONAL TEAM WORK BETWEEN DEVELOPING COUNTRIES

The country-wide network of factories for the manufacture of dies and jigs will also make possible extensive co-operation between individual developing countries. First of all, there may be mutual deliveries of special dies and jigs and thus a satisfactory answer will be found to the problems involved in the utilization of capital assets, and in the amortization of investments. It may also be possible to solve in this way the shortage of skilled workers.

Before a decision is made to build a tool-manufacturing works, it would be highly advisable to consider co-operation between friendly developing countries. The co-operation suggested would entail the participating countries becoming general agents for deliveries of a given specialized kind of equipment. For instance, one country could undertake the manufacture of drop-forging dies, pressure diecasting dies, metallic moulds, moulds for plastics, etc., a second country would manufacture difficult tools for the general and precision engineering industries, and a third one for heavy industry. With this arrangement it would, of course, be recognized that each country would erect a plant for manufacturing certain items, and would become the general agent for their deliveries, for which it would have the greatest demand in its own industry. Needless to say, this proposal does not exclude the possibility of several general agents for a given kind of equipment.

Co-operation in this field, between several developing countries, can be extensive indeed, and, at the same time, be guided by an endeavour to achieve a maximum benefit for all the participating countries. These commercial activities would be greatly assisted by the application of standardization in the manufacture of equipment. They would enable the designers of the equipment in each of the participating industrial establishments to choose, without great difficulties, the most advanced technology without fear of any complications in execution.

One example is the use of standard ranges of clamping elements, cutting dies, broaches, benders, cutting tools and unit assembly fixtures.

ASSISTANCE TO DEVELOPING COUNTRIES FROM DEVELOPED COUNTRIES

It is assumed that developed countries will participate in the setting up of works for the manufacture of dies and jigs, first and foremost by supplying: project personnel; technical equipment; licences for technical documents, works organization schemes, standard specifications for special ranges of clamping elements, cutting dies, and so on; experts and consulting services; and assistance in education and training of personnel.

In connexion with the search for a method of education and training of personnel, consideration should be given to the establishment in the individual industrial regions of assembly and lending stations for unit assembly fixtures, simultaneously with the construction of the works for the manufacture of fixtures, or even beforehand.

Many different unit assembly ranges are already being manufactured for the use of the precision, general and heavy engineering industries. From these unit assembly ranges all kinds of clamping fixtures (for turning, milling, welding, grinding) can be assembled. In practice, this is a matter of establishing a stock of unit assembly ranges of components of fixtures, with hydraulic, pneumatic and mechanical clamping elements, and an assembly shop.

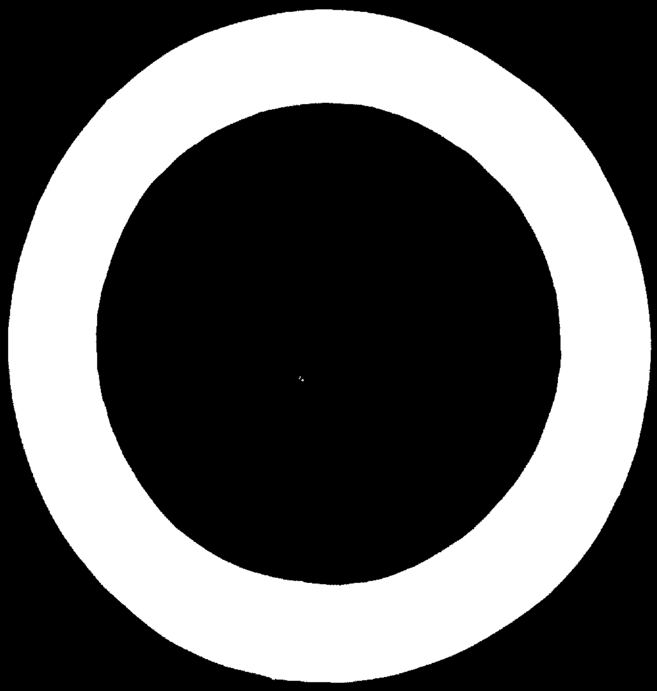
Under the guidance of an experienced engineer, a group of workmen assembles clamping fixtures by bolting together and adjusting unit assembly and clamping elements. The fixtures are assembled directly from a detailed drawing of the work.

The lending station should lend the fixtures for a definite period of time, against the payment of a certain fee, so that their repeated assembly and dismantling can be utilized for training purposes.

In these lending stations it would be possible to train groups of workers as a preparation for their subsequent assignment to more difficult toolmaking and other engineering work. In this manner, several teams could be trained in toolshop attitudes and manual skills in the course of one year.

The possibility cannot be excluded that, under special conditions, an investigation will confirm that a station for lending unit assembly fixtures may be more favourable than a plant for making new fixtures, from the points of view both of economy and of practical achievement. In most cases, however, a lending station for unit assembly fixtures and unit assembly clamping elements can appropriately supplement the production of new fixtures.

Unit assembly clamping fixtures and clamping elements are now being increasingly used. In Czechoslovakia large industrial corporations are manufacturing unit assembly ranges for their own use. In Eastern Germany a specialized corporation has been established for the manufacture of these unit assembly kits and clamping elements.



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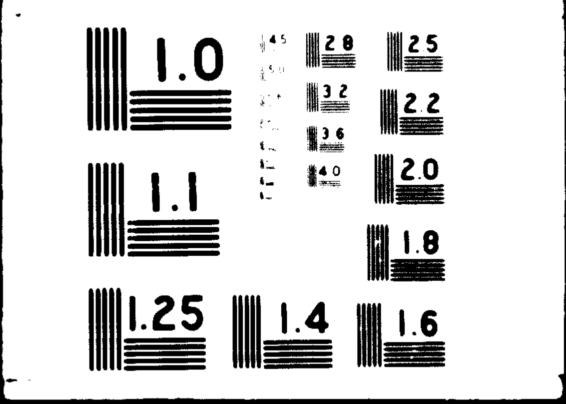


ANNEX I

OPENING STATEMENT BY IBRAHIM H. ABDEL-RAHMAN, EXECUTIVE DIRECTOR OF UNIDO

I WELCOME YOU to this discussion of the design, manufacture and utilization of dies and jigs in developing countries, and I hope that this meeting of experts will contribute to the establishment and improvement of metalworking industries in developing countries.

We here at UNIDO are particularly pleased to note the presence of recognized experts from developing countries as well as from industrially advanced countries. This augurs well for the fruitful collaboration between developing and developed countries in the field of metalworking industries.

Let me outline for you some of the activities of UNIDO in the field of industrialization in general, and in the metalworking section in particular.

UNIDO was established in 1967 as an autonomous organization within the United Nations Secretariat with the primary purpose of assisting in accelerating the rate of industrialization in developing countries.

In broad terms, the objectives of UNIDO are the promotion of a better understanding of the nature of and requirements for industrialization, and of assistance to governments in the process of furthering the economic growth of their countries. To this end, UNIDO is currently engaged in many activities, such as planning and programming for industrial development; formulating and implementing industrial policies; developing particular industrial sectors and specific projects; establishing institutions for the support and promotion of industry; training of personnel; and assisting the establishment and development of small-scale industries and industrial estates.

This work is carried out through three basic types of programme: first, there are technical assistance and advisory services under several United Nations programmes of technical assistance; then there are research projects and substantive support activities; and, finally, there are various international, interregional, regional or ad hoc meetings, such as the one you are attending now.

The subject before you is how best to transfer modern technology to the developing countries, specifically in the field of engineering product manufacturing industries. The application of internationally developed technology in the developing countries requires special examination and follow-up of economic and technological factors that determine the success of industrial enterprises.

With the phenomenal advances in science in recent years, mainly in space research, electronics and telecommunication, a great number of new techniques and processes have been realized, some of which may be suitable for application in developing countries.

Yet the same question arises that has so frequently been raised regarding automation and computers. How many of these innovations can be useful in the industrialization of the developing countries, against the background of shortages of capital and excesses of unskilled manpower?

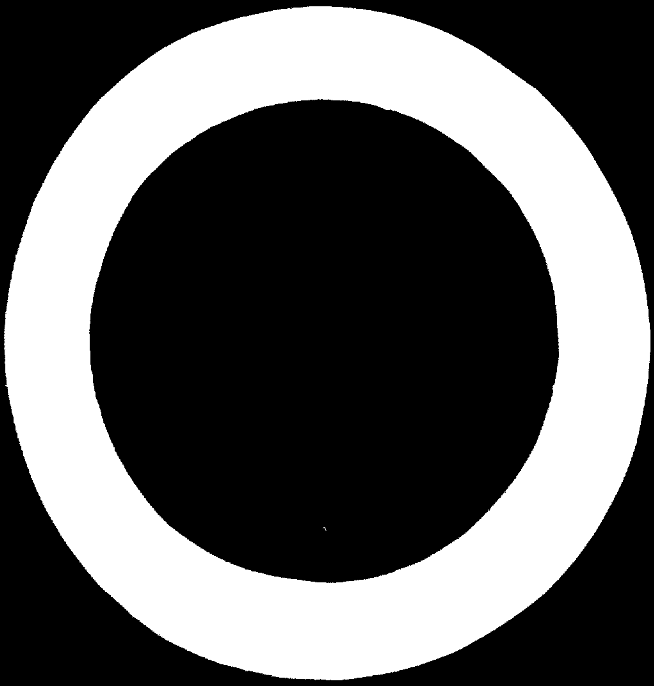
There are other problems to be resolved. One of these is the need on the part of developing countries to increase the amount of manufacturing machinery in general and of machine tools in particular. There are many important factors that must be considered in studying this problem. A country could set up its own production of machinery or rely on imports of machinery from industrialized countries. Yet, it must pay attention to such factors as proper installation of machinery obtained; organization of preventive maintenance and repair; and greater utilization of machinery. An important parameter here is that the number of machine tools per capita in developing countries is still decreasing in comparison to that in advanced countries. This is a serious indication of the growing gap between the developed and developing countries, which, instead of acceleration of industrialization, seems to reflect a relative slowdown in the advance made by the less industrialized countries.

Productivity presents another problem. For instance, the modern technique of cutting tools with throw-away carbide tips, known in developed countries for more than twenty years, has not yet spread sufficiently in developing countries. As a result, low speeds and feeds in machining are used, and the productivity is very low. Also, progressive methods of production, such as pressing, stamping, die casting and plastics moulding of parts, have not been sufficiently introduced in developing countries because of the shortage of skills in the design and making of tools, dies and jigs. Another problem relating to productivity which you may wish to discuss is the use in the developing countries of such sophisticated and new machinery as numerically controlled machines, and the application of modern techniques of die and jig production.

Needless to say, these are only a few problems that may be aired in the course of your meeting. Yet, all these problems are complicated and require the careful examination of all economic, technological and labour factors involved. To facilitate your work, and as your background documentation, UNIDO has prepared or commissioned for preparation by outside consultants several papers on important aspects of the design, manufacture and utilization of dies and jigs in developing countries. A visit to a large machine tool factory near Vienna has also been arranged to enable you to see the application of up-to-date techniques, and to discuss points of common interest with management and plant personnel

All this, we believe, will enable this panel of experts to reach important conclusions and make recommendations for action by developing countries and by UNIDO. We are confident that the nature and form of these recommendations will make possible their successful implementation.

In order to draw conclusions and define its recommendations, this group will, no doubt, examine the following important aspects of the subject matters of this meeting: the current conditions of die and jig production in developing countries; the organizational characteristics of the die and jig shops best suited to the needs of developing countries; the economic implications of die and jig design and production in the metalworking industries of developing countries; and the significance of related labour problems to the performance of this function in developing countries. Because of their particular relevance to the subject here considered, you will also need to examine in more detail the problems of training for the design and manufacture of dies and jigs in developing countries.



ANNEX II

List of documents prepared in connexion with the Expert Group Meeting on Design, Manufacture and Utilization of Dies and Jigs in Developing Countries
Vienna, 10—20 December 1968

Document reference	*Document title*
ID/WG. 24/1	Provision schedule of work
ID/WG. 24/2	List of participants
ID/WG. 24/3	List of documents prepared for the meeting
ID/WG. 24/4*	Die making and metal forming with special reference to developing countries, by J. Dillon, Ford Motor Company, Dearborn, Michigan
ID/WG. 24/5*	Advanced toolmaking techniques for developing countries, by D. N. Smith, University of Michigan
ID/WG. 24/6*	Economic and management aspects of die and jig production, by O. J. Fairbanks, Florida
ID/WG. 24/7*	Design of jigs and dies — its influence on product design, by I. Ham, Pennsylvania State University
ID/WG. 24/8*	Interrelation of product design with development, design and production of dies and jigs, by H. Weseslindtner, Technische Hochschule, Vienna
ID/WG. 24/9*	The design of versatile jigs and dies, each suitable for use in the production of a varied group of parts, by S. Mitrofanov, Leningrad Institute of Precision Mechanics and Optics
ID/WG. 24/10*	Problems of die design and technology of sheet-metal stamping in developing countries, by E. A. Popov, Baumann Higher Technical School, Moscow
ID/WG. 24/11*	Design and manufacture of jigs and fixtures with special reference to developing countries, by V. S. Korsakov, Baumann Higher Technical School, Moscow
ID/WG. 24/12*	Design and manufacture of moulds for plastic parts, by N. Kapustin, Baumann Higher Technical School, Moscow
ID/WG. 24/13*	Report on utilization of dies and jigs in developing countries, by M. Juza, Československa Kolben Danek, Prague
	Proposal for standardizing press tool elements, by L. Dobos, Hungary
	Proposals for setting up lending stations in India for hiring out jigs and fixtures, by L. Dobos, Hungary, and K. Venkatanarayanan, Small Industries Service Institute, Madras
ID/WG. 24/14	The application of precision casting to the tool and die industry, by W. J. Edmonds, The University of Aston in Birmingham, Birmingham, England.

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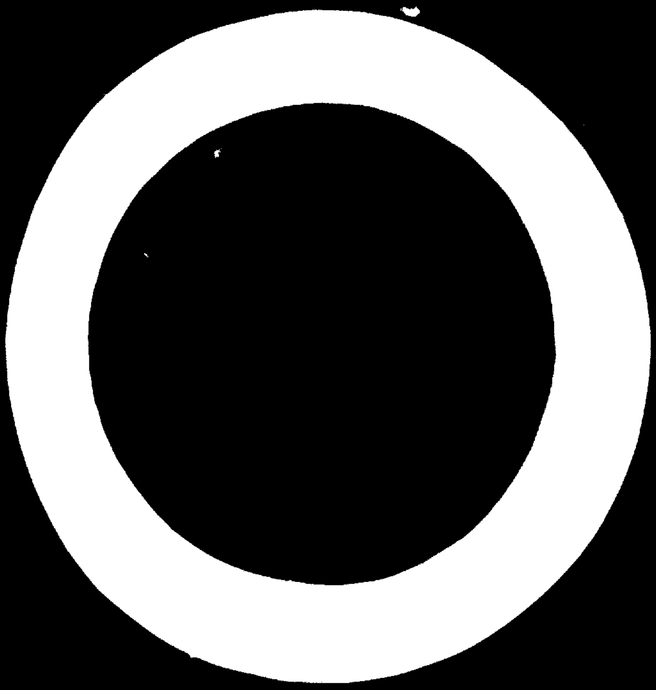
* Prepared by consultants commissioned by UNIDO for this purpose.



ANNEX III

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ANNEX IV

LIMITED GLOSSARY OF CASTING, MOULDING, AND PUNCHING

BANDING DIE: A die for cutting blanks out of sheet, which has cutting edges formed from thin steel strip bent to the required shape and mounted in a die holder. The blanks may be of metal or of other flat material including rubber.

BOLSTER: In a pressing or punching machine, the steel block below the die.

COMPRESSION MOULDING: A process used in the manufacture of articles from thermosetting plastic materials which are heated and compressed into shape in a mould. The mould is usually in two parts, one of which is a plunger that is forced into a hole in the other part, so as to compress the heated thermoset. See injection moulding, transfer moulding.

CORE: A mass of sand or loam in a mould, shaped to form a corresponding cavity in the casting.

CORE PRINTS: Projections from a pattern that make recesses in the mould at points of support for the cores.

DIECASTING: A way of casting metals in permanent moulds or dies. The moulds are usually in two halves that are closed for casting. In gravity diecasting the metal is poured into the die; in pressure diecasting, it is injected.

DRAFT: A taper, or angle from the vertical at which the sides of a pattern are set. It enables the pattern to be withdrawn easily from the mould cavity that it creates.

EJECTOR: Any device which facilitates the removal from a die of a diecasting, a forging, a sheet-metal pressing, or a destructible pattern used for investment casting. It may also remove a moulded plastic article from a mould, the halves of a two-piece shell mould from a pattern plate, or a machined, ground, welded, fabricated, assembled, or inspected component from a jig or fixture. Compare stripper plate.

IN-GATE, or SPRUE: Any channel from the runner along which molten metal passes into a mould, whether it is poured or injected. The term 'sprue' is also used for the entry hole through which wax or other thermoplastic is injected into a die to produce a destructible pattern around which a mould is created in investment casting. Compare runner.

INJECTION MOULDING: A casting method like transfer moulding but used only for thermoplastic, not thermosetting materials. The thermoplastic is heated, and injected under pressure into a mould which may or may not contain inserts. It then cools and is removed.

INSERT: A pre-machined or fabricated piece, such as a threaded stud, which is inserted into a die or mould before injection so as ultimately to form part of the diecasting or plastic moulding.

RUNNER, RUNNER GATE, or POURING GATE: The passage into a mould, through which molten metal is poured or injected. Compare IN-GATE.

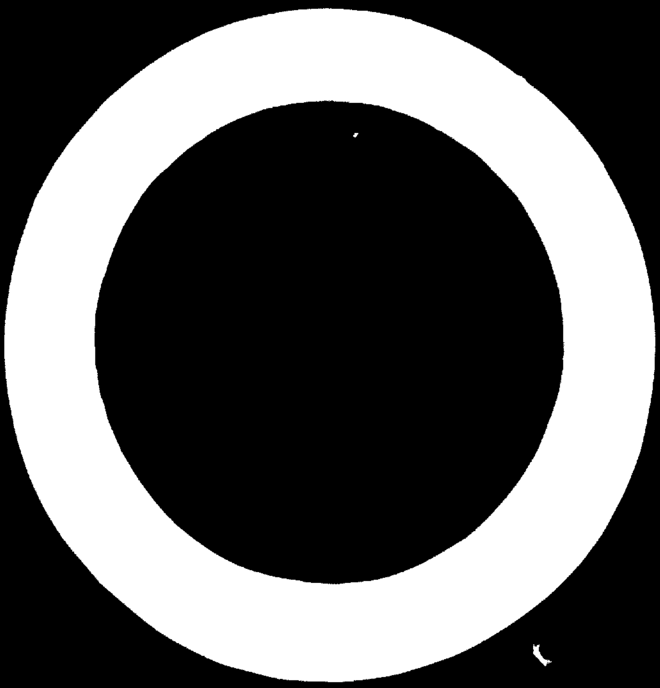
SHELL MOULD: A mould of sand or other refractory material, which is thin walled and therefore uses only a small amount of refractory. Two-piece shell moulds are made by the Croning process in which thermosetting resin-coated sand falls on to a heated pattern plate from a dump box. The pattern plate is inverted and clamped on top of the dump box, forming a lid, the whole is inverted and after a period of time depending on the temperature of the plate, is restored to its original position to allow the unbonded sand particles to be returned to the box. One-piece ceramic shell moulds are made by repeatedly dipping and investing a thermoplastic or thermoplastic-soluble pattern assembly. This builds up a shell around the pattern assembly which is ultimately removed by melting or leaching.

SPLITTER OR SPLITTING JIG: Equipment used for separating the two or more parts of a die or mould after gravity diecasting or injection or transfer moulding.

SPRUE: See IN-GATE.

STRIPPER PLATE: A plate with a clearance hole in it corresponding to the shape of a punch for sheet metal. It is positioned above the material being blanked or pierced, so as to strip it from the punch when the punch returns to the top of its stroke. Compare ejector, and see Part II, Article 1, figure 2.

TRANSFER MOULDING: Like compression moulding, this method is used for forming articles in thermosetting materials. It is used where the inserts to be moulded into the article make compression moulding impracticable. The thermoset is heated in a separate chamber in the mould until it is in a plastic state and is then transferred into the mould itself under pressure.



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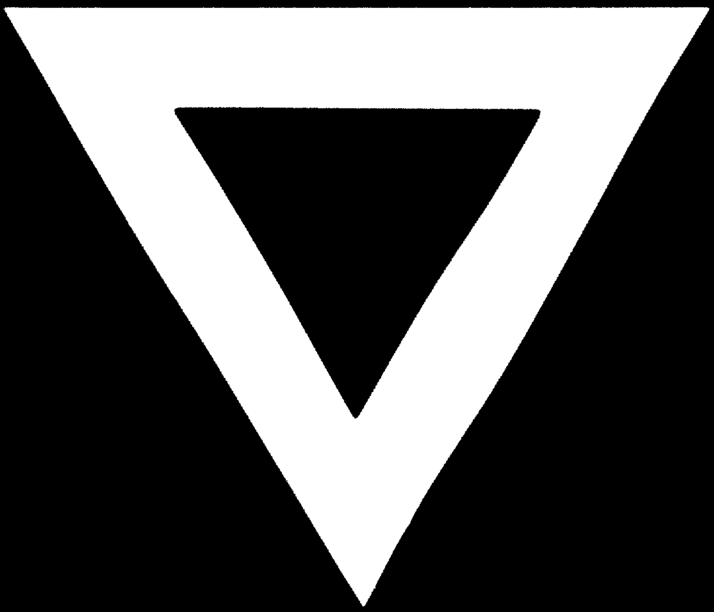

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