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D01239

United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.24/4
14 November 1968

ORIGINAL: ENGLISH

Expert Group Meeting on Design, Manufacture and Utilisation of Dies and Jigs in Developing Countries

Vienna, 9 - 20 December 1968

DIE MAKING AND METAL FORMING WITH SPECIAL REFERENCE TO DEVELOPING COUNTRIES[1]

by

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1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

id.68-3546

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INTRODUCTION

It became evident in a recent study made by a Unido Team at the request of technologically underdeveloped country that a major problem restricting development was inexperience in all types of management skills. Other problems identified as contributing to the low degree of productivity and growth in the diemaking and metal forming field were:

1) Limited knowledge of modern production manufacturing techniques.
2) Inadequate manpower development and training programs.
3) Limited investment capital and high interest rates.
4) Depreciation allowances inadequate and restrictive to new equipment procurement.

The knowledge and application of management techniques in areas of cost preparation and reporting analysis, facility loading, process planning and methods, are absolutely essential to the success of all Metal Working Plants regardless of size, product type, product volume, product mix, and labor content.

COST CONTROL AND ANALYSIS

In most metal-forming and die plants observed by the writer in a former study, the knowledge or use of cost control and analysis principles were not in use. Especially areas of direct product cost.

It was observed that the use and application of a cost control and analysis system was the exception rather than the rule. Labor and other cost elements relating to plant equipment and products, in most cases, were unknown. Maintenance, depreciation, and cost records of machine and perishable tools were rare. Product scrap and repair costs in most cases were not separated from direct production costs. Such information [illegible] is necessary for management control and to create a firm base to develop labor and materials rates per hour for product costs. An important by-product of this informational system is justification of new equipment and process.

FACILITY LOADING

This technique is also a most important management tool. It is essential to know the number of hours per week or month that a given machine is, or can be, utilized.

Some of the machines viewed had as little as 10% utilization, while others were overloaded, but improperly utilized by job selection. There was a bare minimum of machine utilization records, and it is doubtful if many of the shops visited had a detail record of direct labor cost by machining element.

Many plants of approximately the same size in area in personnel producing molds-and-dies had a completely different mix of machines.

Example:

Shop #1	(2) Lathes	(2) Mills	(2) Grinders
Shop #2	(2) Lathes	(5) Mills	(1) Grinder
Shop #3	(6) Lathes	(3) Mills	(2) Grinders

Another important point being overlooked was the lack of justification in using machine and floor space with a relatively high cost per machine hour, when such services could have been purchased from a specialized jobbing service or machining center more economically. The imbalance of machine utilization [illegible] machines on hand, when multiplied by the many plants maintaining equipment for unique operations could be considered excessive and [illegible], and as contributing directly to excessive product cost.

PROCESS PLANNING METHODS

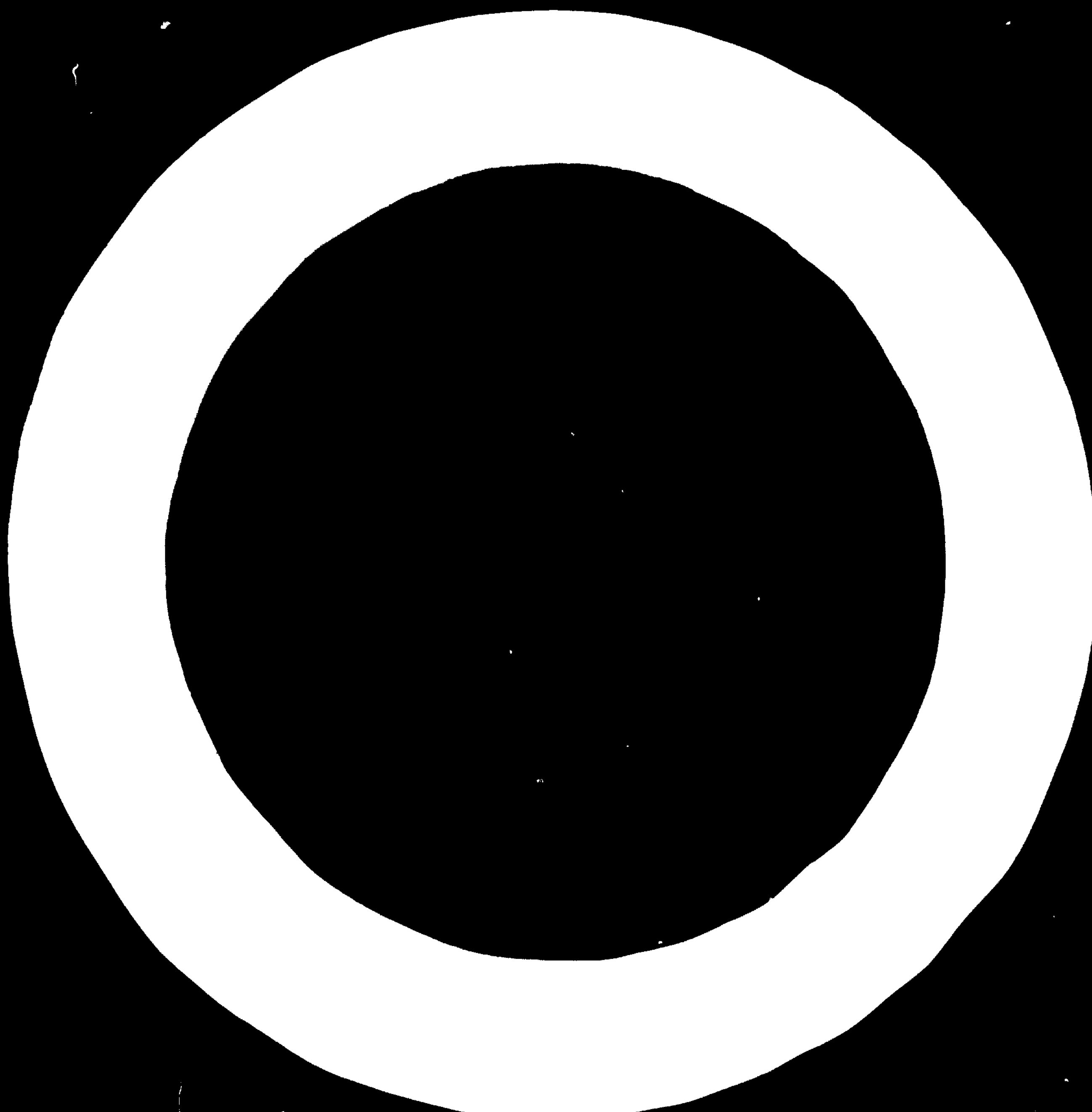
This activity has greater control over product cost than any other.

If a process breakdown and value analysis study had been performed prior to production operations, it would have shown that much work performed by the prime contractor would have been done for less by a subcontractor.

In many plants, considered as medium to large by this underdeveloped country, little or no value was attached to the importance of having an up-to-date and active plant layout.

Work flow diagrams showing material handling from raw stock through machines to finish product were, for all practical purposes, non-existent.

Much improvement of a plant's operation at little cost can be accomplished by better use of methods engineering.



TOOL, DIE AND MOLD INDUSTRY

The structure of the Tool and Die and Mold industry falls within two general classifications, indentified as:

Captive Shop &

(Job Shop) Independent Shop

The captive shop is one whose output is exclusively for the use of a Parent Company. The Parent Company is generally engaged in the manufacture of products other than tooling. i.e. the Ford Motor Company's principal product is automobile manufacturing, while the Ford Tool and Die Plant's principal products are tools and dies for the parent company operations.

The independent shop's principal product is all tools and dies. The independent shop, however, generally supplies more than one customer whose principal product is other than tool and dies.

The peak and valley requirements of tools and dies for industry historically has had an adverse effect on workload continuity, competitive pricing, manpower planning and capital investment of both captive and independent shops. Of the two the independent shop is more vulnerable to these cycles. The captive shop has earlier visibility on volume requirements and has an opportunity to gear for manpower and facility containment, as well as new capital investment, if required, with a reasonable guarantee of return on its investment.

The cative shop also has the added advantage of more balanced workload when tool and die requirements are at a minimum.

In a tooling facility the captive shop has fixed costs that connot be ignored by the parent company--some of these may be identified as building and equipment depreciation, administrative and clerical costs to the parent company, contractural commitments to employes in the form of supplemental unemployment benefits, etc. In addition to these, there is in those unionized plants pressure on parent companies to limit sourcing work to outside contractors, particularly during periods when a reduction in work force is anticipated. All these factors have a significant influence on the parent company in the placement of tool and die orders.

Independent shop union agreements governing the employes' maximum hours to be worked during a period of reduction of work force also have had an adverse effect on the placement of work in the independent shop.

The availability of tooling is the greatest influencing factor in determining the public introduction date of a new product. A highly competitive market and public demand for more sophisticated products, somewhat conditioned by advertising, dictates the cycle of product change and new product introduction. To meet critical target dates, overtime has been inherent in the tool and die industry, and any agreement limiting overtime that results in a reduced work force, forces industry to place in their own captive shops, work of a critical timing nature, that normally and historically would be purchased from the independent shops.

The pricing in the tool and die industry is greatly influenced by the captive shop options. A financially unsound independent tool and die industry with insufficient work load also creates problems for the captive shop. The fierce competition among independents for the limited amount of work available, normally called a soft pricing market, drives the pricing below a normal profit level, and this, in turn, puts pressure on the captive shop to adjust its costs if it is to remain competitive.

Many manufacturing companies have no die construction facility and are entirely dependent upon a source outside their own companies for tool purchases.

The answer in the captive shop has been to automate. The introduction of new technology in the tool and die captive shops has expanded significantly in the past three years and is currently accelerating at a rapid rate. Additional benefits of this process of automating have been improved product quality, a reduction in construction timing, and an overhaul of tool and die design standardization. The large independent tool and die shops are following suit, while some of the smaller ones are going out of business or diversifying. The future of the industry probably lies with the independents supplying tooling of a more specialized nature or that which is not in direct competition with the captive tool and die shops or the major independents.

Most of the changes in the tool and die industry has been the product of economics, pricing in the market place, and the development and availability of the newer technologies. To an industry that has relied over the years on the individual skills of craftsmen without any appreciable increase in productivity, the newer technologies have been revolutionary.

TECHNICAL EDUCATION

The degree of success in upgrading the Tool, Die & Metal Forming Industry in underdeveloped countries will be largely dependent upon the active participation of technical institutions, trades organizations and governmental support.

Most technical institutions are capable of producing excellent engineers whose strength lies in the field of theoretical engineering, science and research; however, there is a positive educational gap between the graduate engineer and the practical industrial engineer required by industry. In many instances the technician is filling the void of the industrial engineer. To suit its need in manufacturing, industry prefers to develope existing personnel than to hire engineering graduates, since, although educational institutions have trained these engineering graduates well in theoritical engineering, they have been deficient in teaching them the more practical application of engineering knowledge.

Cooperative engineering programs similar to the ones operating in the United States would best fit the needs of the industrially underdeveloped nation. This is a four-year program in which the student alternates between theoretical education at the institution and practical application under the tutelage of skilled managers and experienced engineers.

The need can also be filled by providing motivation and incentive to graduate apprentices to participate in continuing educational programs specializing in industrial education, production engineering, and industrial management.

Industrial seminars should be organized by universities or government agencies, and the material presented should originate from private industry managers and production engineers.

In the area of metal forming specialized operations, courses, should be developed with emphasis on such subjects as:-

- Facility loading and planning
- Production programming and control
- Plant layout
- Methods and works standards
- Cost analysis
- Mechanical handling

Special instructional courses for personnel engaged in the manufacture of dies and molds should include:-

- Tool and die design
- Fundamentals of electrical discharge machining
- Fundamentals of tool steels and heat treating methods

A program similar to the technical education proposals outlined through the assistance of the Unido would provide sufficient training and create the necessary impetus for the developing nations who are desirous of meeting the objective of technical equality with developed nations.

MANPOWER DEVELOPMENT

Manpower development and training has been identified as essential to the success of the diemaking and metal forming industry. Apprentice training and related technical education is an integral part of such a program:

"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 journeyman. 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, we have developed standards, procedures, and texts. The basic concept of "learning by doing" has not been altered, but has been supplemented by many modern teaching aids and skilled instructors." 1/

The normal educational requirement for entry into apprenticeship training is a high school diploma. 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 in the tool and diemaking apprenticeship training, however, provided the related educational instruction program is developed to suit.

An example of this deviation from normally accepted levels is the tool and die apprenticeship at Iscar Company in Israel, developed with assistance of the Technion Technical University, it is a cooperative educational instruction and shop training program.

The age of entry eligibility to the program is 14 years, and the training period is over seven years. This apparently is a successful program and meets the needs of a highly successful and progressive company.

The comparison is made merely to show that although a successful program in a developed country may not be practical because of its entrance requirements, to meet the immediate needs of underdeveloped countries, educational requirements at entry may be changed, and the end result be equally successful.

In the United States, the program is normally subject to state approval. In large companies in Europe and the United States the program is often administered by joint apprencticeship committees of union and management. Shop and educational subjects are supervised by a shop instructor or traaining coordinator.

An apprentice training program for tool and diemakers consists of 8,000 hours, 7,424 hours of practical shop experience and 576 hours of classroom work in related training subjects.

Smaller companies participated in accredited programs approved by state laws. These programs meet high proficiency standards. Related training is usually coordinated between employer organizations and local educational institutions [illegible] shop experience and [illegible] programs are in the process [illegible] subject training in the new technological processes. The programs include Numerical Control and Electrical Discharge technical data.

The Ford Motor Company commissioned a National Consultant Group in 1966 to study the tool and die industry on a national and company level. The purpose of the study was to improve the basic apprentice training by re-identifying the job content of work performed by a journeyman tool and diemaker, operating in an era of changing toolmaking technology. The study involved discussion and questionnaire participation at all levels of hourly and management tool and diemaking personnel. Included in this study were the expected levels of proficiency during the early and midpoint stages of their training. The end result of this 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 attrition in the apprentice program must be expected and in like manner those who complete the training may not elect to remain with the Company.

To acquaint the new apprentice to the program, a manual or training guide was prepared for his use. The manual contains the following information:

- The Company's history
- Operating policies.
- Advantages of learning the Tool and Diemaking trade.
- Effective study methods
- Function of the apprenticeship committee.
- Union apprentice agreement.
- Obligation of an apprentice to the Company.
- Obligation of the Company to the apprentice
- Opportunities upon completion of training program
- Safe working habits.

Following the general orientation program, the company becomes more definitive in attempting to create motivation in the apprentice. The opportunity to learn a wide variety of skills is stressed; these include the familiarization of new tool and die technology, including numerical control and electrical discharge machining. Further career opportunities, all of which are available within the company, are highlighted to apprentices upon completion of the apprenticeship program. These are as follows:

- Supervisory positions.
- Programming opportunities in numerical control.
- Electrical discharge machining.
- Manufacturing Engineering opportunities.
- Processing, tool and product design
- Jobs in training and education.

They are then exposed to an overview of the tool and diemaking trade. Educational movies and slides, including manufacturing operations, automotive assembly operations, and other products manufactured by the corporation, are shown. The apprentice is made to feel that he plays a key roll in this manufacturing complex. In the preshop training areas, there are many visual aids. The aids may be identified as a stamping, a metal part that is produced by a die or a series of dies; a die is then depicted 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 in a fixed position during a production or machining operation.

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 program 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 [illegible] are also explained. A very important point stressed at this time is the self pacing concept of the program. This means that the apprentice can have an opportunity to pace himself and master a given task before he advances to the next task. The confidence developed in the apprentice due to a self-pacing concept is one of the outstanding aspects of the program. It is only after he has completed 1[illegible] identified tasks that he achieves an efficiency rating permitting him to go on the regular apprenticeship program. The tasks are:

TOOL AND DIE TASKS TO BE LEARNED IN BASIC TRAINING

Task	Learning Guide Number	Date Accomplished
1. Deburr and stamp rough stock	LG #12	
2. Drill and counterbore a hole	LG #13	
3. Drill and tap a hole using either a floor drill press or a radial drill press	LG #14	
4. Drill and ream a hole by using either a floor drill press or a standard drill press	LG #15	
5. Barber tool or die components	LG #16	
6. Spot tool or die components	LG #17	
7. Stone tool or die components	LG #18	
8. Using a bandsaw, safely cut a tool or die detail to layout line	LG #19	
9. Operate an overhead crane	LG #20	
10. Operate a hydra-drill	LG #21	
11. Layout die or fixture details from a sketch or blueprint	LG #22	
12. Machine stock on a shaper	LG #9	
13. Machine stock on a lathe	LG #10	
14. Machine stock on a mill	LG #11	
15. Machine stock on a surface grinder	LG #29	

TOOLMAKING AND DIEMAKING APPRENTICESHIP

SCHEDULE OF RELATED INSTRUCTION

Course No.	Title
1.1	Shop Arithmetic
101	Bluprint Fundamentals
301	Shop Theory I
2.1	Algebra
102	Elementary Projection and Dimensioning
302	Shop Theory II
3.1	Geometry
103	Manufacturing Engineering Standards
4.1	Trigonometry I
104	Blueprint Reading by Clay Models
5.2	Logarithms
326	Shop Theory III
6	Trigonometry II
327	Shop Theory IV
7	Trigonometry III
105	Advanced Projection
501	Characteristics of Metals I
106	Machine Shop Blueprint Reading I
8	Compound Angles I
502	Characteristics of Metals II
9	Compound Angles II
108	Detail & Assembly Drawing (Tool)
10	Gearing I
108.4	Detail & Assembly Drawing (Die)
541	Elementary Physics I
109.7	Advanced Blueprint Reading (Tool and Die)
327.4	Shop Theory IV (Die)
110.4	Elements of Die Design
503	Heat Treatment I
111	Elements of Tool & Fixture Design
504	Heat Treatment II

TOOLMAKING AND DIEMAKING APPRENTICESHIP

REQUIREMENTS FOR WAGE INCREASES AND TRAINING INCENTIVE

Hours on Course	Related Courses Completed	Wage Rate $	Training Incentive
0 - 1000	4	3.17	A training incentive for each course of related training successfully completed consists of the product of the number of class hours on each course and the straight-time shop hourly rate being received at the course completion date.
1001 - 2000	8	3.205	
2001 - 3000	13	3.325	
3001 - 4000	17	3.47	
4001 - 5000	21	3.65	
5001 - 6000	26	3.87	
6001 - 7000	30	4.145	
7001 - 7424	32	4.375	

TOOLMAKING AND DIEMAKING APPRENTICESHIP

SCHEDULE OF SHOP TRAINING

Symbols	Phases	Hours
S-P-SL	Shaper, Planner, and/or Slotter	500
L	Lather	500
M	Milling Machine	800
G	Grinders	500
BD	BENCH - DIE	2000 - 3000
BT	BENCH - TOOL	800 - 1400 5124
DT-MT	Die Try-Out and/or Model and Templates	500 - 1600
	Related Training	576
V-PR-BM-HM-SG-H	Optional: Vertical Lathe, Profiling Machines, Boring Machines, Heavy Mills, Special Gear, Hardening	
	Total	8,000

BASIC TOOLS

- *C-Clamps ([illegible]")
- *Calipers (3" & 6" inside)
- *Calipers (3" & 6" outside)
- *Calipers (6" hermaphrodite)
- *Center Gage
- *Center Punch
- Chisels (set, small)
- *Combination Square (12")
- *Compasses
- *Depth Gage
- *Diemaker's Square
- *Dividers (3" & 6")
- Files (set, small)
- *Hammer (ball peen, 12 oz., steel)
- Hammer ([illegible] oz., steel)
- Hammer (light, copper)
- *Ideal Indicator
- *Magnifying Glass
- *Micrometers (1" & 2")
- *Parallel Clamps
- Pliers
- *Prick Punch
- *Radius Gage
- *Rule (6" flexible)
- *Rule (6" hook)
- *Rule (6" depth)
- Scraper (3-cornered square)
- *Scriber
- *Sliding Parallel
- *Solid Square (3")
- *Surface Gage
- *Telescope Gage (set)
- *Thickness Gage
- *Thread Pitch Gage
- *Toolbox (20" x 12½" x 8½")
- Trammel Heads
- *Wiggler
- Wrench (crescent, single end, 8")
- *American Machinists' Handbook
- *Reference Tables

SCHOOL SUPPLIES AND EQUIPMENT *

- 3-Hole Ring Binder
- Compasses - 3" Bow & 6"
- Drawing Board
- Scale - (12" Triangular Engineering or 6" or 12" flat)
- T-square
- Triangle (6", 45°)
- Triangle (8", 30°)
- Protractor

*To be purchased by the apprentice

TECHNOLOGY

Since the early advent of the Kellering machine until the current decade, the tool, die and mold industry had remained relatively undistributed by advances in machining technology. Indeed there was great pride in the craftsmanship required and the quality of workmanship that could be created by laborious hours of hand-finishing by the diesinker. Another craftsman much admired and very much in demand was the machinist who could literally make his machine "talk" in producing excellence in form milling and grinding.

While change was on the march in the machine tool industry in the form of newly designed machines for mass production such as screw machines, chucking machines, presses for hydro-forming, explosive forming, powder metal forming, underdrive stamping presses, mechanical handling devices, and other similar forms of automation for the packaging industry, the tool and die industry maintained a "business as usual" attitude. As industrial productivity increased, industry wages also increased, keeping pace with national growth. The introduction of plastic products, the wider variety of automotive styles and new products being introduced onto the domestic market all increased the demand for molds and dies. These demands were usually met by plant expansion, manpower development, and overtime, but rarely by new ideas and improved technology. Minor changes came in the form of tungsten carbide tools which, in turn, necessitated more rigid machine tool with high spindle speeds and feed rates.

briefly the sequence of events related to making a normal die or family of dies for a manufacturing operation is as follows:

An approved product specification (usually in the form of a blueprint) is submitted to a process engineer after manufacturing feasability has been established. The process engineer determines the sequence of operations as to how the part should be manufactured. He then coordinates his processing requirements with facility loading personnel to insure the availability of press equipment to meet production requirements.

A typical process line-up for a formed stamping would require in some instances a blanking die and at least a form or draw die (dependent upon the complexity of the stamping).

In addition to the above a trimming and/ or piercing die would be needed. This operation usually would be used for trimming or removing the surplus material beyond the perimeter of the part outline, as well as for piercing holes and openings if any are required.

To complete the next sequence of operation the process engineer would outline the number of forming or flanging dies required. There may be several such forming or flanging operations dependent upon the die tip or complexity of the part to be manufactured

In establishing the number of operations and operational sequence, the processor considered the best method to be used for inserting and removing in process parts from the various types of equipment in use. The product volume usually determines the method of automation or mechanical handling equipment required.

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 built by the same source.

The final die design is a composite of originality combined with standard die design data to create a set of specifications from which, will be manufactured patterns, castings and the finished dies.

It is important to be completely informed at all times of the impact of tooling costs. Therefore a cost estimate is prepared either by the manufacturing plant or by an approved die supplier. Usually a minimum of three (3) die suppliers are requested to provide a quote as to the amount of money they will require to build the item, as well as, providing time requirements for construction. Simultaneously with the above the patterns and castings are processed in the same manner (if castings are required) in order that they may be available when the die construction source has been selected.

A new cycle or chain of events begin after the various construction sources have been determined. Die components stock lists are prepared and arrangements are made to purchase the materials from approved vendors.

A facility loading coordinator reviews the various die estimates by elements to verify for facility loading and containment. This review is made primarily to determine if the estimates are accurate, if proper construction equipment is available and if the construction date can be met. This is followed by developing an individual die fabrication schedule. The construction progress is reviewed regularly to assure that the construction timing schedule is being followed.

Since a cost estimate is established prior to the construction, the percentage of output is compared with direct labor input at several control points in the die construction process, as a measure of performance.

Shop operations begin with the preparation of tooling aids. These are usually in the form of metal templates and plaster or plastic reproductions of a die model modified to represent the manufacturing conditions unique to each die operation.

The plaster or plastic model and metal templates are subsequently used in conjunction with kellering type machines to create the contour and profile on the die periphery for surface configuration. Simultaneous with the preparation of the tooling aids, layout lines on casting are made for proper machining operations. The machining operations are a coordinated effort between the layout operations and the machining department. After the required machining operations are completed the material is sent to the bench area where the work is assembled. This step in the process is identified as die build-up. Basically this is the process of mounting tool steel blocks to the die casting or die shoes.

When the die build-up or assembly has been completed it is now ready for contouring and profiling to the appropriate model or tooling aid. This contouring and profiling operation is normally performed on conventional tracer controlled equipment or numerically controlled profiling machines. (Electrical Discharge Machining is another method of diesinking that can be used to shape die material. When the E.D.M. process is used, an electrode shaped to the desired contour on a profiling machine is required.) After the die has been profiled it is sent to a bench area where the cusps or cutter ridges left on the die surface by the profiling machine's cutting tool are then ground off by portable hand grinding tools. This operation is generally called die barbering. After the completion of the barbering operation the tool steel sections are removed from the die, and furnace heat treatment operations on the sections are performed. If the die steel is of the flame hardening variety, the heat treatment operation will be performed at a later step in the sequence.

When the [illegible] confinement [illegible] have been completed, the hardened tool steel sections are ground to remove warpage created by the heat treat operation and remounted to the basic die.

<u>MASTER RACK SPOTTING</u>

The hardened tool steel sections are reassembled to the punch or in the case of a trim or flanging die to the die locator (a die locator is the male shape just as the punch is the male shape in a forming die) and this portion of the die is ready for master rack spotting. As indicated in a previous step a master rack is an epoxy cast made from a master die model. The dies are coated with "raw sienna" to readily identify pressure points when being spotted to a "Prussian blued" master rack.

A spotting operation accurately identifies the surface imperfections and inaccuracies inherent in the tracer controlled profiling and contouring operation on a die. These inaccuracies and imperfections are corrected by portable grinding with hand tools (commonly known as hand grinding) until the surface of the punch or die locator is mated to the spotting master.

<u>PUNCH TO DIE SPOTTING</u>

The same techniques are used in spotting a punch to a die cavity as was used in spotting the punch to a master rack with one exception. This exception is that an air gap equivalent to the metal thickness of the stamping is required.

This is accomplished by spacing lead wire strips intermittently in the die cavity and pressure is applied at intervals between grinds and the lead wire thickness is measured for metal thickness uniformity. This grinding and measuring operation continues until a reasonable uniformity of air gap has been obtained. The final spotting operation is completed at a later point in the sequence.

DIE FINISHING

Work in the die finishing area also requires a high degree of skill. A criss-cross intermittent action is used in stoning. This reduces low spots, holes and irregularities. The operation continues until all grind witness marks are removed. The punch can be checked out by feel, scaling, oil stone, or highlight oil

FINAL ASSEMBLY

Once the principal die components have been mated, the die is now ready for final assembly. When final assembly is completed all moving members of a die assembly, such as drop slides, draw bars, scrap cutters, gaging, strippers, and automation must be timed in unison to accommodate the precise mechanical action taking place at the right moment during one cyclical movement of the press. Upon completion of the final assembly the die is processed for preliminary tryout which consist of the final spotting of the die and making revisions due to the unique characteristics of the stamping. These may include form corrections for spring back in the surface of flanges of the stamping. Outline or trim line corrections can also be made due to inaccurate development from a finished product position to a die position. Alteration to the holding beads or die radii are usually necessary to control the metal flow and eliminate metal fracturing in the die. These are but a few of the potential problems in the process of making a die function in a production environment and meeting the high quality objectives demanded by the customer from the die supplier.

During the time that the principal operations as previously outlined are in process of construction. Many other miscellaneous functions are being performed at the same time on a wide variety of die components. These miscellaneous operations are too numerous to be included in this presentation, therefore only a few can be covered in any depth. These are namely:-

- <u>ELECTRICAL DISCHARGE MACHINING</u>

  The basics of EDM process and Ford Motor Electrical Discharge Machining experience.

- <u>THE FLAME HARDENING OF DIES</u>

  Contained in this paper is a brief outline of the process as in use at the Ford Motor Company. This process is applicable to Flame Hardening of die surfaces applied throughout the tool and die industry.

- <u>DIE PATTERN & CASTING PROCESS</u>

  This process relates to the use of polystyrene patterns in the making of die castings. The process originated in the United States in 1958. The first practical use of this process in the United States was in the year of 1963. The first known industrial application was in Germany in 1962. This process is being used extensively today in the United States. All of the patterns used in the process of making die casting for the Ford Motor Company are made of polystyrene. As an interesting sidelight a recent technological breakthrough has been the development and marketing of a duplicating routering machine to shape die pattern from plaster models (see styrofoam pattern exhibits).

A die machining process of importance not covered in this paper is the contouring profiling and lineal machining of dies by Numerical Control Machines. Computor programming and tape processing are also excluded from this paper.

This subject will be covered in depth in a paper being submitted by Mr. Donald N. Smith, for the Vienna expert group meeting. The subject matter chosen for detail description in this paper are relatively new to the industry and are expanding rapidly in the developed countries. In the writers opinion these new technologies would contribute substantially to the upgrading of manufacturing operations in the developing countries.

In 1943 a little noticed process made its appearance in industry. This
process known by several names: Electro - Oxography, Spark Erosion, Eloxing,
and finally Electrical Discharge Machining.

At first the process was not recognized as having a place in tool and
diemaking operations as a machining process.

The process had its humble beginning and was used at the Ford Motor
Company for removing broken taps from engine blocks. The machine
generally had the design and configuration of a bench drill press. This
machine was identified as a disintegrater. Up until this time the removal
of broken taps was an extremely cumbersome operation; in fact, some die
steel details were severely damaged or destroyed in the process of re-
moving a broken tap. A further extension of this process was the use
of copper or brass tubing electrodes to erode a hole in hardened steel
sections. As the use of the process expanded, it became evident that
this new machining technique had the potential to perform precision
operations on hardened steel for the newly introduced exotic metals. The
machine would have to be designed with a servo system to control spark
gap automatically, and include coordinate movement on the machine tables
and precision ways and gibs.

Over a period of ten years electrical-discharge-machining grew from a
simple salvage operation to a high-precision machining system. Let us
examine some of the fundamentals of the electrical discharge machining
system:

ELECTRICAL MACHINING SYSTEMS

There are three distinctly different electrical machining systems in
operation, all using a common fundamental principal - METAL REMOVAL BY
ELECTRICAL ENERGY.

These systems are: First Electrolytic Grinding. Principally, this is used in the cutter and tool grinding process

<u>ELECTROCHEMICAL MACHINE (ECM)</u> The second

E.C.M. is a relatively new machining method by which metal is removed by high electrical current density and electrolyte velocity (a rapid deplating action). The process differs from E.D.M. in that a continuous rather than pulsating DC current is employed. The solution is a salt brine solution. E.C.M. has a potential stock removal rate of up to 60 cubic inches per hour with utilization of a 10,000 ampere power supply unit, which makes this process very promising. Electrodes may be made of any electrical conductive material. A major problem, making this system unfeasible for die machining at this time, is that ELECTRODES ARE NOT THE EXACT OPPOSITE OF THE DESIRED FORM AS IN E.D.M. BUT MUST BE DEVELOPED TO PRODUCE THE DESIRED SIZE AND SHAPE. This generally means exorbitant cost and lead time when only a small number of like parts are to be manufactured.

A salt brine solution is used as the electrolyte. This presents a corrosion problem affecting coolant pumps, fixtures, tooling and machine components. Thus stainless steel and non-ferrous machine components are used. Considerable basic development work in this area for improved filtering systems and electrodes remain to be accomplished to effectively improve this process for automotive manufacturing. Currently E.C.M. is being applied in the aircraft and missile field in machining of exotic materials to make jet engine turbine and compressor blades.

It is also being widely used in many industrial operations whereby the number of pieces and the shape complexity justifies electrode development costs and time. One distinct advantage over all other machining systems is LIFETIME ELECTRODES. The electrode is not subject to wear. It can be destroyed, however, by machine malfunction, and plate itself beyond recognition.

ELECTRICAL DISCHARGE MACHINING

The third and last method which will be covered in more detail in the following section is Electrical Discharge Machining (E.D.M.)

INTRODUCTION

2/ "This discussion on the fundamentals of Electrical Discharge Machining will be 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 Electrical Discharge Machining has been thoroughly investigated and studied, and the results of these investigations have been widely published. Certain deductions about the process can be made and applied. The art however, is preceding the science.

We say that certain theories have been derived to explain the EDM process. This may sound nebulous until we consider that the use of electricty is based on the electron theory. This theory states what all matter is composed of atoms which are composed of a nucleus and literally 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 necleus at fantastic rates. If a substance gives up its free electrons easily, it is called a conductor.

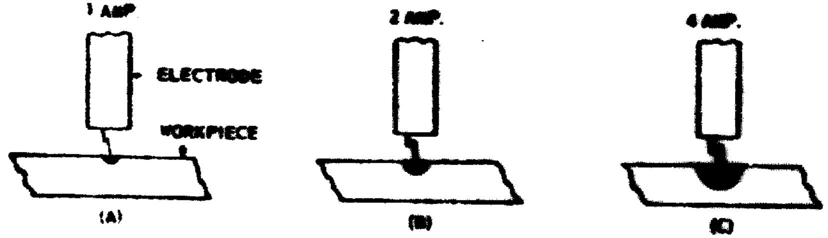
If a certain potential (or voltage) is impressed for a sufficient period (On-time) across a certain gap created by two conductors (electrode and workpiece), we can cause billions of electrons to flow rapidly (186,000 mi. per sec.) and we have current (amperage). In our case the resultant of the electron avalanche is a spark that will create a crater in each of the two conductors. If this procedure is carried out in a medium called a dielectric fluid, it can be better continued and controlled, partly because the fluid can wash away the particles and keep the work-piece cool. Dielectrics used have been mineral and silicone oils, kerosene, ethylene glycol polar fluids, glycerol, de-ionized water, sodium silicate solutions and even compressed air and negative gases.

DIELECTRIC FLUIDS

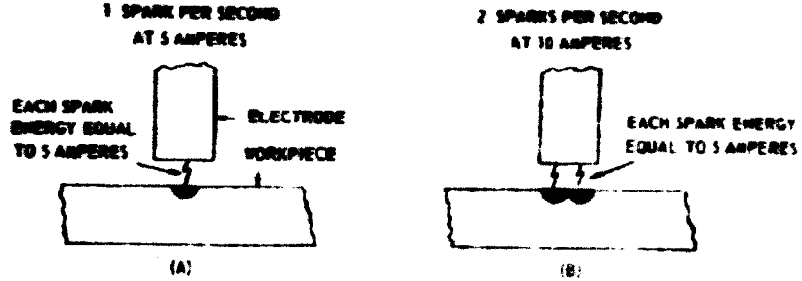
The dielectric fluids most commonly used are mineral oils with certain properties and characteristics. The things we look for are low viscosity (approx. 40 S.U.S. @ 100° F.), high flashpoint (near 300° F.) 200 - 250 volts per mil dielectric strength, no skin irritants, no unpleasant odor, no excessive smoke, low degree of impurities, and no undesirable gap characteristics. Some manufacturers are recommending higher viscosity oils for high amperage work.

These oils are usually isoparaffinic hydrocarbons, and, when subjected to gap conditions, give off various combustible CH group gases, plus some carbon residue. Although the corrosion inhibitors may be consumed, no other significant changes occur in the composition and it may be reused 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 5 to 50 psi range or at 10 to 29 in. hg 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 .0001" at very low voltage and about.002"

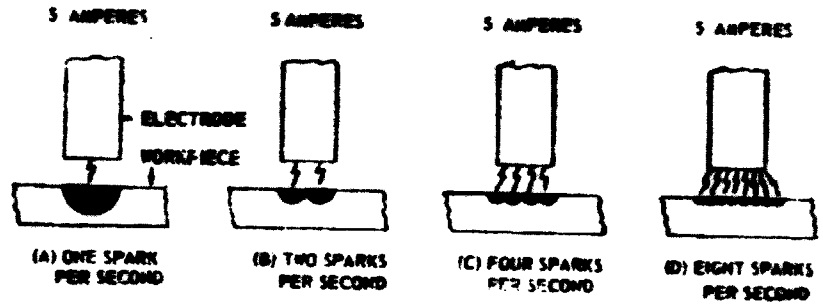
FUNDAMENTALS OF E.D.M.



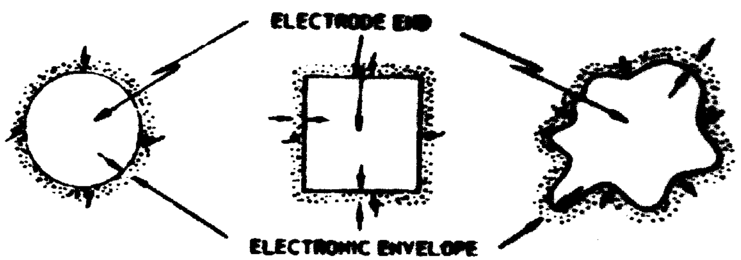
METAL REMOVAL ONE DISCHARGE



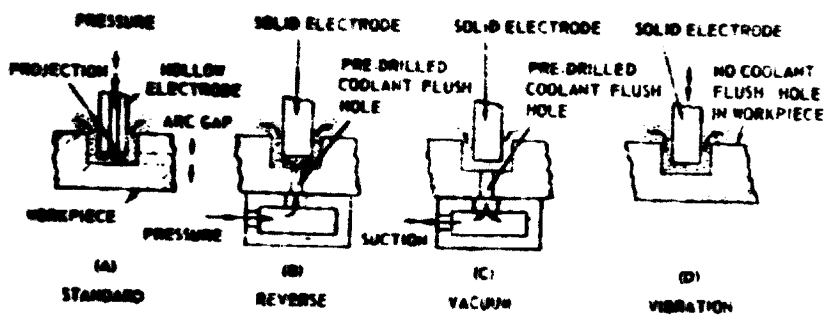
SURFACE FINISH AS AFFECTED BY SPARK FREQUENCY AND AMPERE



SURFACE FINISH. CONSTANT AMPERES - VARYING SPARK FREQUENCY



ELECTRONIC ENVELOPE



TYPES OF COOLANT FLOW

at high voltage. However, the metal and carbon particles, also called detritus or swarf, are conductive, and these add to gap size by acting as spacers or "stepping stones." Normal gap distances at .100 to 100 amps will be in the .005" to .008" range.

PRESSURE AND VACUUM FLOW (See Chart - Type of Coolant Flow) No. 1

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 - you can detect a tendency to short by very dense puffs of smoke and you can sometimes see small arcs. The bubble pattern and size will help estimate 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 maximum. Pressure flow also can be used above 14 psi, which is the vacuum limitation.

Vacuum flow however, does have definite applications and is used exclusively by some die makers. First 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 erratic machining. Secondly, the slugs or spires in the flow holes will cause continually increasing resistance tooil flow. When cuts are one inch or more in depth, these slugs must be broken off periodically in order to proceed to depth. Vacuum flow concentrates the particles around the slug, and excess erosion allows undeterred flow. Vacuum can thus permit full amperage and steady cust to full depth if all of the requirements are met. No air leaks can be tolerated in a vacuum system - the platen is usally submerged in the oil.

The system must have enough capacity to handle the detritus and the gas volume. A sustained reading of 27 - 28 inches 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 trepanned parts, such as valve discs or tensile test specimens. Vacuum flow can also be used to eliminate smoke and to remove dielectric oil from "hard to get at" areas of a cavity.

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 material. 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 where corner radii or EDM taper are a factor however, clean, carbon-free oil is desirable.

Clean oil is achieved by filtering through 3 micron filters which remove about 85% of particles .0001" and larger. Various filter systems will have different capabilities due to their inherent nature and variations in the rating. Asbestos cellulose is considered a polishing type medium and is generally used in surface type filters. Depth type filtration can be accomplished by wound viscose or cellulose yarn, vacuum deposited and resin bound flocculants of cellulose, or wool and diatomaceous earth.

Large areas, where continuous high amperage machining is the norm, 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 cleaner gap supply.

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

THE MACHINING GAP

When an electrode of opposite polarity to the workpiece is brought close enough to the workpiece 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 some 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 Chart - Surface Finish as effected by Spark Frequency and Amperes) No. 1

When parallel capacitance is used, the amperage will divide as the frequency increases and finer finishes will result. The same is true of the zero capacitance, long on-time no-wear circuts.

SURFACE FINISH CHARACTERISTICS

The surface finish obtained by EDM is quite different from conventional finishes. Surface recorders will show approximately the same general roughness pattern; the geometry is considerably different however, as myriad peaks and craters replace the lines and valleys. Thus we have 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 was used in the EDM operation. The friction characteristics are also quite different. Where conventionally machined surfaces stick and then slip with rapidly decreasing friction, EDM coefficients are linear and considerably lower in value. This has been demonstrated by inclined plane tests and the performance ratio is about 3 to 1 in the better finishes. An EDM finish reading 45 microinch rms has been demonstrated to perform as well as 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 thermo-cycling, rotating engine parts. This is because of the possibility of incipient failure due to stress raisers developing at any minute cracks. Fatigue strength of the high strength chrome-nickel alloys, titanium and aluminum will always be significantly lower than conventionally machied surfaces.

CARBON 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 carbon-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. Carbon graphite has recently been used to do successful form grinding of 60° "V" shapes only .010" wide in carbide crush rools. 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. 40 rms is usally considered the switch-over point to metal electrodes. In fact, metallic electrode materials are more efficient than good grades of graphite when machining in the high frequency, low amperage range.

Most carbon-graphite 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 molds. The finish attained is usally hand worked with a 320 grit stone to improve the 30 - 100 rms finish left by EDM.

PROGRAMMING CAVITY DIE WORK

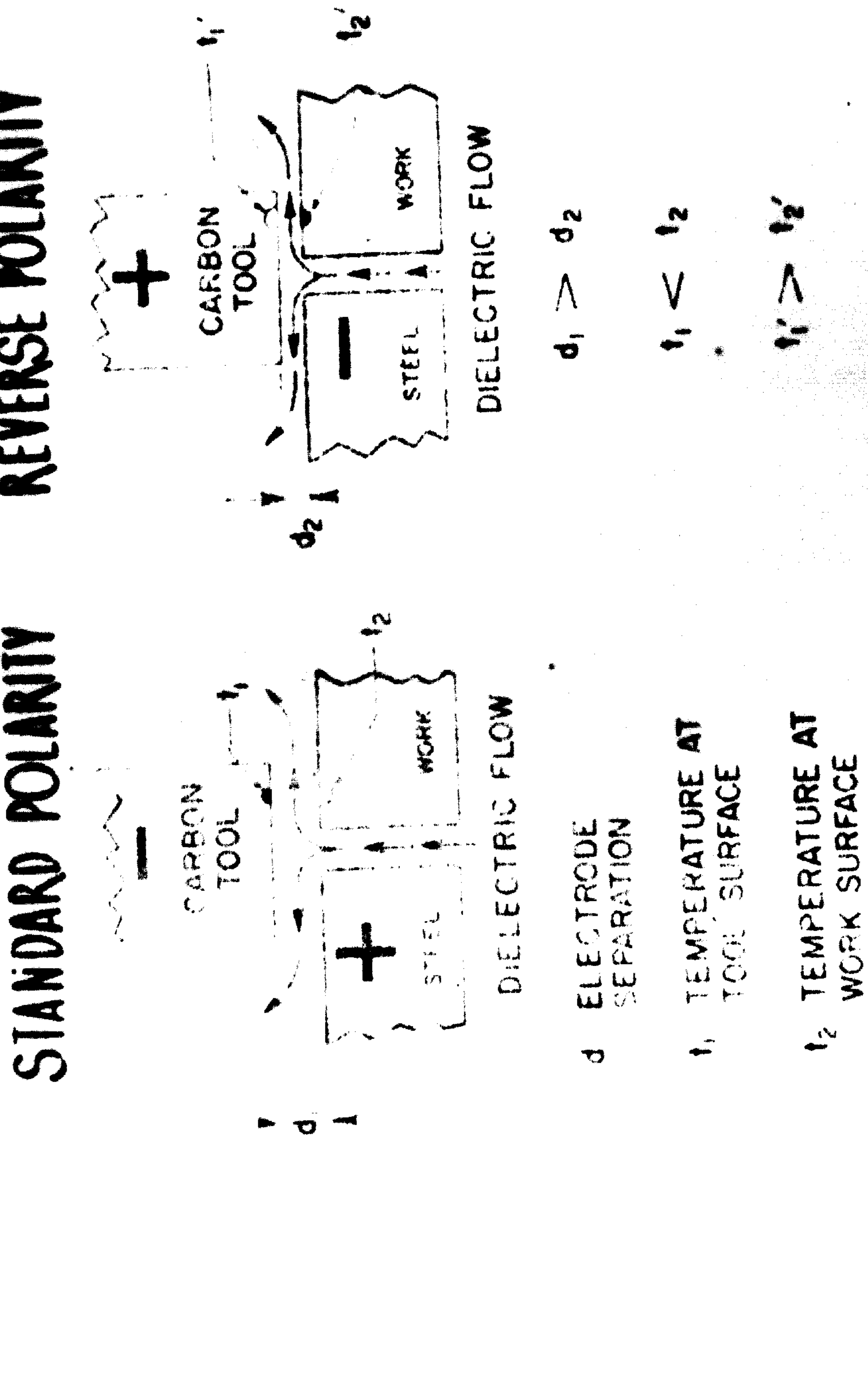
All cavity type work should be programmed for the amount of amperage intended and the degree of draft in the workpiece. By knowing the overcut and pit depth from established data, one can use the sum as one leg of a triangle. The angle opposite is the amount of degrees of draft, and thus, a trigonometric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

MACHINING GRAPHITE ELECTRODES

The rapid evolution of Electrical Discharge Machining from that of a last resort repair method to its present acceptance as a practical metal removal process which has tremendous potential is often attributed to the development of graphite as an electrode material, and, I would add, to the increasing skill of the graphite electrode manufacturer.

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, 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 towards different machining procedures. Obviously, graphite machines faster because it offers less resistance to


STANDARD POLARITY
CARBON TOOL
STEEL
WORK
DIELECTRIC FLOW
d ELECTRODE SEPARATION
t_1 TEMPERATURE AT TOOL SURFACE
t_2 TEMPERATURE AT WORK SURFACE
REVERSE POLARITY
CARBON TOOL
STEEL
WORK
DIELECTRIC FLOW
$d_1 > d_2$
$t_1 < t_2$
$t_1' > t_2'$

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 (or a considerable length in the case of the conventional) per configuration. Consequently, setups and tools often compress the largest portion of manufacturing cost. It is in this area that wider machining latitudes make their most important contribution.

NO-WEAR EDM.

When machining with a carbon electrode at reversed polarity, (carbon electrode positive, workpiece negative), low electrode wear is experienced, 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 an avalanche will vary with electrode materials. Carbon requires a lesser electrice field than steel. Many factors influence field strength, and presently we will consider two: applied voltage and gap dimension.* Since the applied voltage for most power supplies is constant, one way to enhance the electric field is to decrease the gap dimension. We can expect a difference in gap dimension in the two cases: first, when the carbon electrode is negative with respect to the workpiece; and, second, when

* SEE EXHIBIT No. 2

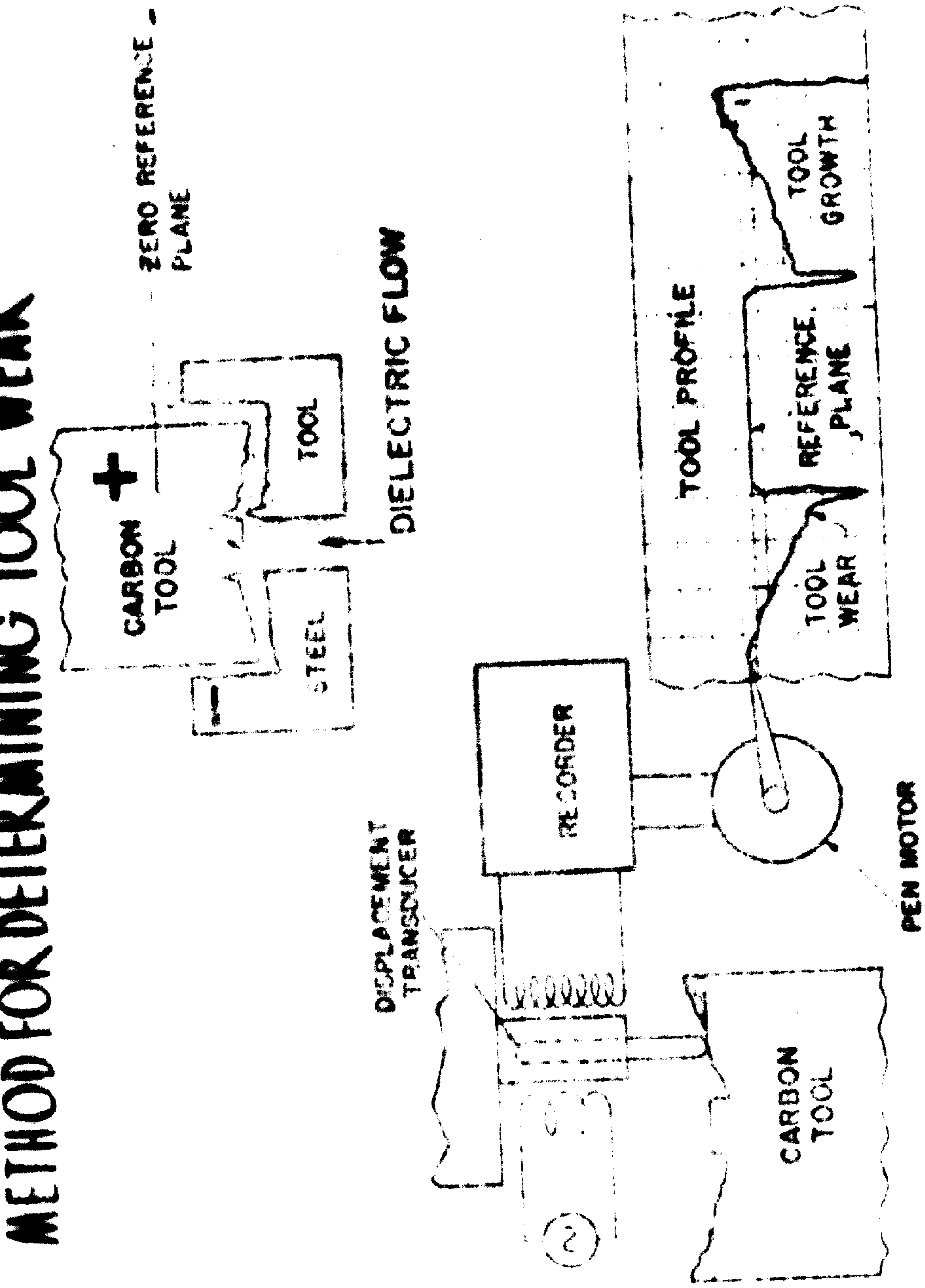
the carbon electrode is positive with respect to the workpiece. We would expect the latter to have a smaller gap than the former, particularly when the work piece is steel.

Considering the sequence of metal removal during a discharge, some metal is removed during the latter stages of a discharge; however, most is removed instantly following a discharge. When discharge times become long, the amount of metal removed during the last stages of a discharge 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 the electrode surface because of the high temperature and the porous nature of the electrode surface. SEE EXHIBIT No. 3 of a photomicrograph of an average electrode surface machined at reverse polarity showing the large amounts of metal splashed onto the electrode surface.

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.

NO-WEAR TESTS

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:


METHOD FOR DETERMINING TOOL WEAR
ZERO REFERENCE PLANE
CARBON TOOL
+
TOOL
STEEL
−
DIELECTRIC FLOW
RECORDER
DISPLACEMENT TRANSDUCER
PEN MOTOR
TOOL PROFILE
TOOL WEAR
REFERENCE PLANE
TOOL GROWTH
CARBON TOOL

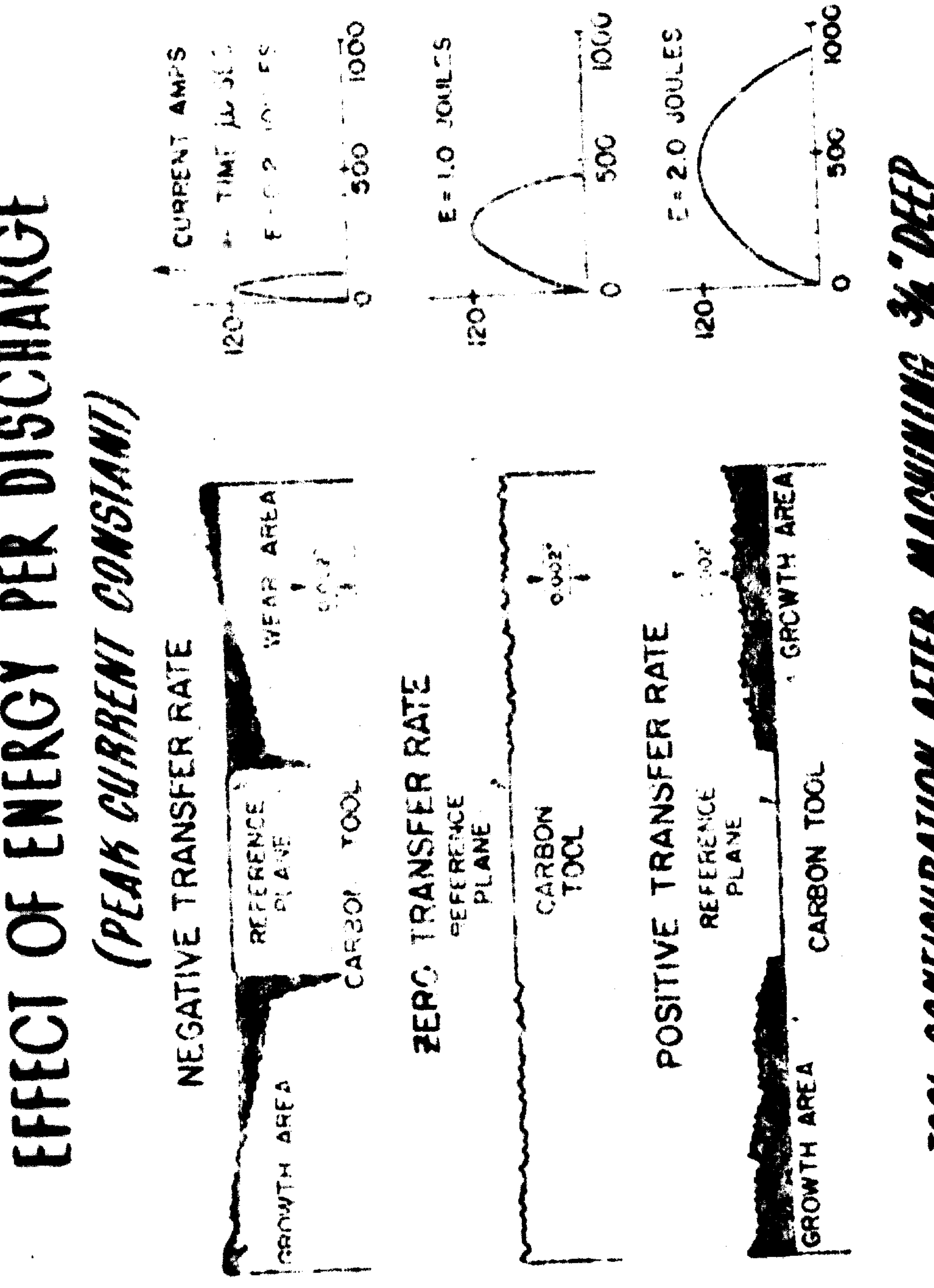
1. What is the effect of energy per discharge on electrode wear?

2. What effect does depth of cut have on electrode wear?

As a means of measuring electrode wear, (SEE EXHIBIT No. 4) a hole was drilled in the workpiece and dielectric flow introduced through this hole (reverse flow). In this manner, the center of the tool was not machined, and served as a zero reference. Since wear is small, an electrode profile 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, trace dips below the zero reference plane indicate electrode wear. Whenever the trace appears above the zero reference plane, the electrode has "grown."

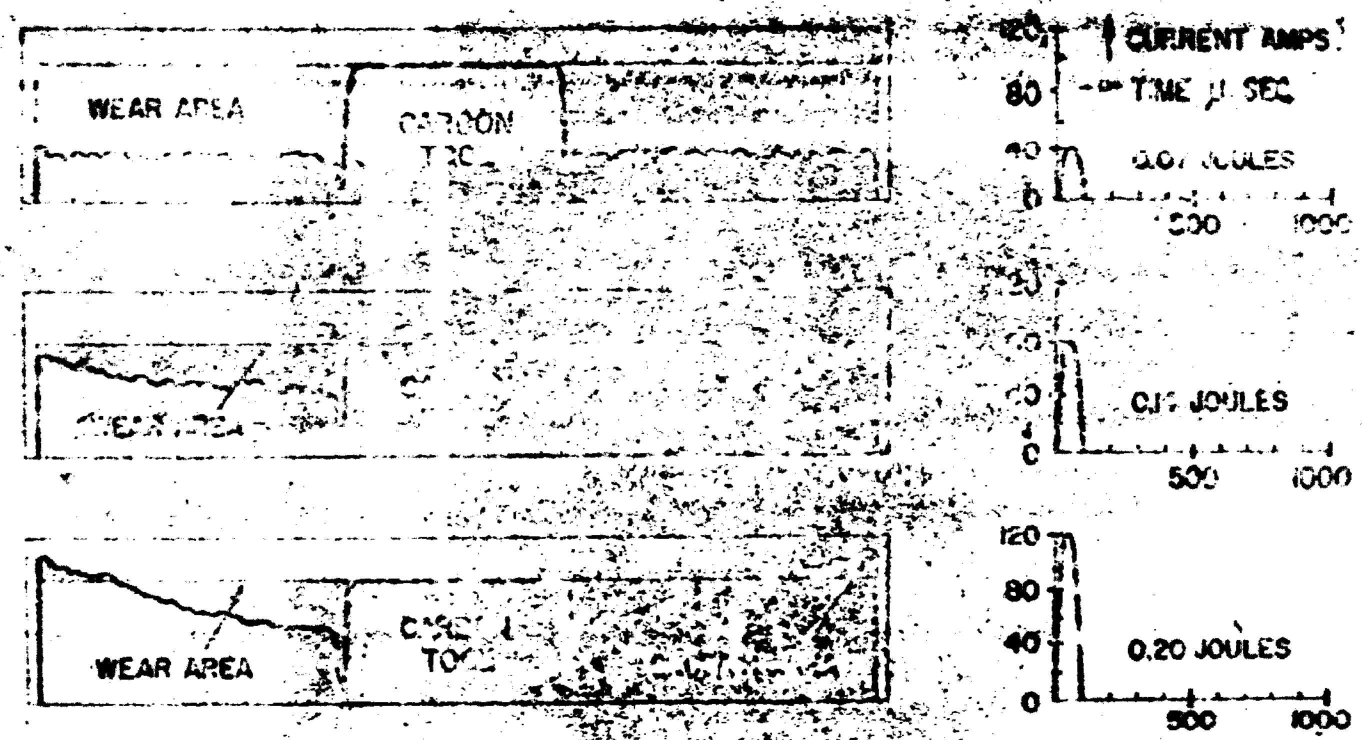
TEST RESULTS

We mentioned above that metal is deposited on the electrode face. There is a certain average amount deposited per discharge, or a certain average amount deposited per 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 in rates 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 zero, there is a state of equilibrium or "no-wear."


EFFECT OF ENERGY PER DISCHARGE
(PEAK CURRENT CONSTANT)
NEGATIVE TRANSFER RATE
GROWTH AREA
REFERENCE PLANE
CARBON TOOL
WEAR AREA
CURRENT AMPS
120
0
500
1000
ZERO TRANSFER RATE
REFERENCE PLANE
CARBON TOOL
0.002"
E = 1.0 JOULES
120
0
500
1000
POSITIVE TRANSFER RATE
REFERENCE PLANE
CARBON TOOL
GROWTH AREA
GROWTH AREA
E = 2.0 JOULES
120
0
500
1000
TOOL CONFIGURATION AFTER MACHINING 3/4" DEEP

EFFECT OF ENERGY PER DISCHARGE

(DISCHARGE DURATION CONSTANT)



TOOL CONFIGURATION AFTER MACHINING 3/4" DEEP

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 than be varied by changing either discharge current or discharge duration. (Electrode profiles are shown after machining 3/4" deep unless otherwise stated). SEE EXHIBIT No. 5 showing these conditions. There is a change in transfer rate from negative (at top of exhibit) through zero (in the middle) to positive (bottom). Notice that the "no-wear" condition is obtained at a discharge energy of 1 joule per discharge. We can then assume that metal transfer rate is related to energy per discharge.

We have seen the effect of increasing energy by keeping peak current constant. Now observe the effect of increasing energy per discharge by holding discharge duration constant and increasing peak current. We may expect, from our previous information, an increase in metal transfer rate as energy per discharge is increased. (SEE EXHIBIT No. 6) This is indeed the case. At 0.07 joules/discharge there is relatively high wear on the electrode, less at .014 jourles/discharge and still less at .02 joules/discharge. From the last two exhibits, little doubt remains that metal transfer rate is dependent on energy per discharge.

In the previous exhibit we noticed that "no-wear" occured at 1 joule/discharge with a peak current of 120 amps and discharge duration of 450 milliseconds. If energy per discharge governs metal transfer rate, as we have seen, then keeping discharge duration constant at 450 milliseconds and reducing peak current should result in a reduction in metal transfer rate. SEE EXHIBIT No. 7 showing results from these conditions.

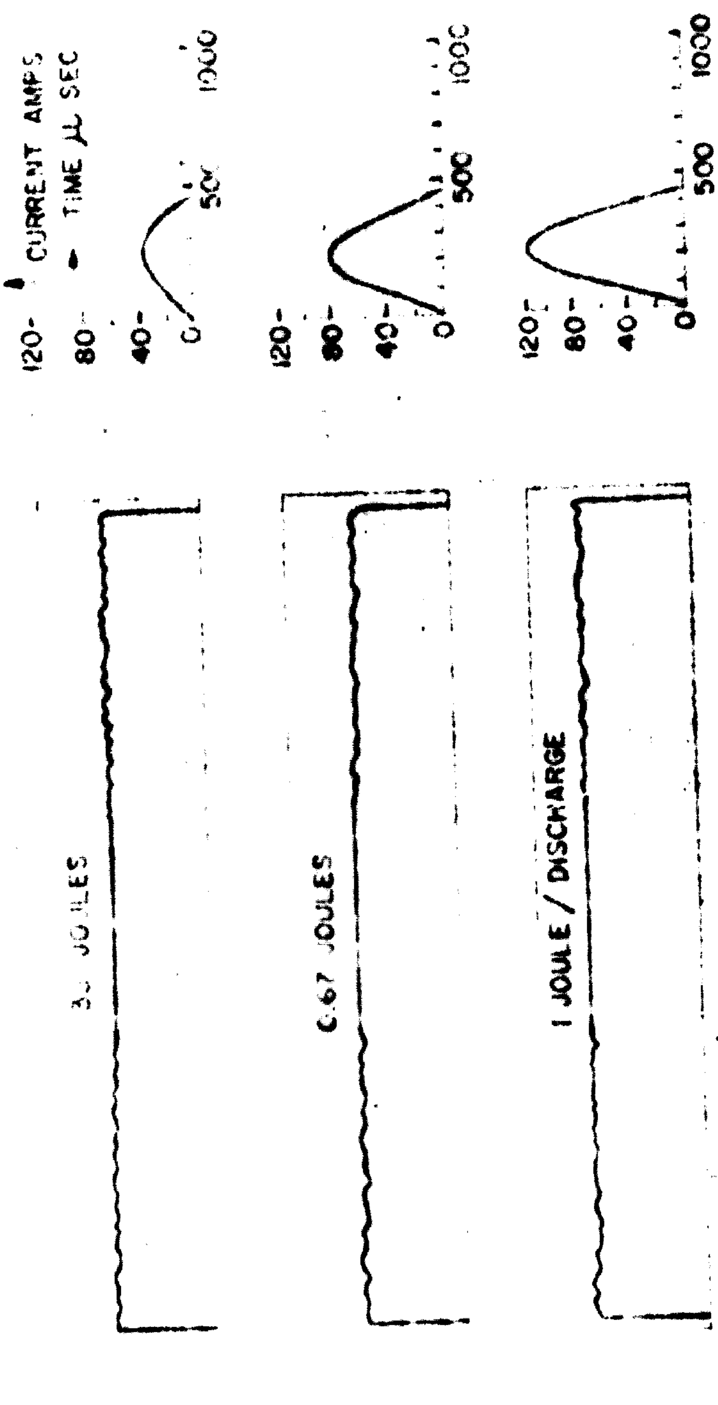
Contrary to our predictions, these results show zero transfer rate for all three levels of energy per discharge (0.33, 0.67, and 1 joule). This indicates that discharge duration is also important to "no-wear." This really should not be too surprising. If "no-wear" is dependent upon metal being transferred 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 time dependent. So we see that time is also essential to the "no-wear" phenomenon. SEE EXHIBIT No. 7.

At a discharge duration of approximately 450 milliseconds, time is the dominant factor in "no-wear" and the effect of energy is masked out. This is fortunate, for now there is a range of finish over which "no-wear" can be obtained.

To consider now the effect of depth of cut on electrode wear, SEE EXHIBIT No. 8 showing electrode profiles as the depth of cut was increased from 1/16" to 3/4" and the energy per discharge maintained constant at 0.2 joules--peak current 120 amps and duration 90 milliseconds. From these conditions we would expect a negative transfer rate, as indeed we have. The deeper the cut, the greater would be the amount of electrode wear. This is shown in the lower right hand corner and is normal EDM electrode wear.

SEE EXHIBIT No. 9 showing 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 3/4". If the energy per discharge were increased by increasing time as shown by the dotted lines in upper right-hand corner, we would have a positive transfer rate and the electrode would "grow" as the

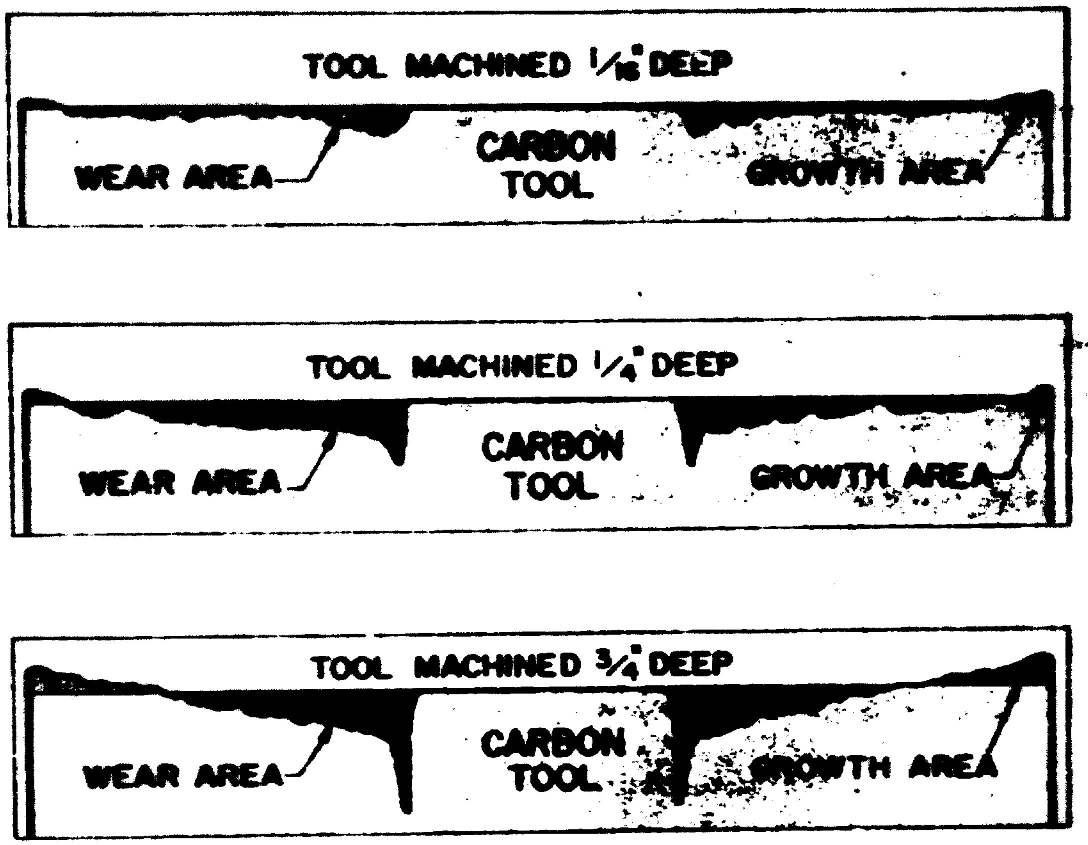
EFFECT OF ENERGY PER DISCHARGE IN ZERO TRANSFER RATE

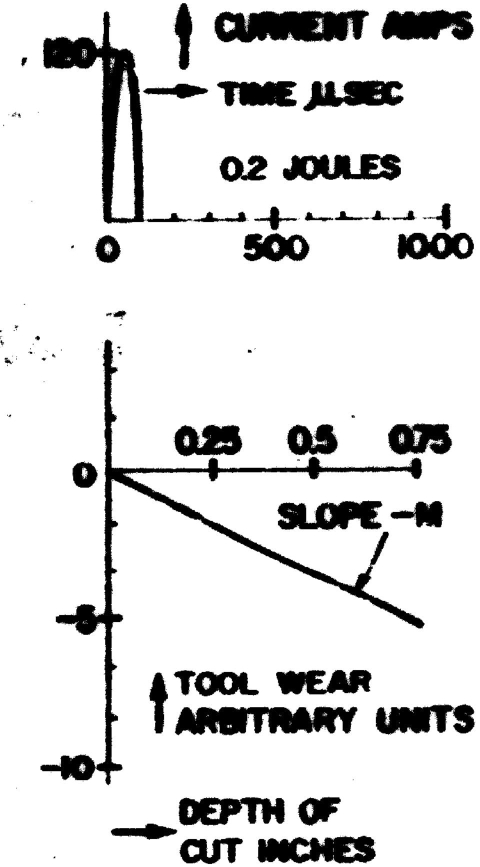


DISCHARGE DURATION CONSTANT

TOOL CONFIGURATION AFTER MACHINING 3/4" DEEP

EFFECT OF DEPTH OF CUT

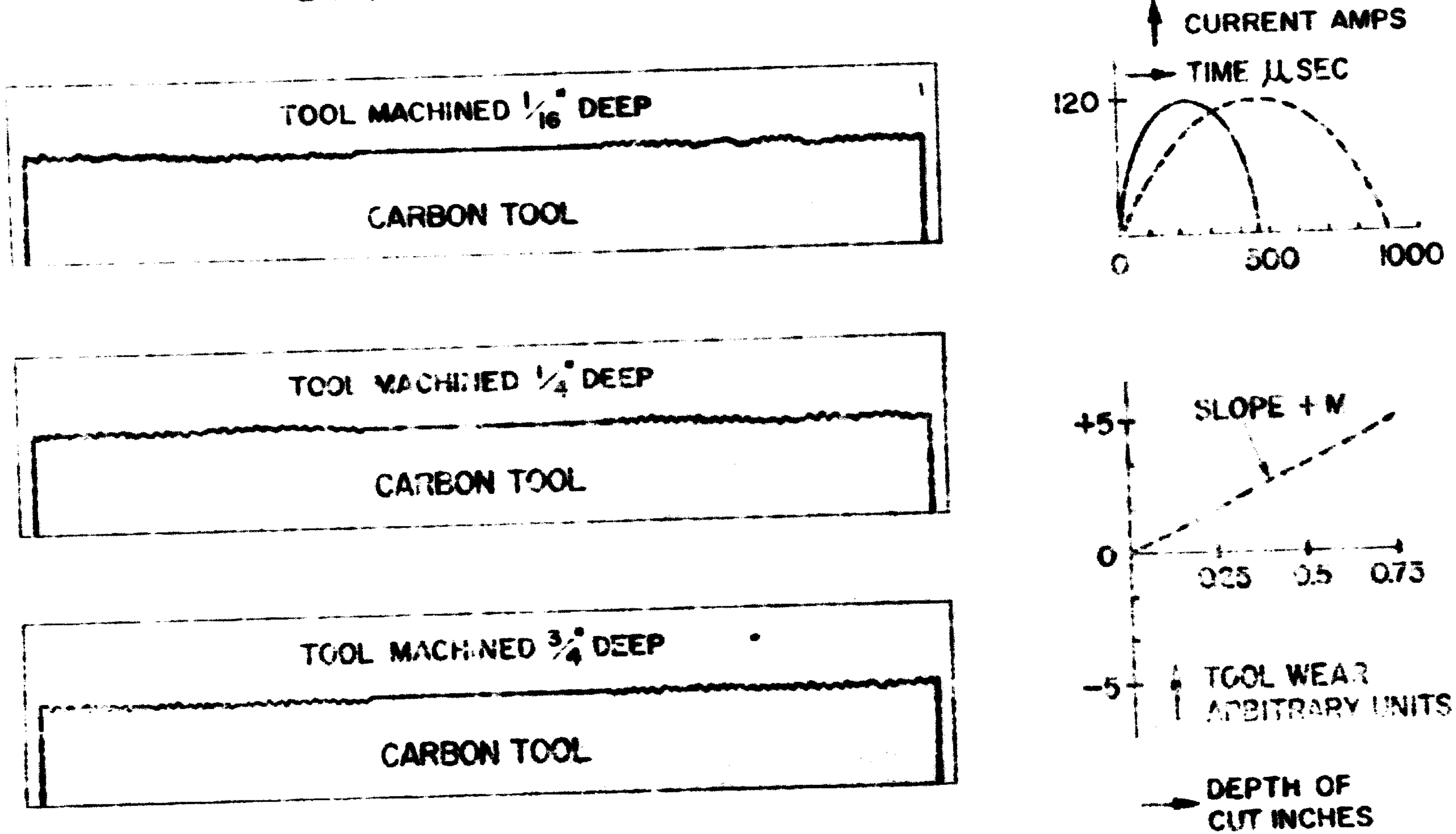




NEGATIVE TRANSFER RATE

CONSTANT ENERGY PER DISCHARGE (0.2 JOULES)

EFFECT OF DEPTH OF CUT



ZERO TRANSFER RATE

CONSTANT ENERGY PER DISCHARGE (1.0 JOULES)

depth of cut increases. This is also shown in the lower right corner 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 finish 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 capability.

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2 OF 2

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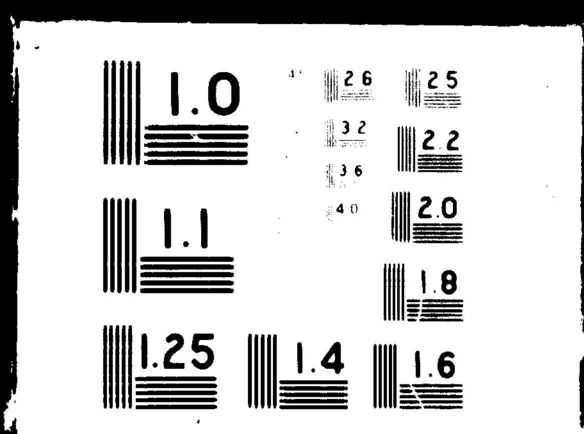


FORD MOTOR CO. ELECTRICAL DISCHARGE MACHINING EXPERIENCE

In May of 1965 the Ford Motor Company reported that electrical discharge machining (EDM) was proving to be a more economical way of producing blank, trim, and flange dies than traditional lead shearing and hand-fitting methods because of the faster rate and the better quality with which the dies could be made. At that time Ford predicted that EDM would soon be used for machining the entire surface and periphery of a die, that more efficient power supplies capable of higher erosion rates and better microfinishes would be developed, and that electrode materials would be found to out perform any available today.

From the various generally know through-hole methods (steel on steel back eroding, double electrode, and carbon or copper mounted on a die or a template) Ford chose the mounting of carbon on a finished die as its usual procedure. This decision to standardize EDM work was made after an evaluation of the distinct advantages of having a variety of processes as opposed to the general ease of introducing and maintaining a single, repeatable sequence in a large die shop in which close, supervisory control over each job is not possible.

Electrical machining with carbon mounted on dies is a simple process. Pieces of carbon are cemented to a conventionally finished male or female die. Whether it is 1/16, 1/8, or 1/4 inch thick, however, is not important because carbon is easy to cut.

They are then finished or routered to conform the die's cutting edge by means of a small, portable grinder mounted on a portage layout machine. The cutting tool is guided along the die's cutting edge by a round "pilot" attached to the end of the tool. The side of this "pilot" can be changed to provide varying amounts of overcut on the mating steels.

To support the carbon the protect it from accidental breakage or dislocation, plastic bond epoxy is packed behind ... The completely carboned die is then ready for mating to its opposite half by EDM. The amount of machining, grinding, and hand-finishing required to mate this die conventionally would have been tremendous.

Obviously, the use of EDM leads to savings. Five to ten percent can be cut from the total cost of making trim dies - savings are even greater in the production of blanking dies. If only the affected operations are compared, the savings to be had with EDM are still greater. For instanct, to hand fit 100 inches of cutting edge on a trim die takes from 1-1/2 to 3 hours an inch (about 200 hours). To do the same job with EDM takes approximately .2 hours per lineal inch for electrode preparation (that is, for cementing the carbon to the steel and routering it) and another 6 to 14 hours depending on the complexity and the size of the die, to load, maching and unload the die set. Loading and unloading takes 2 to 4 hours and the machining 4 to 10 hours. But machining time with EDM is not directly chargeable to the cost of the die because the machine needs no direction from diemaker or operator at the appearance of a malfunction, the machine will automatically shut itself off. The total time with EDM (20 hours - .2 hours per inch x 100 inches plus 4 for loading, inspection while machining, and unloading) is about 176 hours less than that taken with conventional method.

In addition toreducing the time and cost of die fitting EDM also improves quality by making simplified designs' and by assuring a uniform punch and die clearance and a uniform, cross-sectional hardness. The many punch and die [illegible] conventional [illegible] are no longer necessary. The uniform envelope between punch and die in EDM permits a longer production run without causing burrs, pinches, tears, or fractures in the product, which occur all too frequently on hand-fitted dies. Since dies are hardened before they are made in EDM, the cutting edges have neither hairline fractures from excessive hand grinding nor the hard and soft spots which result from the annealing or welding process during repairs.

The reduced time and cost of making cutting dies and the increased quality possible with EDM machines made the extension of Ford's EDM capacity inevitable. To supplement the 48 inches by 84 inch single purpose machine at the main tool and die plant, two large spotting presses were converted to EDM. The first such machine with an 84 inch by 144 inch capacity, has been in operation since 1963. The second conversion, in use since the end of 1969 is 84 inches by 196 inches. It can machine the largest automotive dies produced by Ford. It dielectric tank holds 3,000 gallons and has a reservoir of about 7,000 gallons

Small or medium sized shops have difficulty justifying a large, single purpose EDM machine. But since the EDM work at Ford is now of a volume sufficient to justify [illegible] machines to replace the combination machines developed in the past, one such machine is already in operation at the new Ford Woodhaven plant, and several other are currently on order for the die construction units in Ford's stamping plants. These machines are designed for work on surface as well as on cutting dies and will give Ford's major die making centers the capacity for eroding large cutting dies. Further success of the EDM process in respect to mating, cutting and flanging dies depends now on refinements and the speed with which capacity can be extended.

The most recent development at Ford has been the use of numerical control and EDM in tandem to produce three-dimensional surfaces on automotive body dies with more accuracy and lower cost than is possible through the use of conventional methods. This new process uses numerical information to machine carbon electrodes for use with high amperage, modularized power supplies to machine electrically die surfaces for production dies. This method eliminates many of the conventional die construction techniques, such as die models and spotting aids, and is certainly the most important development in die-making since the advent of numerical control itself.

Since the introduction of EDM into the large captive die plants eight years ago, many attempts have been made to economically produce accurate surfaces in automotive dies with this process. First, metal was sprayed onto master shapes and backed with an easily constructed base of plastic or wood. The distortion and the unavailability of master models frustrated this effort, however. Next zinc-tin electrodes were tried, but electrode wear and size limitations and unavailability of master models frustrated this experiment also.

In these attempts as in many others, the master model for spraying, casting, or otherwise duplicating shapes was not available long enought because of the automotive company's tight tooling schedules. The union of EDM and numerical control provided an invaluable substitute for master models. With numerical information from styling and engineering phases, carbon electrodes can now be machined without models.

Another major problem was tool wear. The cost of resurfacing the electrode after each machining operation used to undercut the economy of EDM for die surface work. Within the last two years, however, a refinement in the EDM process has virtually eliminated tool wear by reversing the polarity with a carbon electrode [illegible] is used. Because of the [illegible] electrode [illegible] with [illegible] reverse polarity, certain power settings produce higher surface temperature on the electrode, permitting some of the [illegible] metal eroded from the work peice to adhere to the electrode's surface with no apparent effect on conduction. This plating action results in what is called 'no-wear'.

Recently Ford electronically machined with reverse polarity a small die for the hot forging of stabilizer bar eyes. The die was roughed and finished to 500 [illegible] with no measurable wear on the carbon electrode. Moreover, the die was put into production and performed satisfactorily with no hand finishing whatsoever. The cost of producing the die was 50% less than the cost of the old method. When the die needed redressing it was refinished with the same electrode, again with no hand work and no wear, at a saving of [illegible].

In another experiment in which a test die was cut with reverse polarity and a copper electrode, there was no wear roughing and only slight wear finishing. This was a marked improvement over what had formerly been possible with copper electrodes.

Encouraged by the results of several test Ford decided to try machining an entire line of dies with one electrode, thereby taking full advantage of both numerical and electrical machining. A hood outer panel was selected for the experiment. Styrofoam patterns for castings were numerically machined with provisions for shrinkage - the same precise patterns could also have been obtained by numerically machining a master cast, and the casting the various dies in a line from the master, rather than individually machining, [illegible] with the aid of numerical information gathered from [illegible], [illegible] machined on a [illegible] easily [illegible]. Since the [illegible] left on the carbon were only 0.003 [illegible] high, little [illegible] was required. But where more was necessary - [illegible] lines, for instance - the carbon was so soft that it presented little difficulty. After machining the draw, trim and flange dies, and the partial draw and trim dies with reverse polarity, the electrode had worn so little that [illegible] lines could still be seen on its face - they do not appear in the exhibit, however.

This experiment was successful enough to warrant the making of additional production dies with EDM, but new problems were encountered which had not appeared in through-hole work. Stronger machines were needed because of the forces generated by dielectric flushing. For example, flushing with 40 pounds of pressure against a die with 3,000 square inches of surface area puts 120,000 pounds of separating force in the gap which force the machine must tolerate without deflection. Better flushing technizues had to be found to remove the large quantities of eroded material in excess of 100 cubic inches per hour and to control the gas and heat being generated. Particulars about these developments are not in the province of this article, but the system looks promising enough for Ford to machine number of 1969 automobile body dies with it.

The addition of EDM surfacing capacity to the tool and die industry will drastically alter diemaking techniques within the next decade. Complete electrical machining of die surfaces and peripheries is already possible. Furthermore, as has been shown, this new tool reduces die building costs and lead time. Finally, with the extension of "no-wear" to the higher frequencies and to other types of electrode material, and with the development of modularized, adaptive power supplies which can rough and finish die surfaces automatically, EDM will become as integral a part of surfacing automotive body dies as it is of fitting trim dies today.

The process just outlined as operational at Ford is growing at a rapid rate in the independent shops engaged in the manufacture of blank and trimming dies, cavity sinking in forging dies and for roughing and finishing white metal and plastic molds.

A major forging die operation in Canton, Ohio has 9 EDM machines in a two shift operation.

A plastice mold company in east Hartford, Connecticut has 11 machines engaged in the manufacture of plastic dies.

A company in Portsmouth, Maine has four machines engaged in making forging dies for chains and hoist forging.

The electrodes are made principally out of graphite and machined on decal, gorton and bridgeport conventional duplicators, it is this type of application what would meet the immediate needs of tooling being manufactured in underdeveloped countries.

The training of personnel in these techniques can be developed in amuch shorter time span than for conventional methods.

The quality of tooling produced by this method is of higher quality and at a lower cost.

INTRODUCTION

FLAME HARDENING OF DIES

Flame hardening of tool steel is a growing technology in the die-and-mold industry in the United States today. The equipment is inexpensive, but its operation requires a high degree of skill. The benefits realized are in the uniform surface hardness after all machining operations have been completed. In addition, no re-machining, such as the grinding and refitting that is required after conventional heat-treat operations is necessary. This reduces the scrap and repair work generated by the usual heat-treat damage.

FLAME HARDENING DATA FOR DIES

DEFINITION

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

WHY FLAME HARDEN DIES

The flame hardening of dies can be described as a means of "having our cake and eating it too". Our die irons and steels, as received for machining into the die shapes, must be low in hardness to make the die machining operations as easy as possible. Without further hardening, the relatively low "as received" hardness in the die materials does not result in good wear resistance from the die materials and rapid wearing results.

As draw die components are large in size and weight, normal hardening methods are not practical or desireable to use, nor would desired hardnesses be obtained readily. Consequently, in comparison to all other hardening methods, flame hardening is the only practical way to harden the wearing area of draw dies.

DIE MATERIALS THAT ARE FLAME HARDENED

Certain die steels and irons are specified and used because they have the properties needed for the application. In the case of larger die components where good wear resistance or resistance to deformation is needed, flame hardening of critical areas is specified.

See chart I for a tabulation of the Ford Motor Company die materials that are flame hardened together with the approximate flame hardening temperature, quenchant used, and minimum hardness expected.

DEPTH OF HARDNESS

The desired depth of hardening for die surfaces is 3/32" to 1/8". 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 Ford Motor Company die materials have alloying elements present, a quenching media with a cooling rate slower than water is being used to reduce cracking of die surface and reduce retained austenite to give better hardness. This quenching media is mixed with water in a mixing tank and then pumped to the flame-quench heads. The quenching media 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 media to bounce off. It should not splash off the die surface being hardened.

QUENCHING MEDIA

As mentioned under quenching equipment, a quenching solution of water soluable plastic dissolved in water is being used. The main purpose for using this quenchant solution rather than plain water is that the tendency to crack or check is reduced and better as-quenched hardnesses are usually obtained.

CHART I

	DIE MATERIAL	FLAME HARDENING TEMPERATURE	QUENCHANT	MINIMUM HARDNESS
1.	M-3A71A Alloy Cast Iron	1650°F Light Red	Water ≠ 3% P.V.A.*	Rc 58 - Test File
2.	M-3A30A Alloy Pearlitic Nodular Iron	1650°F Light Red	Water ≠ 3% P.V.A.	Rc 58 - Test File
3.	M-3A76 Alloy Die Steel Casting	1650°F Light Red	Water ≠ 3% P.V.A.	Rc 55 - Test File, Rockwell or Scleroscrope Type Test
4.	4-3A62A Alloy Die Steel	1600°F Light Red	Water ≠ 3% P.V.A.	Rc 55 - Test File, Rockwell or Scleroscrope Type Test
5.	SAE 1060 Steel	1600°F Light Red	Water ≠ 2% P.V.A.	Rc 60 - Test File, Rockwell or Scleroscrope Type Test
6.	SAE 1045 Steel	1650°F Light Red	Water	Rc 50 - Test File, Rockwell or Scleroscrope Type Test
7.	Speed Treat or Premax 45 Steels	1600°F Light Red	Water	RC 50 - Test File, Rockwell or Scleroscrope Type Test
8.	SAE 0050A Carbon Steel Casting	1650°F Light Red	Water	RC 50 - Test File, Rockwell or Scleroscrope Type Test
9.	SAE 4150-SAE 6150 Alloy Steels	1650°F Light Red	Water ≠ 3% P.V.A.	RC 55 - Test File, Rockwell or Scleroscrope Type Test
10.	SAE G3500 Gray Cast Iron	1700°F Very Light Red	Water ≠ 1% P.V.A.	Rc 55 - Test File
11.	SAE W108 Road Stock	1600°F Light Red	Water ≠ 2 % P.V A.	Rc 60 - Test File, Rockwell or Sclero scrope Type Test

* P.V.A. - Polyvinyl Alcohol

As can be seen from the sheet, polyvinyl quench is specified in concentrations ranging from 1% by volume up to 3% by volume. The following chart illustrates the amount of polyvinyl to add for different amounts of water.

QUENCH SOLUTION STRENGTH DESIRED	1%	2%	3%
GALLONS WATER	GALLONS POLYVINYL	GALLONS POLYVINYL	GALLONS POLYVINYL
25	1/4	1/2	3/4
50	1/2	1	1-1/2
75	3/4	1-1/2	2-1/4
100	1	2	3
125	1-1/4	2-1/2	3-3/4
150	1-1/2	3	4-1/2
175	1-3/4	3-1/2	5-1/4

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 175 gallon 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.

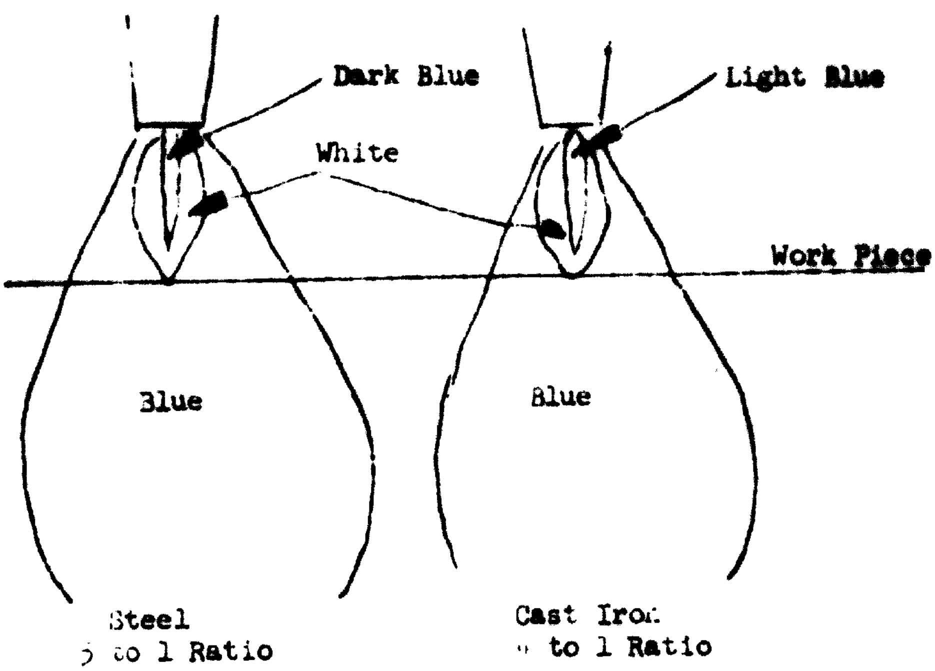
Each time water is added to the main supply tank, the proper amount of polyvinyl must be measured and added as outlined above. When mixed with water as quenching solution, the polyvinyl solution will not burn so there is no fire hazard. The polyvinyl leaves a residue of plastic in the flame-quench heads,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

FUEL GASSES

The fuel gas that is being used is MAPP gas from the Dow Chemical Company. MAPP is an abbreviation for Methylacetylene Propadiene. Although the MAPP-oxygen gas mixture burns with a temperature of 5300° F and oxygen-acetylene 6000-6200° F, in die flame hardening there are advantages from using MAPP gas. One of the advantages is greater safety in use and handling. The lower flame temperature gives greater depth of hardening with less danger of burning the surface and makes the flame hardening in general less critical when varying die contours are being hardened.

A ratio of 3-5 to 1 between oxygen and MAPP gas produces an efficient heating flame. When properly adjusted, the center flame color will be light to dark blue. The coupling distance, (distance from flame-head face to work), should be 1/2" to 3/8" approximately when the flame is properly adjusted.

MAPP gas can be safely operated at high pressures so outlet gage pressures of 20 to 30 pounds can be used as needed to operate the larger flame-quench heads.



FLAME-QUENCH HEAD

A series of flame-quench heads have been supplied for various surfaces on dies. Each of these heads is intended for a specific purpose in flame hardening dies and should be used for the die area that each is designed for.

LIGHTING OF FLAME HEADS

The following general procedure should be sued in lighting flame heads. Care must always be used to keep the heads cool to prevent burning of the heads around the gas ports.

1. Adjust MAPP gas and oxygen gas outlet meters to proper pressure setting.
2. Turn quench liquid on always before lighting flame. Turn on a small flow of oxygen and MAPP gas and light. Increase oxygen to shorten flame to approximately 1/4" long
3. Turn up the MAPP gas and the oxygen in successive steps, increasing the velocity until the flame becomes slightly unstable. The primary center part of the flame should remain 1/4" long with a neutral blue color.
4. When the flames are neutral and approaching instability at high velocity, operating conditions have been reached. The flames should become completely stable when applied to heating of 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 the MAPP gas is turned off.

6. The quench water or solution is turned off last.

As outlined above and on the previous page, the heating flame should not remain burning for longer than a few seconds without the quench liquid flowing through the head.

COMPLETE PROCEDURE FOR OPERATING FLAME HARDENING EQUIPMENT

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% Nital* etchant for checking welds.
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 flame head using 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 quality of hardening with a test file and acid etch.
10. Complete hardening of areas.
11. Shut off flame heads using correct procedure.
12. Check quality of hardening, using test files and nital acid etch.
13. Shut off pump, mixer, turn off gas and oxygen
14. Run pure, warm water through heads to remove residue of polyvinyl to prevent clogging of quench ports.

* A 5% nital etchant consists of 5% nitric acid added to methyl alcohol.

SUMMARY

Flame hardening of dies is done by the progressive or scanning method. The hardening is done by moving the flame-quench head over the die surface to be hardened. Proper hardening results depends on the judgement and skill of the operator. He must adjust his flame height and quench properly to give proper results of hardening depth and 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 maximum attainable hardness without burning the surface.

DIE PATTERNS
FULL MOLD PROCESS
THE DIRECT APPROACH TO METAL CASTING

INTRODUCTION 4/

Patternmakers have worked hand in hand with the foundry man for over 2,000 years in one of the first and most basic industries. There have been many changes in this industry in recent years, but none has been so dramatic and exciting and has had such far reaching effects as the new "Full Mold Process." No development has so attacked the very basic nature of the age-old art of metal casting as well as patternmaking. Only a few years ago, no patternmaker would have thought it possible to cast an intricate configuration in a sand mold without the usual use of core boxes, loose pieces and other devices to make the pattern moldable.

This new revolutionary development had its formal birth with the issuance of a U.S. Paten #2,830,343 on April 15, 1958 to Harold F. Schroyer, entitled "Cavityless Casting Mold and Method for Making Same." The primary purpose of this effort was to promote more art work castings in this country. However, the industrial application of this process was promoted by a Dr. Wittmosser in Europe, after his company, Grunzweig & Hartmann, purchased the patent from Mr. Schroyer. Its first commerical use as an industrial tool came about in Germany in 1962. A small group of Americans, seeing its potential, got together and purchased the rights to bring the process back to the United States under the name "Full Mold Process."

FIRST COMMERICAL CASTING

The first commercial casting produced by this process in the United States was made in Detroit on June 26, 1963. As is typical of Americans, they developed and refined the process to where it is today a proven method capable of producing consistent quality castings of any size or shape in sand molds. As evidence of its rapid adoption in the United States, foundry licensees here have produced, in the first year of its use, approximately 12,000 tons of castings ranging in size from a few lb to 30 tons.

It is the author's purpose to show that the Full Mold process, to date, has proven itself to be the most direct approach to metal casting. This premise will be based on the fact that the overall cycle to produce a finished machined casting is shortened with resulting economic savings, and that it is also simplified, reducing the chances of error. The steps to be considered in this cycle will be design, patternmaking, casting and machining; however, being a foundryman, the emphasis will be on the making of the castings. Likewise, this discussion will be limited to prototype and one of a kind castings such as those used for making metal stamping dies.

SIMPLER DESIGN FUNCTION

The overall design function should be simpler with this process, now that there is no need for the designer to be concerned with the moldability of the casting parts. Anything that sand can be put in or around can be cast, thereby giving more design freedom. This simplicity has some limitations, however. Good metallurgical considerations must still be observed, such as avoiding drastic changes of metal thicknesses, using fillets, and being cognizant of the physical properties of the metal to be used. The designer can now also easily inspect his idea in three dimensions by visiting the pattern shop and viewing the polystyrene duplicate of the part.

The pattern being merely a duplicate of the unmachined casting, it can now be constructed in a much more direct way. The patternmaker no longer needs to scratch his head while studying a blueprint, trying to visualise how this part can be molded. There is no need to provide core boxes, loose pieces and draft, or to consider parting lines. He no longer needs to think of how to frame in and tie a wood pattern together to produce a durable product. He can now simply reproduce the part from the print providing only for machine stock and solid shrinkage of the metal. Checking the pattern accuracy should also be shortened resulting in less chance of error.

Since the castings made using the Full Mold process can, at best, be no better than the pattern that is furnished the foundry, it is fitting that a foundryman should make a few remarks about the quality of the patterns required for good results. Presuming the patterns are made accurate to the print, these remarks will concern only the material and construction. First, the most successful material used to date is expanded polystyrene bead boards. The beads should have good adhesion, one to another, and the density should be in the range of 1 to 1.2 lb per cu ft, with compressive strength of 13 to 15 psi. This material can be purchased in boards 4 by 12 ft, with thickness varying up to 17 in. For stability, the material should have been cured properly by aging one month by the supplier. The patterns can be fabricated from these boards using all woodworking tools, plus the use of hot wires.

There are, however, important precautions that should be taken in its construction. Patterns should be solid, not framed in; adhesives should not attack the polystyrene, and should be fast drying. Wax fillets and cold self-hardening waxes for patching or for sealing seams and joints can be used. However, all of these materials, adhesives, waxes, etc., should have low ash content, preferably less than one per cent. In regard to the surface finish of the pattern, it should be remembered that the casting surface faithfully reproduces the pattern texture. Therefore, the casting finish is to a large extent determined by the patternmaker.

PATTERNMAKER'S RESPONSIBILITY

It must be emphasized that it is the patternmaker's responsibility to construct a good pattern as outlined previously because the foundry can no longer doctor up a poor one. It was possible, before, with a wood pattern. The mold could be patched up, but not so with a poly pattern, which never leaves the mold.

The making of a casting from a good polystyrene pattern in the foundry will be discussed in a chronological order. The basic steps to be considered are the following: preparing the pattern, coating with refractory, gatings, facing with suitable sand mixture, backing sand, roll over, preparing cope, clamping and binding, pouring, shake out, and cleaning the finished product.

During the transporting and storage of the poly pattern, some minor damage may occur. These minor defects can be repaired by the foundry with the use of waxes and pieces of polystyrene glued in as patches.

Now the pattern can be coated with a refractory wash. This is necessary to prevent burn on of sand to the casting. There is no other time to put on this coating in this process, since the pattern never leaves the mold. Several layers of wash are applied by means of brushings, swabbing or spraying to build up approximately a 1/16 in. wall. A good wash is made of a combination of zircon, graphite and ceramic binder with an isopropyl alcohol carrier. When the coating is being applied, it should be remembered that the casting surface is the pattern refractory interface. The refractory build-up is actually the beginning of the mold.

The gating system can be put on either before or after the coating. We prefer having the molder put them on after the pattern is on the molding floor. These gates and runners are made of polystyrene strips cut to standard dimensions. We use strips cut as follows: 1 in. by 2 in. by 12 ft, 2 in. by 2 in. by 12 ft and 2 in. by 3 in. by 12 ft. These strips can be cut with a knife or dull hacksaw blade and fastened to the pattern and to each other by low ash adhesives or small nails. At this point in the development of this process molds are always bottom gated. On deep patterns, step gates can be used as long as they are inclined toward the cope to prevent metal from entering the step gates prematurely.

This procedure aids in supplying hot metal to the top of the column of metal rising in the mold. The number of gates to be used depends on the size of the casting. The general rule is to gate heavily to insure that the metal flows in rapidly with a minimum of turbulence. It is also good practice to gate into all the lowest points in the drag.

SAND MIXTURES

With the gates in place, the pattern can now be faced with a good sand mix- tures include low moisture green sand, oxygen setting sands, sodium silicate bonded sands and furan "no bake" bonded sands. Our preference on large jobs is the no bake furan acid setting sands. It is most essential, no matter which type of facing sand is used, that they be hand tucked, packed and even rammed to sufficient density to insure good results. Low density facings will cause metal penetration into the voids around the sand grains. It is good policy to use some rods in deep horizontal pockets and through window openings. Since there is no opportunity to inspect the finished mold, great care should be exercised at this stage. An extra minute spent here can save an hour of possible cleaning labor.

The remainder of the drag portion of the mold can be rammed with regular green back-up sand. This green sand backing should be an open sand or at least sufficiently vented to the facing. With the plate put on, the drag is bolted or clamped and then carefully rolled over. Unclamped, the molding board or plate is removed exposing the cope surface of the poly pattern. This surface is prepared by filing away any loose sand, attaching risers in the appropriate locations, and locating the down sprue to the runner.

SPRUES AND RISERS

A few words about the sprue and risers are in order. Both of these items are best to be made of polystyrene to prevent having to lift the cope. Risers, either side or top, should be blind to prevent excessive flames and smoke by providing oxygen to the excessive concentration to CO gas formed by the vaporization of the poly while pouring. Sprues should be large enough to supply metal to the gating system but less in area than the sum of the ingate areas. This will help to discourage metal turbulence. At least one riser should have a 1/4 in. pop off on top to help indicate when the mold is full during pouring.

With the cope flask in place, the cope can be made similar to the drag. It is again most important to get good sand density but likewise good permeability. If the whole cope is not made in no bake sand, the green back-up sand should be vented to the facing. It is also good insurance to hang rods in deep cope pockets. The cope now should be clamped right to the bottom of the plate of the drag. If the flask equipment is not rigid, binders should be used. Mold weights are likewise good policy. The mold must be secured in all directions to withstand the tremendous gas pressures generated by the vaporization of the polystyrene pattern while pouring. Allowing sufficient time for the chemical sand mixture to cure and securing the mold properly, the mold is ready to be poured. Metal is the first thing to go into the mold, in fact it actually forms its own cavity by causing the polystyrene to vaporize just ahead of the melt. Since the poly has no permeability, the gases formed must travel out toward the side wall of the mold and then either continue horizontally or follow along the pattern wall vertically to the cope. The present theory and practice is to prevent any burning of the poly in the mold, but rather on the outside of the mold after the gases filter through the sand. By doing this, the flames are reasonably short and smoke is hold to a minimum. The flames burn out very shortly after the mold is poured full, except the normal blue flame of the burning of the sand binders.

It appears at this time that this type of mold can be and should be poured hotter than conventional molds. It can be poured hotter because the polystyrene being an insulator, protects the upper portion of the mold while the metal is filling the mold thereby eliminating expansion defects such as scabs, rat tails, buckles, etc. It should be poured hotter because heat is extracted from the melt during the ply vaporisation process. Pouring hot will also insure little or no residual.

POUR MOLD RAPIDLY

It is imperative to pour the mold rapidly and without interruption in order to insure that the molten metal keeps up with the vaporisation rate of the polystyrene, thereby preventing any large voids between the metal and poly. The pouring rate will be determined by two factors. The first one is naturally the design of the gating system. The second consideration is the permeability of the closed mold. If the gases, CO and H-2, formed by the vaporization of the poly can not escape fast enough through the sand, they will create a back pressure which will tend to reduce the pouring rate. On large molds, a good rate to aim at is one ton of iron per ten sec per ladle.

When the casting is cooled in the mold to the proper temperature, it is removed in the usual manner. At this stage, it can be seen that the refractory coating that was sprayed on the pattern has been completely transferred to the casting. This coating easily peels off. The fact that this takes place indicates that the mold is always full either with polystyrene, iron or sufficient gas pressure between them to hold the thin coating in place. Next, it can be noticed that there is a lack of fins, holes in side wall are completely through.

If the mold is carefully rammed up particularly in corners and pockets to the proper density, no "burn on" or metal penetration of the sand appear on the casting, providing, likewise, that the mold was poured at a reasonable temperature. If all goes right, the casting made by the Full Mold process has the potential of being cleaned easier than a conventional casting. Again, the best casting finish that can be expected will be exactly the surface finish of the polystyrene pattern.

IMPROVED MACHINING

Due to the quality of the casting made with this process, the machining operation can be greatly improved. This quality is exemplified first of all by a casting which has closer tolerances and which should require less stock for machining. This accuracy can be explained by the fact that the casting duplicates the pattern for there is no pattern removal or core setting. Also, due to the chemical setting binder in the sand placed completely around the pattern, the mold is completely rigid and seamless, which affords little or no mold wall movement. Besides being more accurate, this casting is also potentially cleaner under the surface than a conventional casting. There is no mold dirt or sand to float to the surface. Metal is the first thing to enter the mold and with proper pouring practice no slag will enter the cavity. With the absences of sand and slag inclusions along with no chaplets, nails, or chilled fins tool life will be increased. With cleaner castings held to closer tolerances there is a significant reduction in machining costs.

CONCLUSION

The Full Mold process is a proven and progressive method of making castings having far more advantages than disadvantages. The overall cycle, from design to finished machined casting, is shortened resulting in economic savings and reducing the chance of error. Its few disadvantages are stated as follows. The pattern is destroyed in the casting process but if all goes well this could be considered an asset for it eliminates the need to get rid of the wood pattern in prototype jobs. The patterns are more delicate and require more careful handling. There is also the possibility of entrapped residual in the cope surface area, but this can be minimized by using low ash materials and proper gating and pouring practice.

The advantages far outweigh these few disadvantages. Design freedom is greatly increased. The chance of error from design to finished casting is considerably reduced by the elimination of the reverse thinking required with the conventional wood pattern and core box method. There is definitely an increase in the casting quality, both in regard to closer tolerances and cleaner castings for reasons stated previously. All things considered, the Full Mold process is certainly a sensible, practical and the most direct approach to metal casting to date, producing economic savings as well as fewer headaches.

GENERAL RECOMMENDATIONS

The Tool, die and mold shops in developing countries have been created for the most part by a master craftsman. The success of his business is largely dependent upon his personal technical skills and in his ability to meet product commitment. In such circumstances business growth is severely restricted, since he is completely pre-occupied with current operations. In a previous study while a member of a Unido metal working expert group, rarely did we find where the independent shop owner had a qualified replacement to manage the shop in his absence. In many cases the owner or shop manager was ill equipped to develope sound plans for continuing growth in keeping with new technological changes. The business practices that formerly prevailed can no longer be pursued. The inability or lack of opportunity to prepare for such developments can only result in erosion to the operations ability to produce products competitively or possible business failure. It is owners or managers facing these problems in developing countries who could gain most, and probably contribute more through the upgrading of technology and manpower development programs.

In consideration of the above the following recommendations are submitted:-

1/ Closer liason between educational institutions and industry to upgrade the practical requirements of production and industrial engineers.

2/ Continuing education programs for shop managers and foremen with special reference to - Tool cost estimating - Electrical Discharge Machining - Numerical Control Machining - Job analysis and evaluation - Industrial organization and management manpower planning and facility loading.

3/ Industrial workshops conducted by universities in similar manner to those in the United States and Europe should be pursued. Experts in the newer technologies should be invited to participate in there development.

4/ Expert assistance by the United Nations Industrial Development Orginization in the prime subject matter outlined in this paper.

5/ A problem facing the die and mold making industry in developing countries is that it is severely fragmented. The many small shops have overlapping facility of low productive capability. (Bridgeport, Decal, Toolmaster) if the combined production volumes of for example four (4) plants represents 100,000 direct labor hours and a total skilled force of diemakers and machinists of 48 were to be integrated into one manufacturing operation, the selection of machine tools would be much different. The total number of machines would be less. The capital investment may be the same or greater. The newer machine tools would be capable of a much higher rate of productivity, more rigid, higher feed rates, higher spindle speeds, more horsepower, etc. The operation with this new equipment would be capable of supporting full utilization of numerically controlled drilling and milling equipment, and electrical discharge machines for cavity sinking and finishing operations.

Modern die and mold making equipment and techniques will permit easier estimating patterns, meeting estimates with higher qulity and less scrap repairs. The die and mold making industry is much in need of expert assistance in the production use of electrical discharge machining equipment. Much hand filing and fitting is performed on blanking dies which should be processed for spark erosion (E.D.M.). Much bridgeport and decal duplicating equipment is being used on cavity sinking where carbon electrodes and spark erosion (E.D.M.) would be more economical and will produce tools of higher quality. The ability to master this technique would be a major step forward in making this industry competitive in both quality and cost in the export market. A machining center or model plant would be an excellent media to introduce modern methods and technology to the developing countries.

FOOTNOTES

1/ Ford Motor Company "Tool & Die Training Guide" of 1967

2/ Cincinnati Milling Machine Company
Publication No. EM-118A
"Electrical Discharge Machining"

3/ Ford Motor Company "Process of Flame Hardening of Die Surfaces"
as of 1967

4/ Extracted from information prepared by:
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