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DESIGN OF JIGS AND DIES[1]

- its influence on Product Design -

by

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[I] INTRODUCTION

Modern industries utilize numerous types of production tools, machines and processes, much manpower and investment to produce useful goods for the needs of society. The competitive nature of today's production forces the industries concerned, whether in the technically advanced or in the developing countries, into careful systematic selection and utilization of processes, methods, tools, machines, manpower and investments. Thus only is it possible to obtain lower production cost per piece and also higher productivity and profit with acceptable quality standards.

Articles must be designed to meet three basic requirements, namely: (a) function, (b) sales and (c) production. The following factors influence design:

(a) Manufacturing methods and processes
(b) Production tools and machines: cutting tools, jigs fixtures, machine tools, etc.
(c) Quality requirements: dimensional accuracy, surface finish, etc.
(d) Production quantity: total quantity, lot size, etc.
(e) Sales requirements: price, profit, market appeal, etc.

For a desirable product there are many alternative processes, tools and machines, and operational sequences available which can be selected as most suitable. Tooling in manufacturing, such as jigs, fixtures, and dies, influences greatly the evolution of a final product and is one of the major day to day tasks and problems for almost all fabricating industries.

Tools used in shops are devices

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

(b) For holding workpieces and/or guiding tools, e.g., jigs and fixtures, and machine tool accessories such as chucks, vises, etc.

(c) For measuring and inspection of parts, e.g., gages, precision instruments, etc.

(d) For sensing necessary information for operational control of machine tools, e.g., tool force dynamometer, power indicators, etc.

(e) For the transmitting instructions to machine tools for desired operations, e.g., N/C tapes and control units.

The functions of machine tools are (a) to hold the workpiece and the tool at proper, related positions, and (b) to generate movements between the workpiece and tool for the productive motion (cutting, forming, etc.). The relationship between the machine tool, workpiece, and cutting tool with the respective basic requirements for optimum production is illustrated in Fig. 1-1.

Definitions of Workholding Devices and Dies:

The term workholding devices includes all devices that hold, chuck or support a workpiece in a desired manner and location,

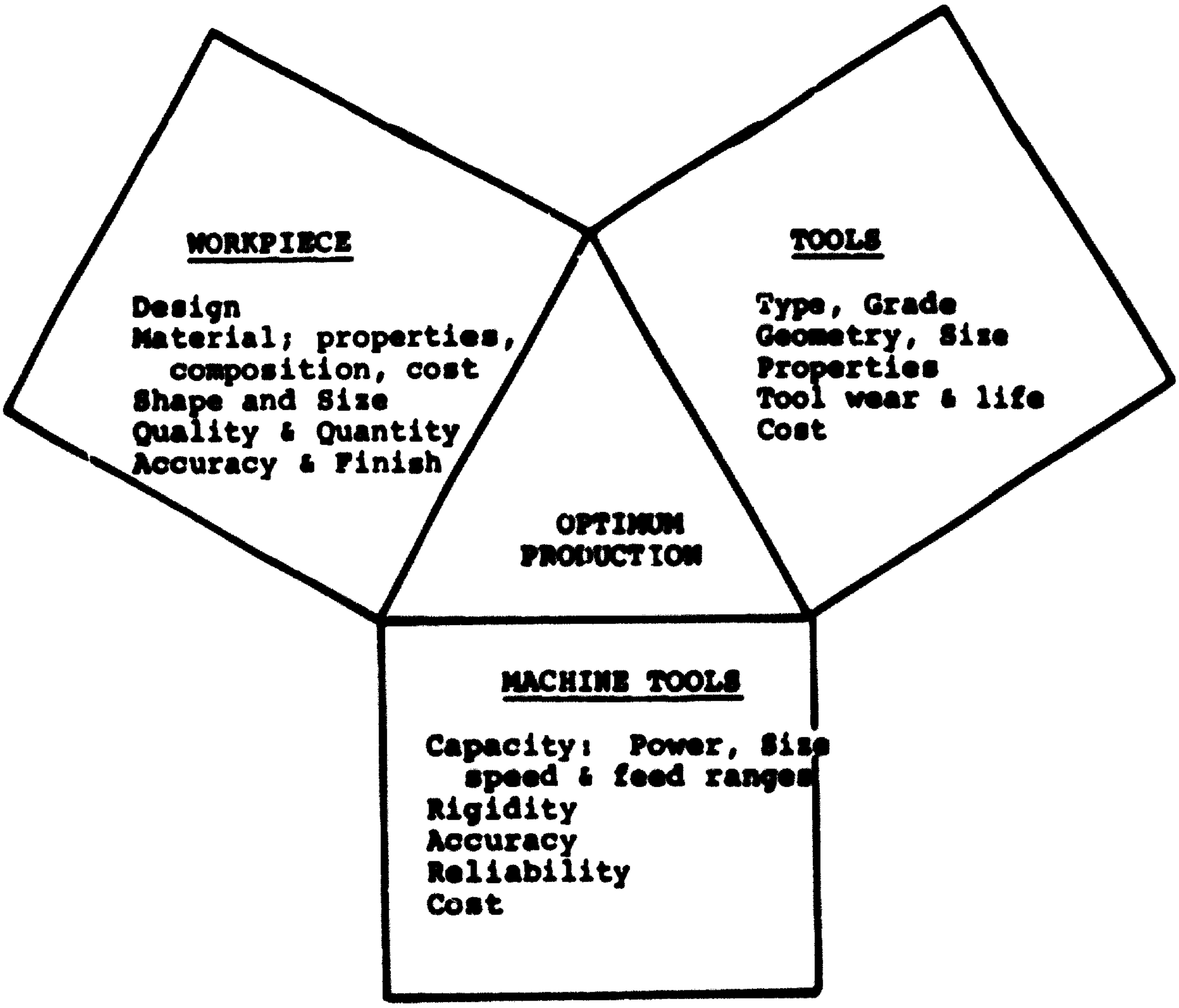


Fig. 1-1 Machine-Workpiece-Tool Requirements for Optimum Production

which also guide the tool to perform a manufacturing operation. They are known as "Jigs and Fixtures" and are extensively used in the machining of mass-produced parts.

A jig is a device for positively locating and guiding both the workpiece and the cutting tool. A fixture is a device for holding and positioning a workpiece, but does not necessarily guide the tools. A schematic sketch showing the basic elements and features of workholding devices is exhibited in Fig. 1-2.

Pressworking operations are performed on power presses with punches and dies. Generally a complete set of pressworking tools are simply called a "Die Set" which usually contains a punch holder, and a die or die block with accessories.

The Functions of Tool Engineering:

Tool engineering is concerned with the economic production of manufactured goods and deals with the development, design, analysis, planning, construction, operation, application, supervision and follow-up of production methods, tools, equipment, and facilities for the manufacture of industrial and consumer goods.

The specific areas of tool engineering are analysis, design selection, construction, application and control of

(a) Cutting tools and accessories

(b) Workholding devices (jigs and fixtures)

(c) Pressworking and forming tools (punches and dies)

(d) Measuring instruments and gages

(e) Tooling for welding, casting, assembling, etc.

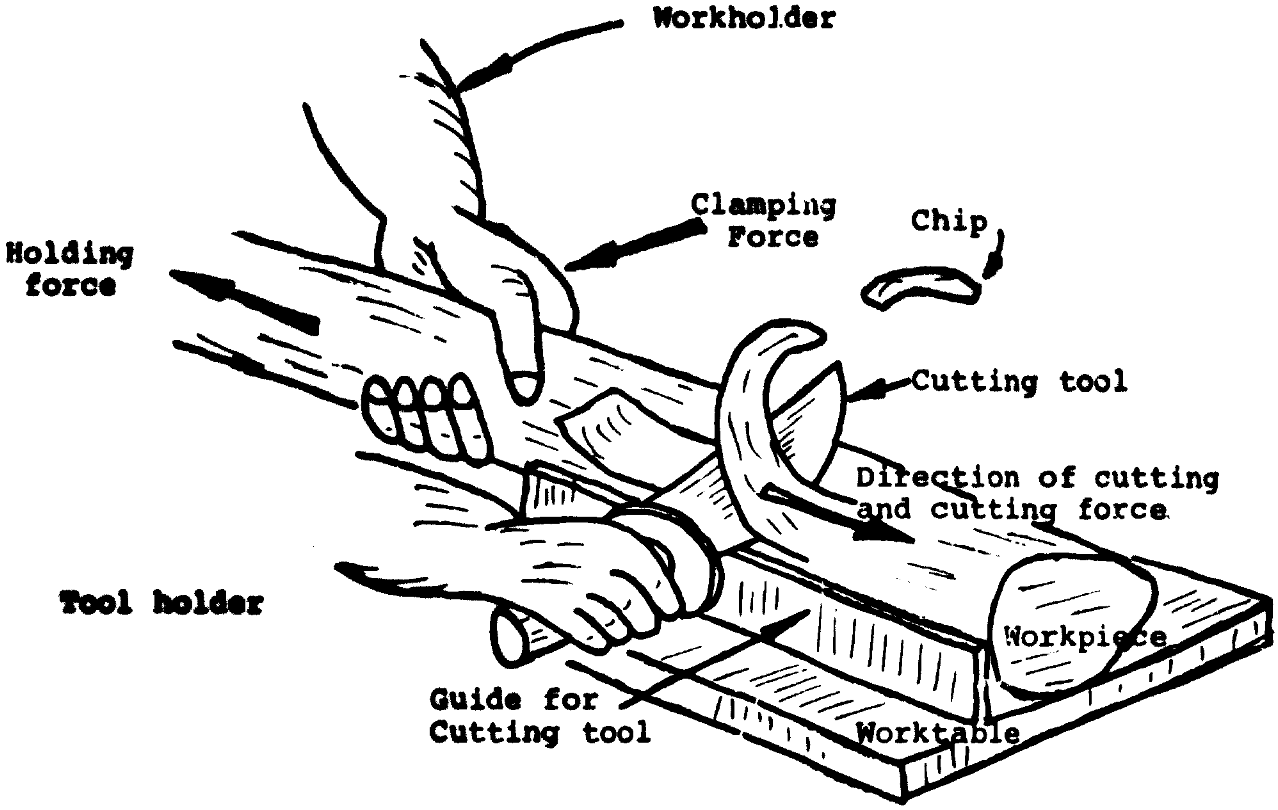


Fig. 1-2 Basic Elements and Features of Workholding Devices (Jigs and Fixtures)

(f) Tooling for non-conventional processes such as ECM, EDM, EBM & W and etc.

(g) Programming and tooling for N/C and A/C machining and processes

(h) Special machine tools and components

Tool Engineers:

The primary function of the tool engineer is to analyze the tooling problems and to design or select, and apply suitable tools and tooling set-ups based upon technical knowledge, experience and ingenuity. In order to achieve these objectives he organizes MEN, MATERIALS, METHODS and MACHINES so that quality products may be made economically and efficiently. The continuing task of the tool engineer is the development of improved manufacturing techniques. The complexity of modern manufacturing requires that many functions of tool engineering be carried out by specialists who usually are graduate engineers in either industrial or mechanical engineering, and/or engineering technicians with practical experience in tool and die making and production processes. A schematic diagram showing the functions and interrelationships of tool engineering in manufacturing, from product design to production is given in Fig. 1-3.

Process Analysis and Planning:

The policies and decisions of management are implimented through process analysis and planning. These are carried out to select or design an optimum process for a specific operation. In process planning the following factors should be carefully analyzed:

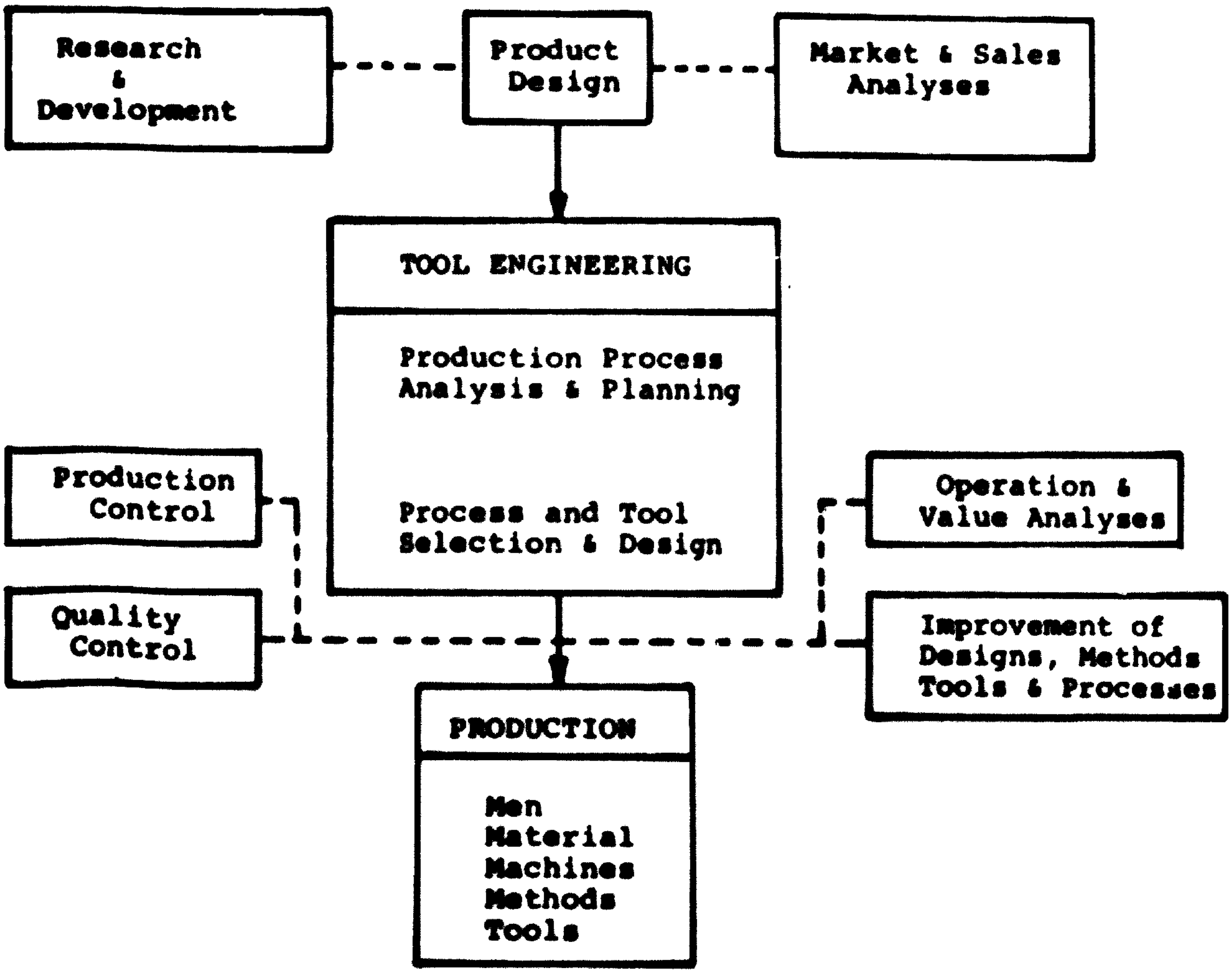


Fig. 1-3 Tool Engineering in Manufacturing

(a) Functional design requirements of the product; shape, size, material, strength, specifications, surface, appearance, weight, volume, etc.

(b) Production requirements of the product; quantity and quality, tolerances, fits, surface finishes, cutting tools, workholding devices, gages, machine tools, equipment and facilities available, etc.

(c) Economy of production; tooling cost, set-up cost, production cost, material cost, equipment cost, equipment cost, maintenance and power cost; gaging and inspection costs, etc.

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

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

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

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

Requirements for Tool Design:

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

(a) Design for satisfactory performance of a specific function with maximum simplicity
(b) Design for quality specifications
(c) Design for the optimum production
(d) Design for the maximum motion economy
(e) Design with standard parts and available materials
(f) Design for economy

By considering these factors, analysing the problems involved and screening alternative designs, decisions may be made of the most suitable selection.

[II] TOOLING FOR WORKHOLDING DEVICES

Workholding Devices:

Jigs and fixtures provide the following advantages:

(a) Elimination of workpiece layout before machining thus, reducing the set-up time and workhandling time

(b) Increase of machining accuracy because of accurate self-positioning of workpiece

(c) Increase of productivity due to machining of multi-workpieces or with multi-tools

(d) Increase of production rate due to the increase of cutting speed, feed, and depth of cut because of improved clamping rigidity

(e) Reduction of the costs for quality control

(f) Maximum utilization of machine tool capacity

(g) Increase of motion economy and application of automation features

A workholding device must meet two basic requirements:

(a) Positioning and locating a workpiece in definite relation to the cutting tool and the machine tool component

(b) Withstanding clamping and cutting forces while maintaining the precise position or location required.

Types of Workholding Devices:

Many standard workholding devices are readily available in the market, however, most workholding devices are designed and constructed to meet the specific requirements of the operations.

Types of Jigs:

Jigs are usually classified by their structural design. Common types are templet, plate, channel, open, box, leaf, universal, etc. The main features of typical jigs are

(a) Templet jigs; a simple type used only for limited production of large workpieces for correct location of holes

(b) Plate jig; a simple type used mostly for limited production and usually consists of three essential parts, plate, drill bushings, and locating pins. In most cases it does not have its own clamping device thus requiring other clamps such as "C" clamp, etc.

(c) Channel jig; a channel-shaped structure in which the workpiece is clamped

(d) Open jig; a type constructed with a main supporting structure having clamps, bushings, locating devices, etc., but no leaf or cover. The advantages of this type is that (i) workpiece handling and chip removal is easy and (ii) fabrication of the jig is made less costly by utilizing standard parts. However, this type of jig can only be used for drilling into one surface of the workpiece with a single loading

(e) Leaf jig; a type with a hinged cover or leaf which can be swung open for loading and unloading of the workpiece. With this type of jig, complicated workpieces with irregular contours can be handled. Quick loading and unloading of workpieces is possible, and more than one surface can be machined with a single loading. Unless some provisions are made, accumulated chips inside the jig may cause trouble

(f) Universal jigs; standard basic units to be adapted for specific jobs

Jig Bushings:

Standard components of a drill jig are drill bushings which guide the drill. They are standardized by commercial or national standards with principle dimensions and tolerances, and are usually classified by their application methods and design features. The most common types of jig bushings are

(a) Press-fit bushings

(b) Fixed and slip renewable bushings

(c) Screw bushings

(d) Special bushings

The lengths of jig bushings are based on the thickness of the jig plates. Attention must be given to the placing of jig plates with drill bushings. Adequate clearance between the bottom of the bushing and the workpiece is required for smooth chip removal.

Types of Fixtures:

Fixtures are usually classified by application and function; such as workholding devices used in milling, boring, tapping, broaching, grinding, welding, assembly, inspection, etc. Many components of fixtures, e.g., clamping devices, vises, jaws, pins, etc., are standardised for economic design and interchangeability.

Analysis of Workholding Devices:

The design or selection of any workholding device should be on sound economic and technical bases, considering many related factors as illustrated in Fig. 2-1. A workholding device has the following basic features:

(a) Locating elements
(b) Structural elements
(c) Clamping elements
(d) Tool-guiding elements
(e) Power devices for operating the clamping elements
(f) Indexing devices for accurate positioning
(g) Fastening parts
(h) Auxiliary elements

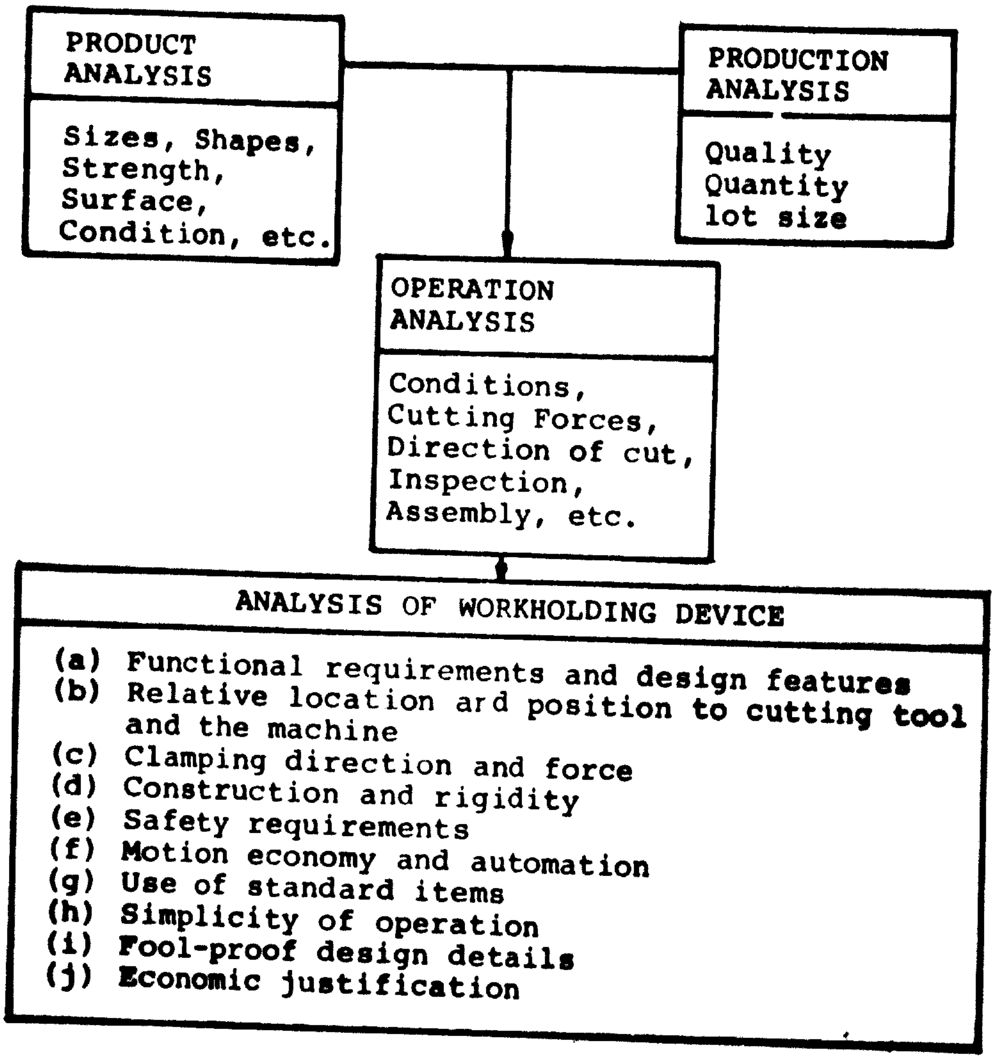


Fig. 2-1 **Procedure for Design and Selection of Workholding Devices**

To insure proper operation of the workholding device, the locating elements should position the workpiece accurately and the structure should withstand the clamping and cutting forces. The clamps should apply only adequate force for maintaining the position of the workpiece and the attachment should hold the device on the machine properly.

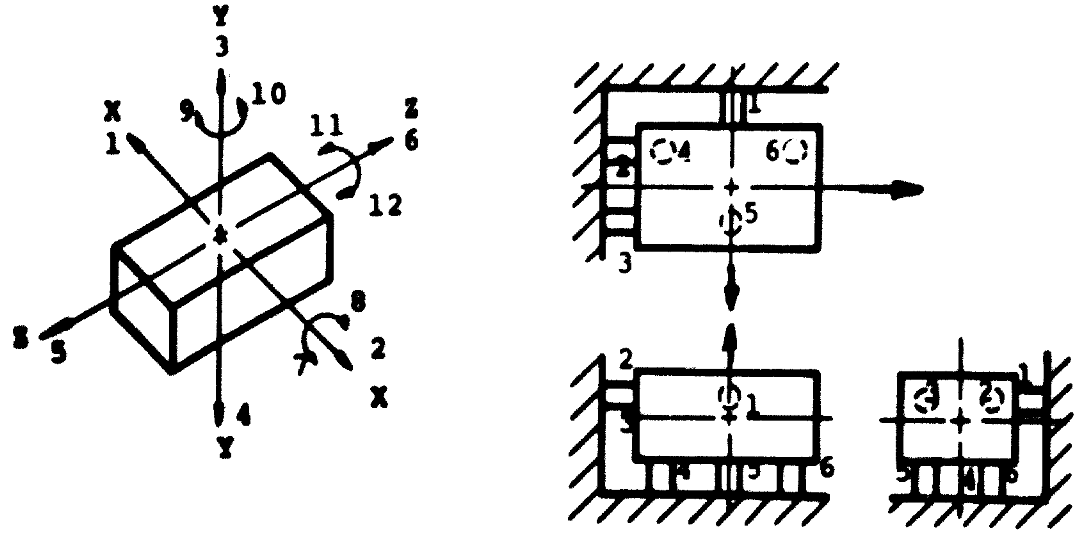
There are many types of workholding devices which are used for other than machining operation, e.g., welding, assembly, inspection, etc. However, the basic design requirements and procedures are similar.

Locating Methods:

For consistant production results, it is essential to accurately locate the workpiece relative to the tool. This relationship is fixed by locators in the workholding device. A workpiece must be confined and restricted against movement in all directions except those needed for operation or handling. A workpiece in space has twelve degrees of freedom as shown in Fig. 2-2 (a) and it may be positively located by eliminating nine degrees of freedom. The remaining three degrees of freedom may be restricted by means of clamping devices. This arrangement is called the 3-2-1 method of location and is shown in Fig. 2-2 (b). The basic requirements for successful pin-locating are

(a) Selection of location surface

(b) Use of least points for location



(a) 12 degrees of freedom in space

(b) 3-2-1 locating method

Fig. 2-2 Locating Method

(c) Extreme positions of locating points

(d) 3-2-1 locating principle

(e) Use of mutually perpendicular planes

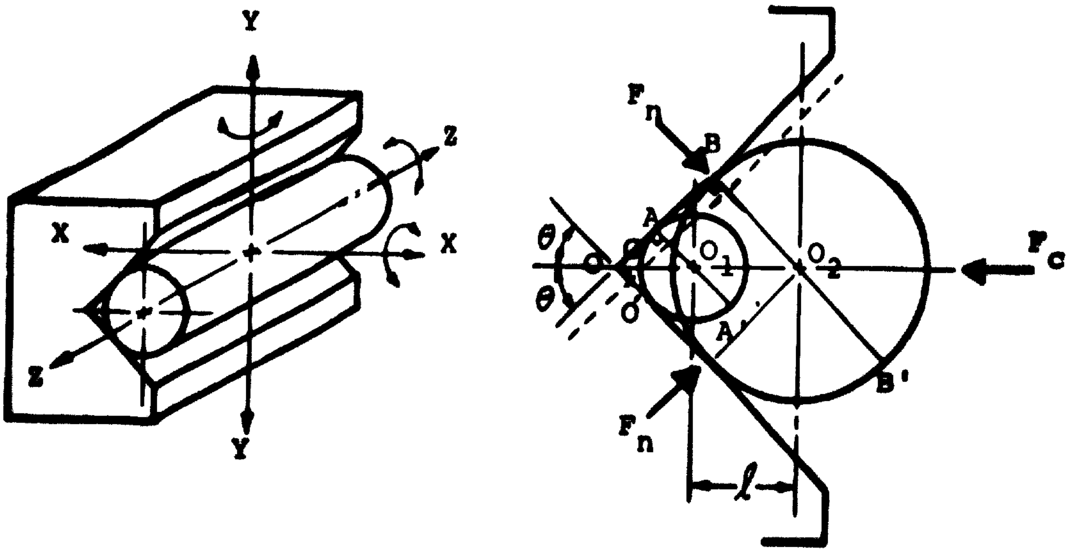
One of the most popular locating devices is the V-locator for cylinderical work. As shown in Fig. 2-3, the best design for a V-locator to meet the requirements for the least displacement of centers of different diameters and for positive location of a workpiece is a 90° included angle for the V.

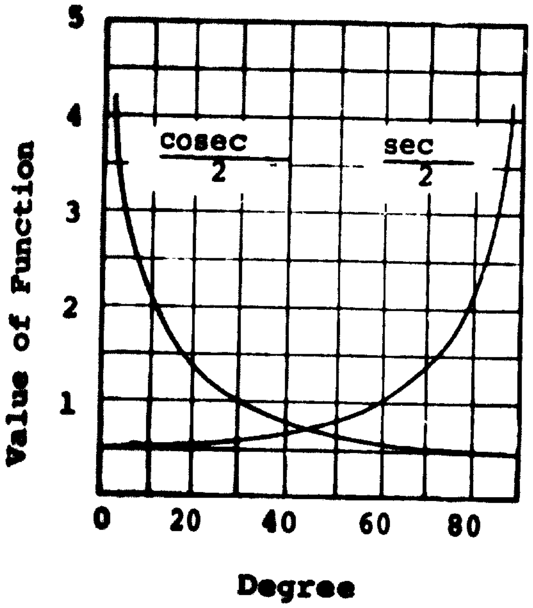
Clamping Devices:

All clamping devices must meet some common requirements and the selection of a proper clamp demands definite consideration. They are

(a) Rigid holding of workpiece during the production operation
(b) Quick acting and ease of operation
(c) Clamping with no damage to the surfaces of the workpiece
(d) Magnitude of clamping forces, its direction, and location
(e) Types of clamping devices, mechanism power sources, etc.
(f) Economy of clamping

The types of clamps used in workholding devices are numerous, but the majority exhibit several basic, common mechanical features such as a screw, cam, wedge, hook,





$$\ell = \frac{\text{cosec}\,\theta}{2}(D''-D')$$

$$O'C = \frac{\sec\theta}{2}(D''-D')$$

Fig. 2-3 V-Locator Design

toggle and lever. Clamping by pneumatic, hydraulic, and electric means are also common in supplementing manual operation.

Since the clamps hold the workpiece against a locator and must also counteract any disturbing forces, it is essential to estimate the required clamping force in order to select a clamp. The clamping forces must neither disturbe the location of the workpiece nor distort or damage the workpiece. Typical examples of magnification of clamping forces are shown in Fig. 2-4. For example, as shown in Fig. 2-4 (a), the applied force (F) with a wrench is magnified to excert the clamping force (F_c) by $F_c = (a/b)F$. The force (F) required to actuate a clamp should be known for proper selection of a clamping device. Manual force values for different operations and conditions are generally available. Usually 50 to 100 lbs. of force may be exerted by manual operation of simple levers, hand knobs, screw heads, etc. Locating and clamping should not be thought of as the same operation. Locating is obtaining the most effective way of positioning the workpiece, whereas clamping is to give stability to the location chosen.

Screw Clamps:

Screw clamps are the simplest and most versatile type of clamping elements. They have the advantage of exerting adequate force and resisting loosening tendencies of vibration.

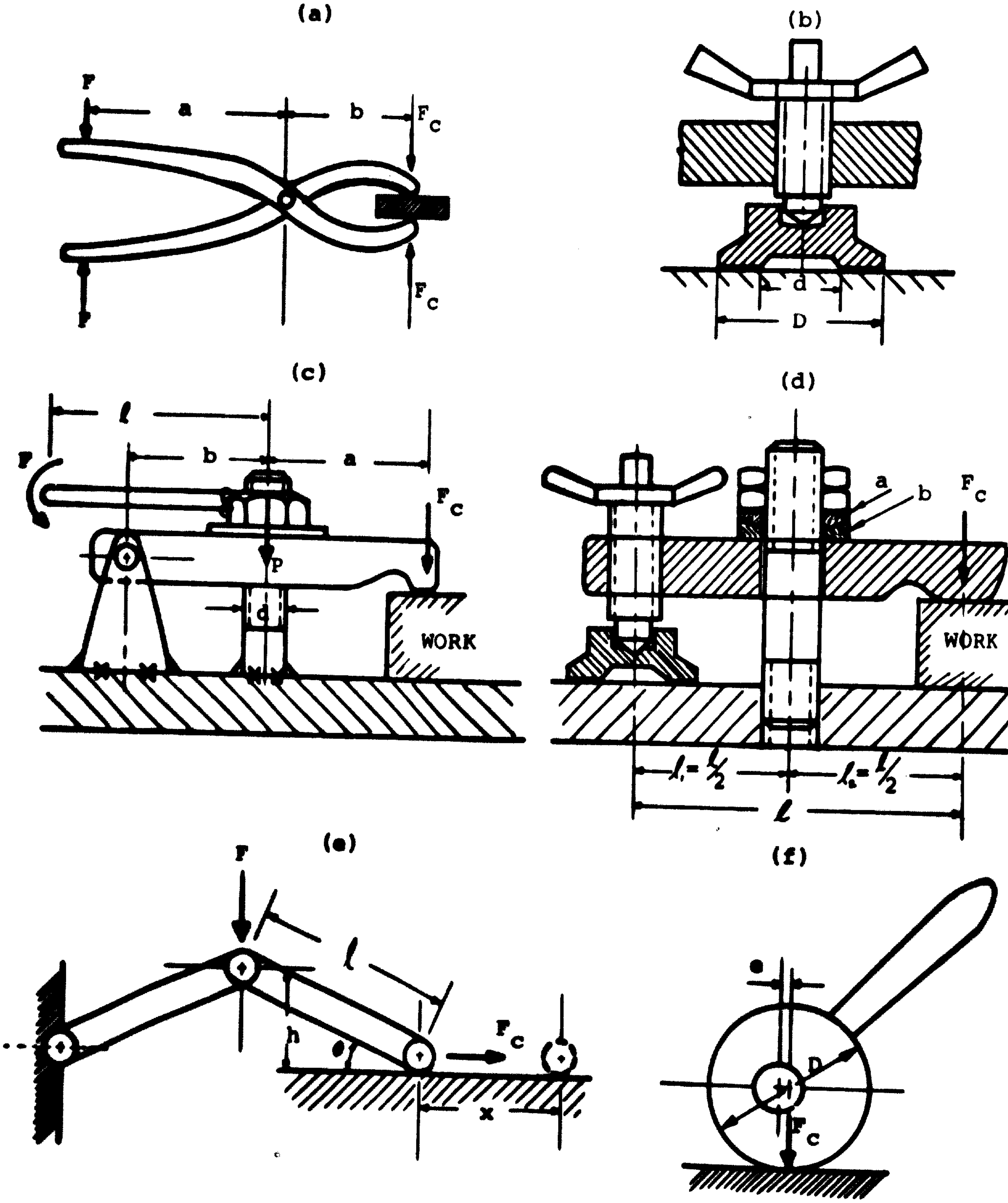


Fig. 2-4 Clamping Forces of Typical Devices
(a) Wrench, (b) Screw Clamp, (c) Strap Clamp,
(d) Screw-strap Clamp, (e) Toggle Clamp,
(f) Cam Clamp

However, they possess the following disadvantages:

(a) The workpiece may be moved by the frictional force at the end of screw, or the workpiece surface may be damaged

(b) Comparatively more times and effort is required

(c) The clamping force is not constant

Screw clamps may be actuated by hand, wrenches, levers or handwheels. Swivel pads are usually provided on the ends of screw clamps to reduce possible workpiece damage.

The forces acting on standard bolts varying in size from 1/4 to 1 in. can be represented by

$$T = 0.2\, d P$$

Where T = Torque applied to nut, in-lb.
d = nominal diameter of bolt, in.
P = load on bolt, lbs.

The force (F_c) exerted by a screw clamp (Fig. 2-4 b) may be computed using the following formula:

$$F_c = \frac{FL}{R_p \tan(\theta + \psi) + 0.33\mu\left(\frac{D^3 - d^3}{D^2 - d^2}\right)}$$

Where F = the force applied on the wrench or handle, lbs.
L = the length of the wrench or handle, inch
R_p = the pitch radius of the thread, inch
θ = the helix angle of the thread, degree
ψ = the friction angle in the thread, degree
μ = the coefficient of friction on the force of the swivel pad

Combinations of screw and lever or screw and wedge devices are often used. A combination of a screw and lever is called a screw strap clamp, and an example of this type of clamp is shown in Fig. 2-4 (d). The clamping force (F_c) of this type of strap clamp may be computed as follows:

$$F_c = F\,\frac{l_1 l_2 - (l_1 + l_2)\mu R}{l_2^{\,2}}$$

if

$$l_1 = l_2 = \frac{L}{2}$$

then

$$F_c = F\left(1 - \frac{4}{L}\mu R\right)$$

where F = the force applied to the head of the screw

μ = the coefficient of friction between the ball face washers (a) and ball socket washer (b) (Fig. 2-4 (d))

R = the radius of the ball socket in the washers

Strap Clamps:

Strap clamp is a simple and commonly used device along with other clamping devices such as: screw, cam, wedge, lever, etc.

The clamping force (F_c) as shown in Fig. 2-4 (c)) is given by

$$F_c = \frac{a}{b}P$$

where P = applied force, lbs.

a, b = distances from fulcrum

Hook Clamps:

There are three main types of hook clamps; (a) bolt types (b) latch type, and (c) screw type.

Toggle Clamps:

The action of toggle clamps is based upon the movement of coordinated links. There are many commercial standard toggle clamps available and they have to be designed only in exceptional cases. The principles of clamping action are shown in Fig. 2-4 (e) and the clamping force (F_c) may be estimated as follows:

$$F_c = \frac{F}{2} \cot \theta$$

where F = applied force, lbs.

θ = angle between links and the horizontal line

Since the smaller the angle (θ), the value of the cotangent becomes larger. Therefore, the clamping force (F_c) is greater than the applied force (F) for angles less than 25°. From the diagram of Fig. 2-4 (e), the following relationships can be obtained for design of toggle clamps:

$$X = 2\ell(1 - \cos\theta)$$

$$h = \ell \sin\theta$$

Cam Clamps:

Quick-acting cam clamps are popular in workholding devices. There are two main types of cam clamps, (a) direct-acting levers and (b) shaft eccentrics. As shown in Fig. 2-4 (f) the cam has a pin mounted on stationary supports of the device. The axis pass through point O. Distance from point O to points on the working surface of the cam are variable. The cam profile may be either an arc (circular eccentric) or a spiral. An eccentric circular cam is designed with definite ratios of its diameter (D) to its eccentricity (e) for looking.

The diameter (D) of the eccentric cam is usually selected to suit the design of the device, while the eccentricity (e) is determined by the ratio ($D/_e$) which is usually from 14 to 16 in value.

The clamping force (F_c) of an eccentric clamp may be computed as follows:

$$F_c = \frac{Fl}{[\tan(\psi + \phi_1) + \tan\phi_2]f}$$

where F = the force applied on the handle of the eccentric cam, lbs.

$l \simeq l_1 + \frac{D}{2}$

l_1 = the length of handle

D = the diameter of the cam

ψ = the cam rise spiral angle of the eccentric

ϕ_1 = the friction angle between the eccentric and its support

ϕ_2' = the friction angle of the pilot on which the eccentric rotates

f = the distance between the center of rotation of the eccentric and the point of the contact with its support

Power Clamping Devices:

Manual clamping has many disadvantages such as

(a) Non-uniformity of clamping force

(b) Difficulty of computing the required clamping force

(c) Physical fatigue of operator

(d) Limited clamping force (max. 90 lbs.)

(e) Time delay

To compensate for these handicaps of manual clamping, power clamping devices with pneumatic, phdraulic, hydro-pneumatic, fluidic, or electric systems, are most frequently used.

For pneumatic clamping devices, the pressure available from a compressed air supply system in shops is around 80 to 100 psi. The force (F_c) exerted by the rod of an air-operated piston device is given by

$$F_c = P_a\left(\frac{\pi d^2}{4}\right)$$

where P_a = the air pressure, psi

d = the cylinder diameter, in.

Sometimes considerable force is required for clamping, particularly for multiple-clamping devices. Hydraulic or hydro-pneumatic power elements are then used rather than a pneumatic device alone. Large forces can be developed in hydraulic clamping units due to the high pressures obtainable. The clamping force (F_c) realized from a hydro-pneumatic system (Fig. 2-5) may be computed as follows:

$$F_c = \frac{D^2}{d^2} F_r \eta_o$$

Where D = the rod diameter of the pneumatic piston, in.
d = the diameter of the hydraulic piston, in.
F_r = the force acting on the rod of the pneumatic piston, lbs.
η_o = the efficiency (0.8 - 0.85)

Electrically-operated power clamping systems such as motors and solenoids are also used for special cases.

Manual Clamp-actuating Forces:

Although power clamping is often used, most clamps are hand-operated. The force exerted by an operator on a lever or handle depends on his strength. There have been studies on human strengths for manual handling of machine parts and examples of such studies are shown in Table II-1 and II-2.

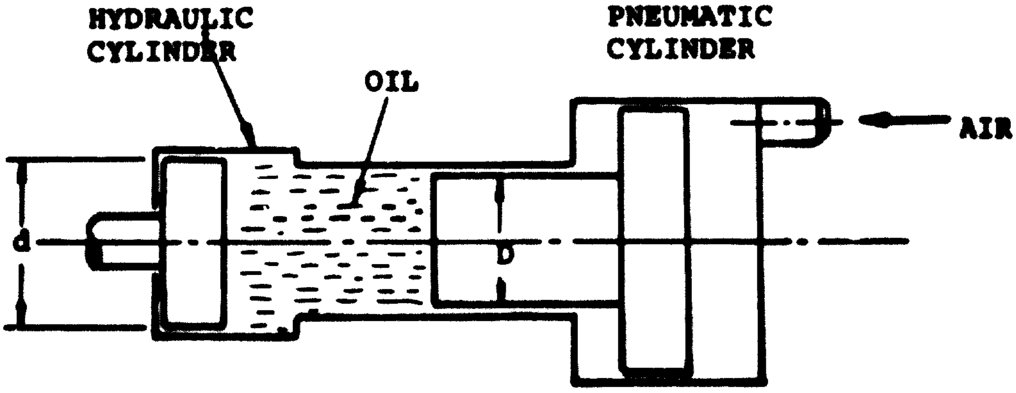


Fig. 2-5 Hydro-pneumatic System

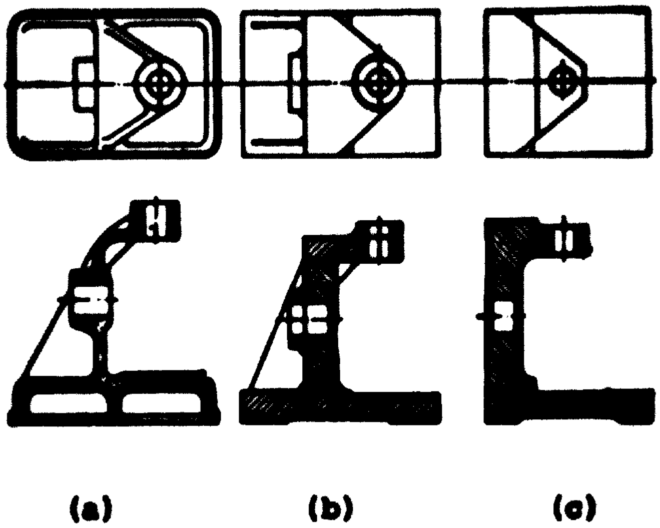


Fig. 2-6 Structural Frames of Workholding Devices

(a) Cast iron
(b) Weldment
(c) Steel block

Table II-1 Summary of Manual Forces Exerted on Various Types of Levers

Type of Lever	Average Force, lbs.
Single Lever:	
Push or pull vertically from about 20 to 35 in. above floor level	95
From about 35 to 50 in. above floor level	65
Push or Pull Horizontally	65
Crossbars:	
Push or pull vertically or horizontally	160
Handwheel:	
Vertical and parallel to body	125
Vertical and perpendicular to body	160
Horizontal	140

Table II-2 Hand Grip Strength

Action	Force in lb.		
	Max.	Mean	Min.
Grip (ave.)	154	95	52
Right Grip	183	124	65
Left Grip	165	113	61

Body Structures:

Main structures of workholding devices may be

(a) Gray iron castings

(b) Steel plates

(c) Steel forgings or blocks

(d) Weldments of steel plates

(e) Standard steel shapes (angles, channels, I-beams, etc.)

Large workholding supports are usually made of cast iron. However, in many cases, steel weldments are more economical than castings, (See Fig. 2-6).

Design Procedure:

The design of special workholding devices (jigs and fixtures) differs from the design of machine elements or products since it is rather restricted by the design and production specifications of the product. All workholding devices must meet the following requirements:

(a) Perform a specific function

(b) Meet precision requirements

(c) Satisfy the production rate and schedule

(d) Fulfill auxiliary demands such as safety, adaptability, and convenience

(e) Use standard parts whenever possible

(f) Justify cost

A tool designer must first define the problem and determine criteria for all factors to be considered and then ask the following questions:

(a) Will the tool perform the function intended?

(b) Will the specific quality requirements be met?

(c) What are the limitations on funds available for design and construction of the tool?

(d) When must the tool be completed?

(e) What are auxiliary factors to be considered?

(f) Would multi-tool or multi-workpiece operations be possible?

In designing a workholding device, it is advantageous to deal as shown in Fig. 2-7 with the various elements and auxiliary parts as listed:

(a) Lay out the product (workpiece) in at least three views (preferably use red color)

(b) Draw the elements of the workholding devices around the workpiece

   (1) Lay out cutting tools involved and check possible interference

   (2) Arrange the elements for guiding the tools (drill bushings, etc.)

   (3) Indicate all locations for the workpiece

   (4) Satisfy clamping needs

(c) Check chip space, chip-removing methods, etc.

(d) Decide how the workholder will be fastened to or placed on the table during machining

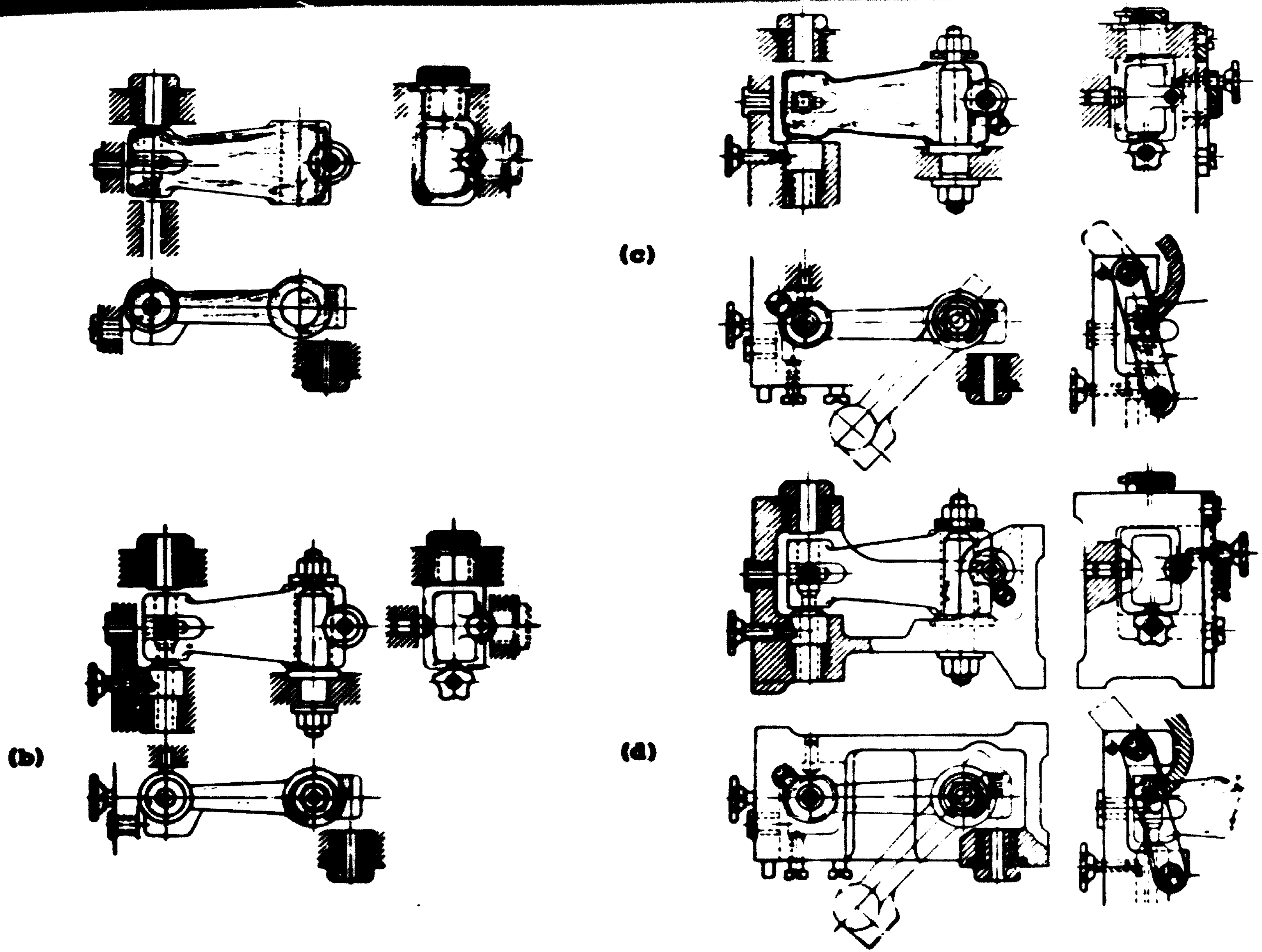


Fig. 2-7 Sequence in Designing a Drill Jig

(e) Build the body structure around the workpiece linking the elements into an integral unit

(f) Add the necessary auxiliary elements

(g) Specify the standard parts, materials, accuracy and finish requirements, etc.

Design Computation Examples of Drill Jig:

Design of a drill jig for the workpiece as shown in Fig. 2-9: let's assume that the work material is soft-grade gray cast iron, the operation to be performed with the jib is to drill two holes of 1/2 in. diameter with a twist drill, and the cutting condition is cutting speed (V)=50 rpm and feed (f) = 0.005 ipr.

(a) The thrust force (T_h) for drilling is

$$T_h = 57{,}500 f^{0.8} D^{0.8} + 625 D^2$$
$$= 57{,}500 (0.005)^{0.8} (0.5)^{0.8} + 625 (0.5)^2$$
$$= 634 \text{ lbs}$$

For simultaneous drilling of two drills,

total trust force (P) = $2T_h = 2(634) = 1268$ lbs

(b) The size of the screw for clamping

$$T_h = \left(\frac{\pi d^2}{4}\right) \sigma_t$$

Where σ_t = permissible tensile screws (10,000 psi for mild steel bolt with safety factor)

d = diameter of bolt

$$1268 = \left(\frac{\pi d^2}{4}\right) 10{,}000$$
$$d = 0.4 \approx \frac{1}{2} \text{ in. bolt}$$

(c) The know size or length of lever (l) for the bolt is

$$\text{Torque} = 0.2 d P = l F$$
$$l = \frac{(0.2)(0.5)(1268)}{65} = 1.95 \approx 2 \text{ in.}$$

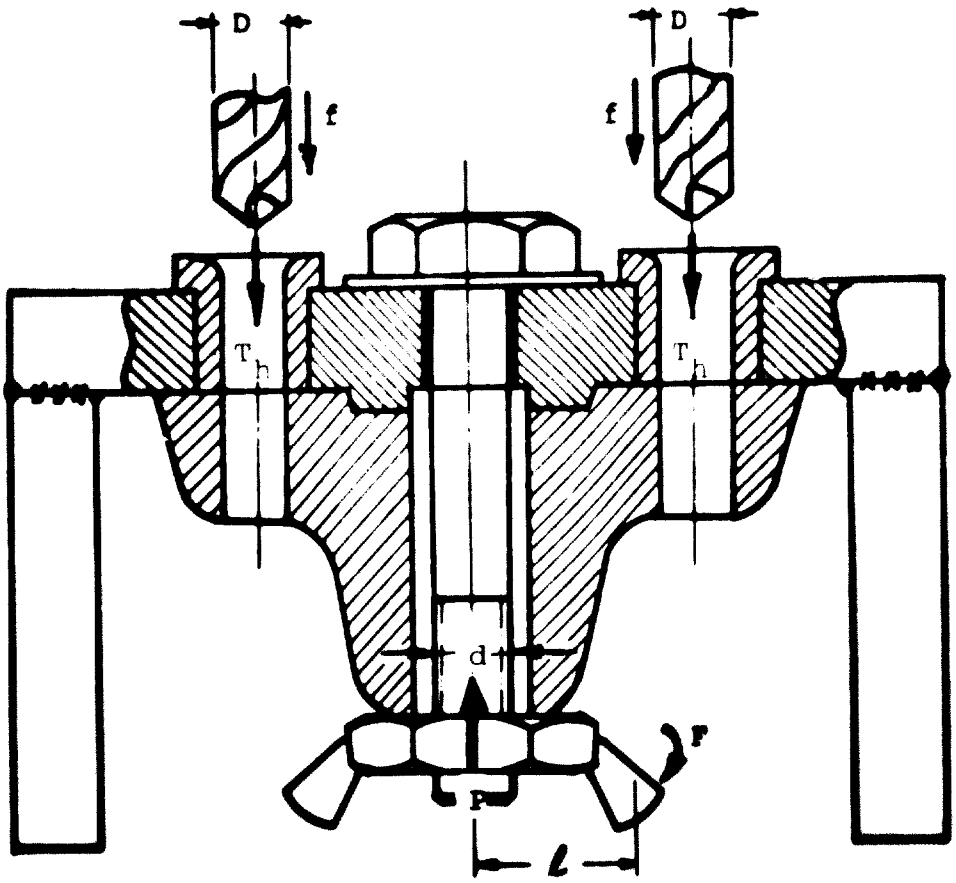


Fig. 2-8 Example of Drill Jig Design

Design Computation Examples of Milling Fixture:

Design of a milling fixture with a strap-screw clamp as shown in Fig. 2-10: let's assume the following conditions:

Workmaterial: mild steel block
Milling cutter: H.S.S.; 6 in. diameter (D); 1/2 in. width (w); 16 teeth (n)
Cutting speed (N): 100 rpm
Specific horsepower (Uhp): hp/in^3/min.
Feed (f): 0.005 inch/tooth
Depth of cut (d): 1/4 in.

(a) The clamping force (F_c) required:

$$Q = d w f n N = (\tfrac{1}{4})(\tfrac{1}{2})(0.005)(16)(100) = 1.0 \ \text{in}^3/\text{min}$$

$$V = (\pi D N)/12 = [(3.14)(6)(100)]/12 = 157 \ \text{fpm}$$

$$Hp_c = U_{hp_c} \cdot Q = (1.0)(1.0) = 1 \ \text{hp}$$

$$F_t = (Hp_c)(33{,}000)/V = (1)(33{,}000)/157 = 210 \ \text{lbs}$$

$$\cos\theta = 2.75/3 = 0.9167 \qquad \theta = 23°33'$$

$$F_v = F_t \sin\theta = (210)(\sin 23°33') = 84 \ \text{lbs}$$

Since $F_v = 2F_c$, the clamping force required for each strap is then $F_c = 42$ lbs.

(b) Strap design:

Assume that

tensile strength of strap material: 52,000 psi
factor of safety for strap design: 4
human manual force applied for lever action: 3 lbs.
length of lever (l): 3 in.
length of strap (L): 4 in.

$$T = 0.2\,dP$$

$$P = (3)(3)/(0.2)(0.5) = 90 \ \text{lbs}$$

$$F_c = \left(\frac{l-a}{a}\right)P$$

Allow stress $(\sigma_a) = \dfrac{52{,}000}{4} = 13{,}000$ psi

Moment of strap (M) $= (Pab)/L = 90$ in-lb

Section modulus (Z) $= bh^2/6 = (1.250-0.625)t^2/$

also $M = Z\sigma_a$

Thus the thickness of the strap (t) is about 1/4 in.

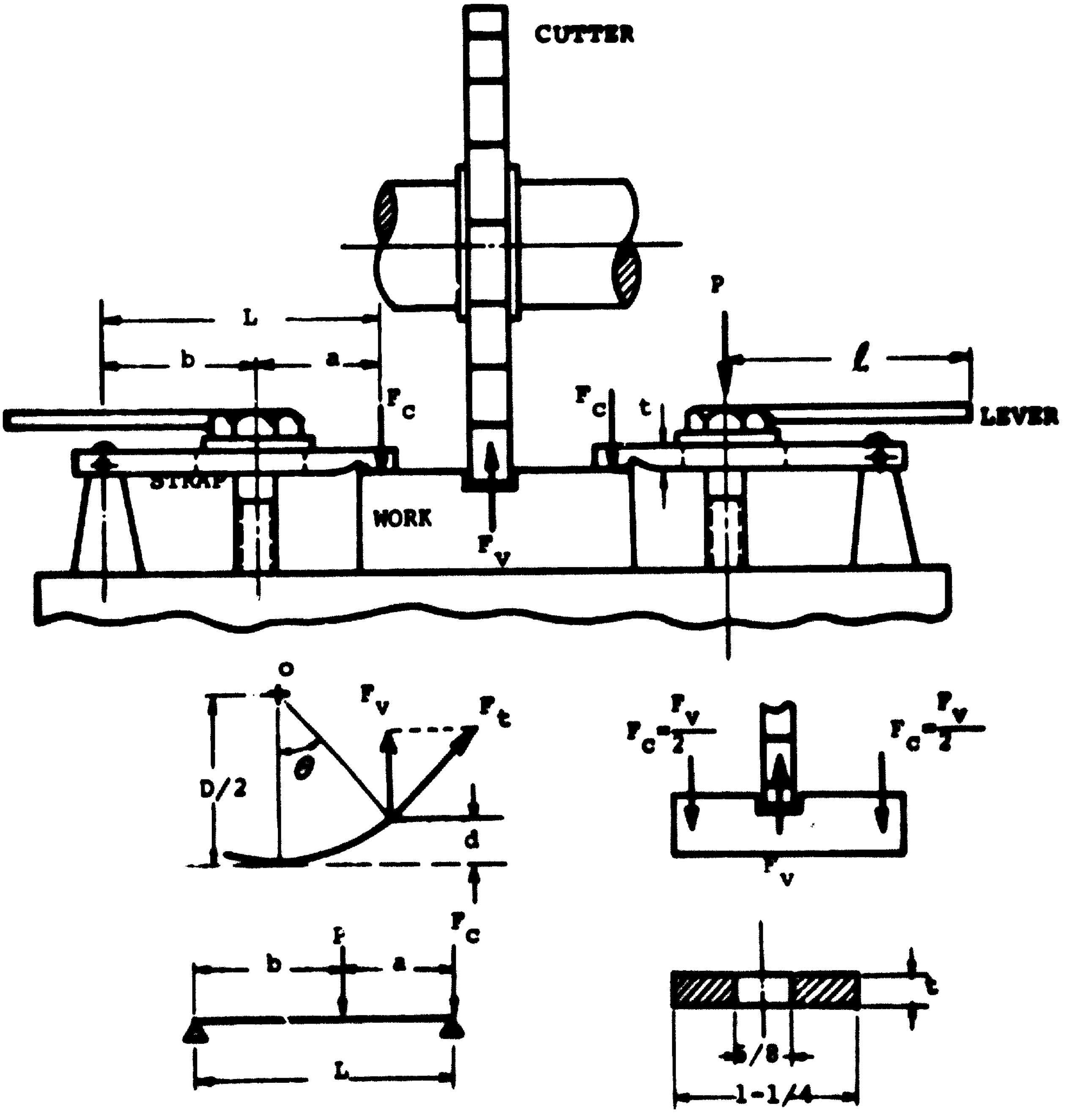


Fig. 2-9 Example of Milling Fixture Design

[III] ECONOMICS OF TOOLING

In designing, selecting or purchasing cutting tools, workholding devices, assembly fixtures, special instruments, etc., it is first necessary to analyse their economic effects. Although the technical requirements and functional neccessity of the tool are of prime concern, its economic justification should be considered equally.

Analysis of Tooling Costs:

In dealing with the economics of tools, there are many types of problems and many factors to be considered. For a simple case of comparison of two different tooling set-ups, the saving (s) occasioned by the new improved method or tool will be

$$S = N(Cu_1 - Cu_2)$$

For the saving to be equal to or larger than the cost of the new tool

$$S \geq I_2 \qquad N \geq \frac{I_2}{Cu_1 - Cu_1}$$

Where S = total annual saving, \$

N = number of pieces produced per year

Cu_1 = annual unit cost per piece with the old method, \$

Cu_2 = annual unit cost per piece with the new method, \$

I_2 = cost of the tool for the new method, \$

However, where quantity production is involved, many other factors must be taken into account. In dealing with them the following questions come up most frequently:

(a) How many pieces must be run to pay for a specific tool and will show a given estimated saving in direct labor cost on a given number of pieces?

(b) How much may a tool cost which will show a given estimated unit saving in direct labor cost on a given number of pieces?

(c) How long will it take a proposed tools, under the given conditions, to pay for itself, carrying its fixed charges?

(d) What will be the profit earned by a fixture, of a given cost, for an estimated unit saving in direct labor cost for a given output?

The first approach is to consider the break-even point at which two methods are equal, or where the annual operating savings equals the total fixed charges and set-up costs for the period considered as given by

$$(S_d + S_o + S_p) = C_i (R + T + M + D) + U + E$$

Where S_d = annual saving in direct labor cost, $

S_o = annual saving in labor overhead, $

$S_o = S_d t$ when t = rate of overhead on the labor saved

S_p = annual saving through increased production, $

S_e = saving in unit direct labor cost, $

C_i = estimated initial cost of the tool, $

R = annual percentage interest rate on investment

Y = annual percentage allowance for insurance, taxes, etc.

M = annual percentage allowance for maintenance

D = annual percentage depreciation allowance on a straight-line basis

n = number of years for depreciation

U = annual cost of set-ups, \$

E = annual cost of power, supplies, etc., \$

N = annual production quantity, no. or pc.

V = annual gross operating profit in excess of fixed charges, \$

since $S_d + S_o = NS_e(1+t)$

and in most cases for small tolls, $E \ll 0$, $S_p \ll 0$

$$NS_e(1+t) = C_i(R+Y+M+1/n)+U$$

(a) The number of pieces required to pay-off the new investment is given by

$$N = \frac{C_i(R+Y+M+1/n)+U}{S_e(1+t)}$$

(b) The initial investment to justify the expenditure is given by

$$C_i = \frac{NS_e(1+t)-U}{R+Y+M+1/n}$$

(c) The number of years for pay-off is given by

$$n = \frac{C_i}{NS_e(1+t)-U-C_i(R+Y+M)}$$

(d) The annual gross operating profit over all fixed charges is given by

$$V = NS_e(1+t)-U-C_i(R+Y+M+1/n)$$

In applying these relationships, the items R, Y, M and D ($= \frac{1}{n}$) are fixed by operating policy. However, for depreciation, the number of years to depreciate (N) should be adjusted to meet the various requirements, i.e., rapid deterioration and obsolescence of small tools.

Methods for Comparison and Selection of Tools:

For almost all tooling problems, the following three basic questions must be answered:

(a) What is to be done?

(b) By what method and with what tools can it be done?

(c) Which method is best or most economical?

In most cases, the primary problem is usually the comparison and selection of machines, equipments, tools or tooling set-ups to obtain a desired output and quality and required production rate at the lowest cost. Comparison of alternative tooling methods is made by

(a) Two or more proposed methods on technical and functional aspects

(b) Proposal for new tooling method to replace the present one

(c) Determination of the most desirable features of the selected alternative methods

(d) Decision on whether to invest in the proposed tooling in house or outside purchase

(e) Comparison of annual costs or unit costs

Cost Method:

A comparison on the basis of annual and unit cost may be made as indicated in the following procedure:

(1) Calculate average annual interest and other allowance rate (γ_a),

$$\gamma_a = \frac{\gamma}{2}\left(\frac{n+1}{n}\right)$$

where: γ = annual interest an other allowance rate, % : $\gamma = (R + Y + \cdots)$

n = depreciation period, year

(2) Determine annual percentage allowance for depreciation (D_a)

$$D_a = \frac{1}{n}$$

(3) Determine net investment (C_i)

(4) Calculate total annual fixed charges (C_f)

$$C_f = C_i(\gamma_a + D_a)$$

(5) Compute other costs such as maintenance and repair; cost (C_r), power cost (C_p), etc., if necessary

(6) Determine direct costs such as labor cost (C_d), material cost (C_m), etc.

(7) Determine overhead cost (C_o)

(8) Calculate total annual cost (C_a)

$$C_a = C_f + C_d + C_m + C_o + C_p + C_r + \cdots$$
$$= C_i(\gamma_a + D_a) + C_d + C_m + C_o + C_p + C_r + \cdots$$

(9) Calculate total annual unit cost (C_u)

$$C_u = \frac{C_a}{N} = \frac{C_i(\gamma_a + D_a) + C_d + C_m + C_o + C_p + C_r}{N}$$

(b) Steps for comparison of alternative methods:

(1) Calculate the total annual cost (C_{u_1}) for the present method

(2) Determine the total annual cost $(C_{u_2}, C_{u_3}, \cdots)$ and the total investment $(C_{i_2}, C_{i_3}, \cdots)$ for the proposed alternative methods

(3) Compute "gross annual savings" (S_g)

$$S_g = C_{u_1} - C_{u_2}$$

(4) Determine "net annual savings" (S_n)

$$S_n = S_g - C_{u_2}$$

(5) Calculate "percentage return" (P_r)

$$P_r = \frac{S_n}{C_{u_1}}$$

(6) Calculate "pay-off period" in years (Y_p)

$$Y_p = \frac{C_{u_2}}{S_n}$$

Break-Even Method:

A common approach for selecting processes, methods and tools is to use a break-even model. In determining which of the two tooling set-ups is most economical, the total cost (T), which are composed of the fixed tooling costs (F) with the related variable costs (v), of the methods involved can be compared as shown in Fig.3-1. For example, in comparing two possible alternative tooling set-ups, assume the fixed tooling costs (the initial investment for tooling) and the variable cost [(the production cost per piece) x (number of pieces produced)] are F_1 and V_1 for method #1 (high initial tooling cost but low production cost per piece) and F_2 and V_2 for method #2 (low initial

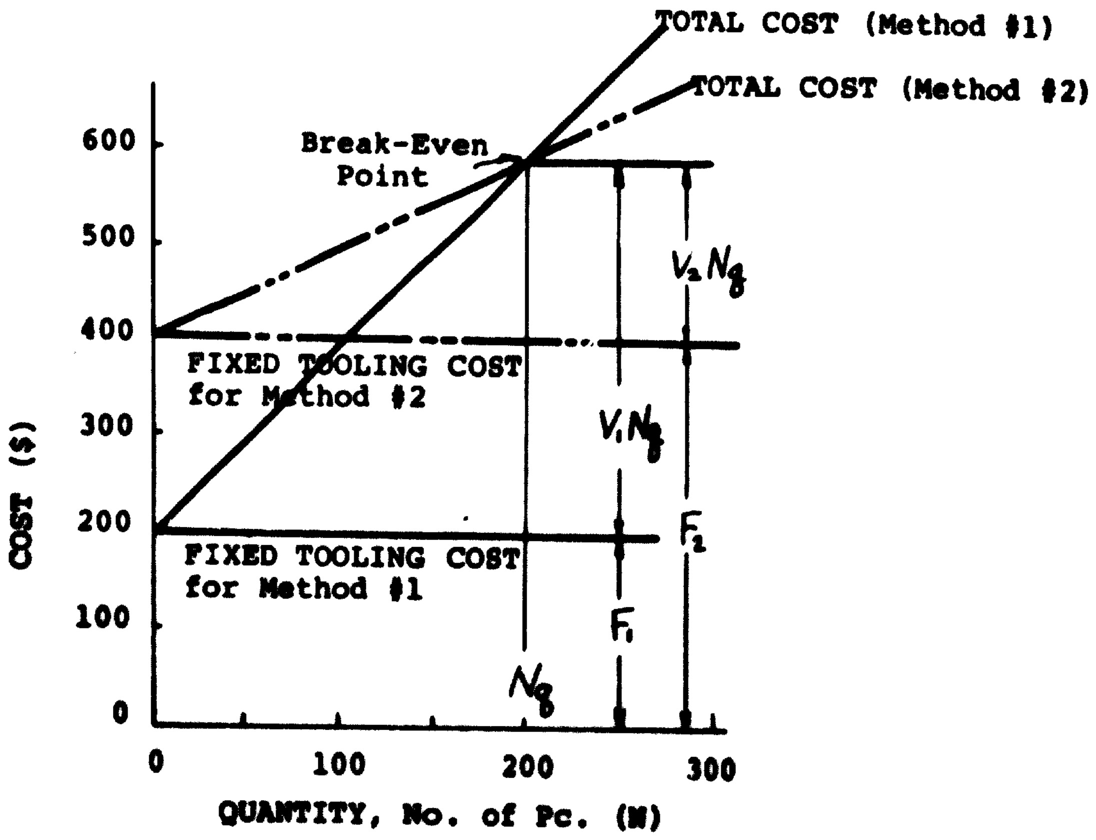


Fig. 3-1 Break-Even Chart

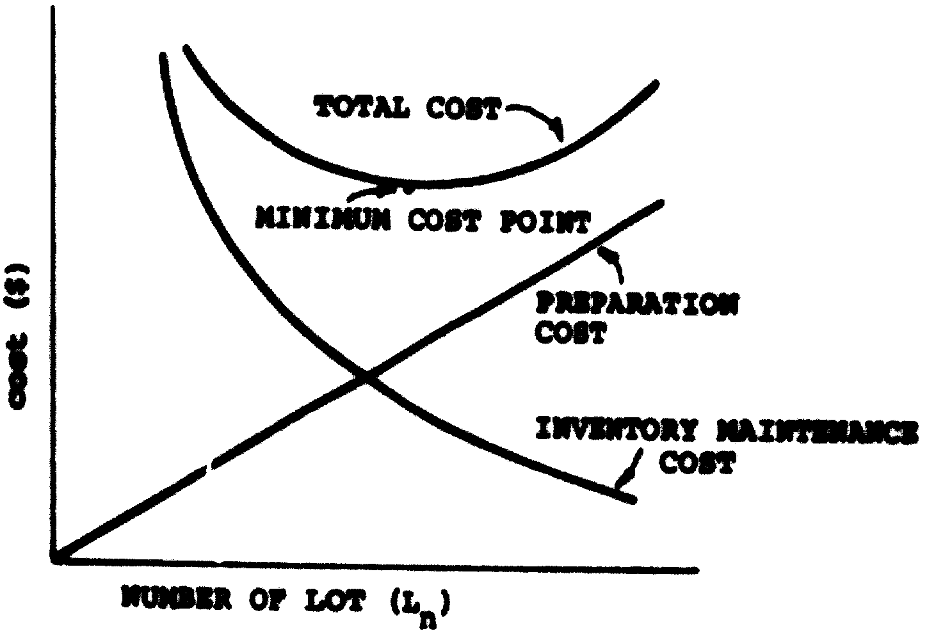


Fig. 3-2 Minimum Cost Curve

tooling cost but high production cost per piece) respectively. From Fig. 3-1, the break-even quantity (N_g) can be obtained as follows:

Assume $F_1 > F_2$, $V_1 < V_2$

$$T_1 = F_1 + V_1 N, \quad T_2 = F_2 + V_2 N$$

When $N = N_g$, $T_1 = T_2$

Then $F_1 + V_1 N_g = F_2 + V_2 N_g$

$$N_g = \frac{F_2 - F_1}{V_1 - V_2}$$

Also unit cost per piece (C_u) can be calculated by

$$C_{u_1} = \frac{T_1}{N_l} = \frac{F_1 + V_1 N}{N_l}$$

$$C_{u_2} = \frac{T_2}{N_l} = \frac{F_2 + V_2 N}{N_l}$$

Where N_l : lot size (no. of pieces per a single run)

This analysis with the break-even chart (Fig. 3-1) and the above computation shows that it is more economical to select method #1 if production quantity (N) does not exceed N_g. However, for higher production quantities ($N > N_g$) the economy lies with method #2.

Minimum Cost Method:

The minimum cost method is often used to obtain the lowest production cost of a given product by calculating so-called economic lot sizes for a given condition. As shown in Fig. 3-2, this minimum cost condition is satisfied when the preparation cost (P): the costs of planning, ordering, setting-up, handling and tooling, equal the inventory maintenance costs. Also a simple model of the relationship can be written as follows:

$$N_l = \frac{A_p}{L_n} \quad , \quad L_n = \frac{A_p}{N_l}$$

$$P = S_t L_n = \frac{S_t A_p}{N_l}$$

$$M = \left(\frac{A_p}{2L_n}\right) C_u R_a = \frac{N_l C_u R_a}{2}$$

Where N_l = lot size
A_p = annual production requirements
L_n = number of lots per year
S_t = set-up cost
C_u = unit cost per piece
R_a = the decimal equivalent of the average expense percentage

Since the total annual cost (C_t) is the sum of the preparation cost and the inventory maintenance cost,

$$C_t = P + M = \frac{S_t A_p}{N_l} + \frac{N_l}{2} C_u R_a$$

Thus the optimum lot size for the minimum total annual cost is obtained by differentiating C_t with respect to N_l

$$\frac{dC_t}{dN_l} = - S_t A_p N_l^{-2} + \frac{C_u R_a}{2} = 0$$

$$\therefore \quad N_l = \sqrt{\frac{2 S_t A_p}{C_u R_a}}$$

[IV] TOOLING FOR FORMING PROCESSES

Material Forming Processes:

Material forming is achieved by numerous processes and operations. Shearing, bending, drawing, squeezing, forging, rolling, extrusion, etc. are the most common processes (Fig. 4-1). The majority of these processes employ press-working operations by which a large force is applied by tools, usually punches and dies, to shear or form the work material into a desired shape. This force is usually applied by a press.

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

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

Pressworking Operations:

Pressworking is performed with power presses consisting a structural frame, a bed or bolster plate, and a reciprocating mechanism with a ram or slide which exerts force upon the work material through a punch and die set mounted on the ram and bed. There are many types of presses possessing different structural and functional designs, capacities, driving mechanisms, and power sources. A complete set of the pressworking tools is called a die set and usually

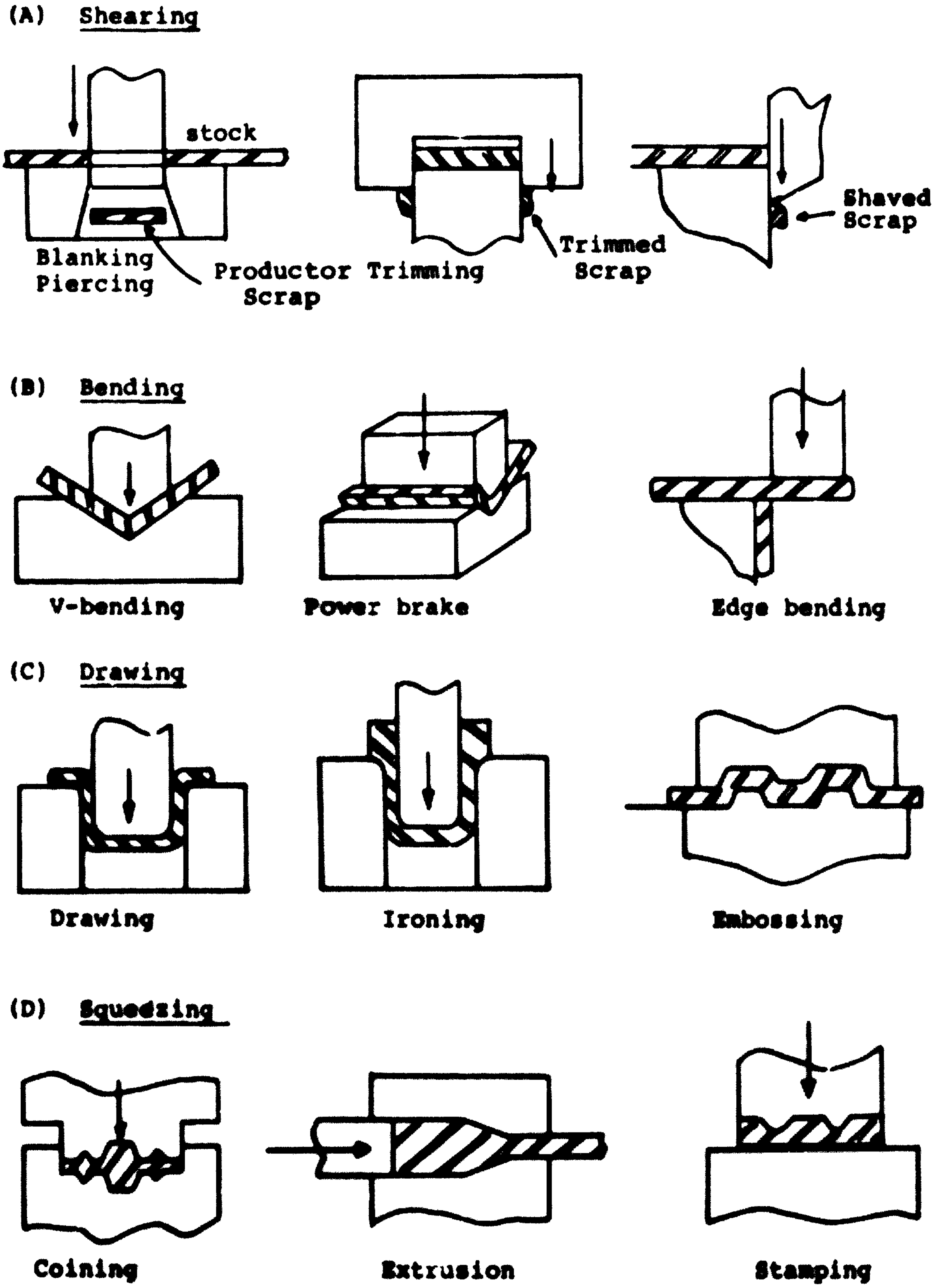
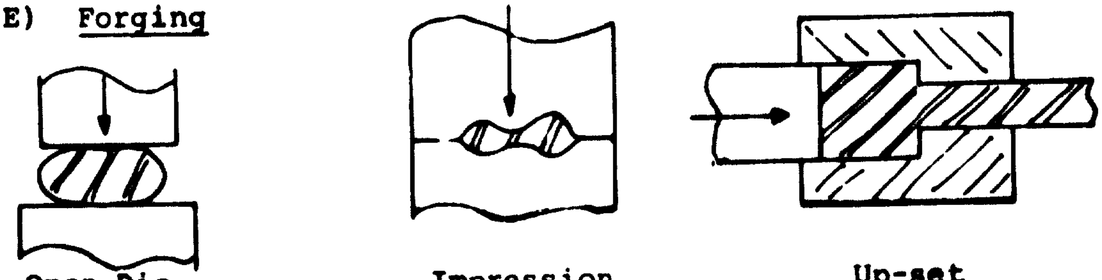


Fig. 4-1 Typical Material Forming Processes (a)

(E) Forging

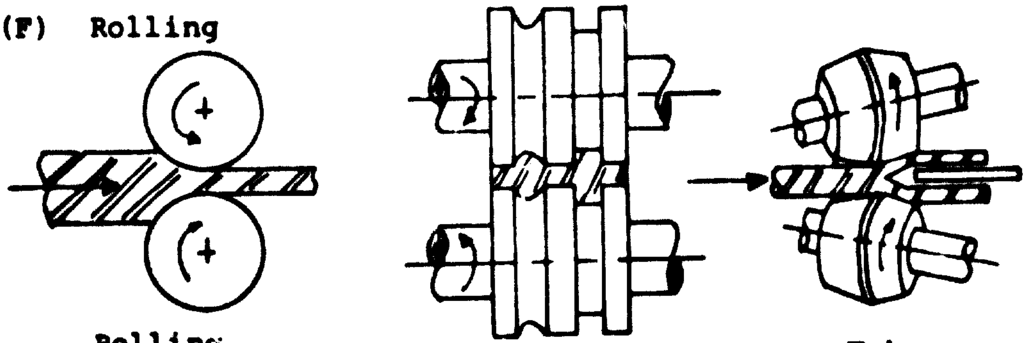


Open Die

Impression (closed die)

Up-set

(F) Rolling

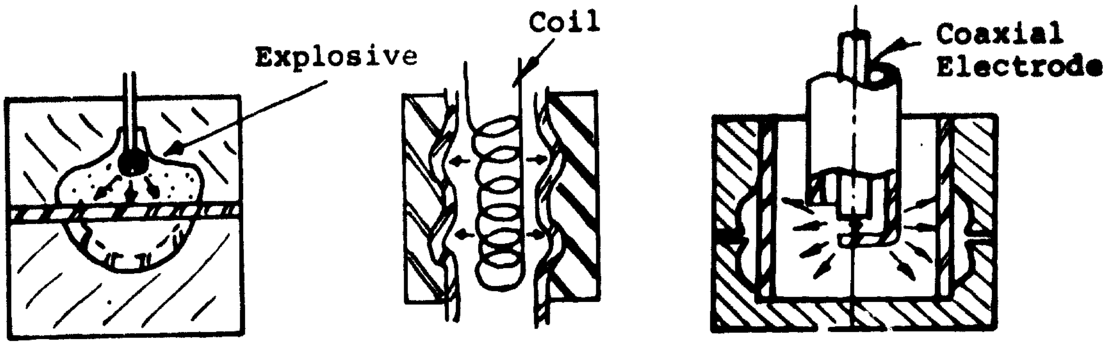


Rolling

(Forge) Form Rolling

Tube Piercing

(G) High-Energy-Rate Forming



Explosive Pressure Forming

Electro Magnetic Forming

Electro Hydraulic Forming

Fig. 4-1 Typical Material Forming Processes (b) (continued) contains a punch and punch holder, and a die or die block on a die shoe, which are aligned by guide pins, and other accessories as shown in Fig. 4-2. In most cases standard die sets are available commercially in a large variety of styles and sizes, and are used for convenience and economy.

Shearing:

In pressowrking of sheet metal the dies are mounted in various ways, depending upon the operation to be performed. Some of the typical arrangements are: (a) simple die, (b) inverted die, (c) progressive die (Fig. 4-2), (d) compound die.

In blanking, piercing, trimming, shaving, etc., are a shearing process in which the material is stressed in shear between the cutting edges of the punch and die. As the load is applied and increased, the material is subject to tensile and compressive stresses, plastic deformation occurs through the elastic limit and when the ultimate tensile strength is exceeded the fracture occurs. As illustrated in Fig. 4-3 (a), the punch penetrates the metal to a certain depth before fracture. Penetration (p) as shown in Table 4-I is usually expressed in percent of the material thickness and varies with the materials and treatment received. To reduce the peak load of the operation by shearing little at a time, an angular shear is ground on the punch or die as shown in Fig. 4-3 (b). The shear (s) is usually expressed as either a percentage

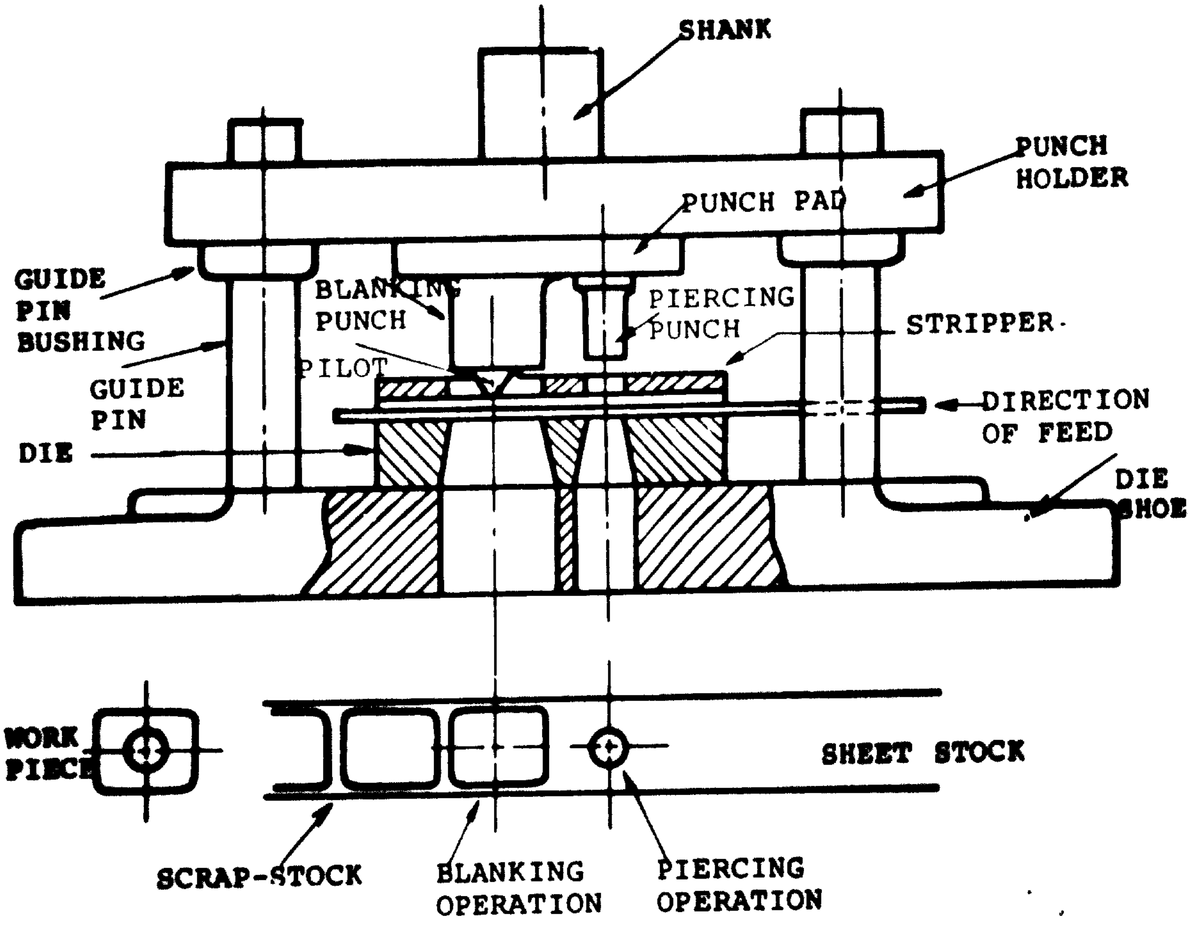
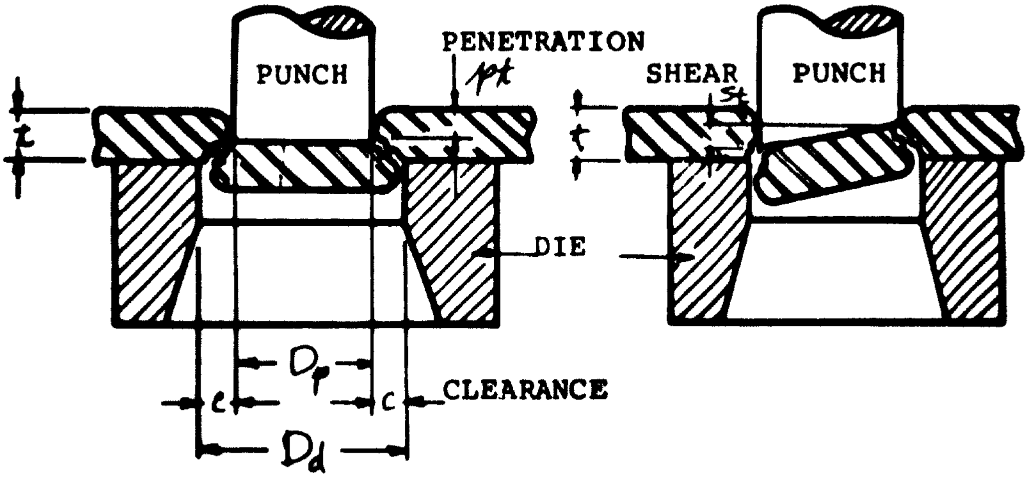


Fig. 4-2 Basic Components of a Punch -Die Set (Progressive Die Set)



(a) Penetration (p)　　　(b) Shear (s)

Fig. 4-3 Shearing Process in Pressworking Operations

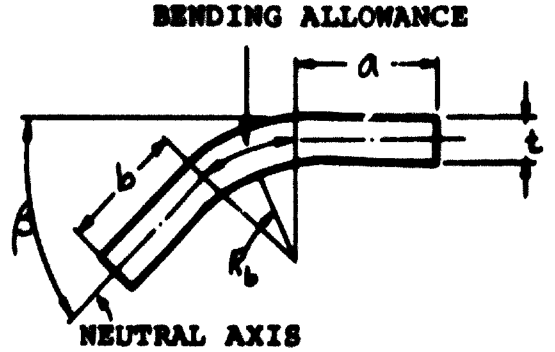


Fig. 4-4 Basic Relationships of Bending Operation

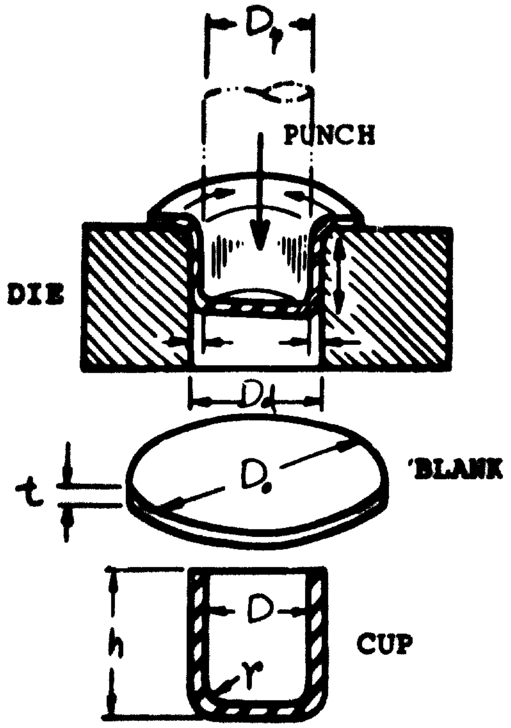


Fig. 4-5 Basic Relationships Drawing Operation

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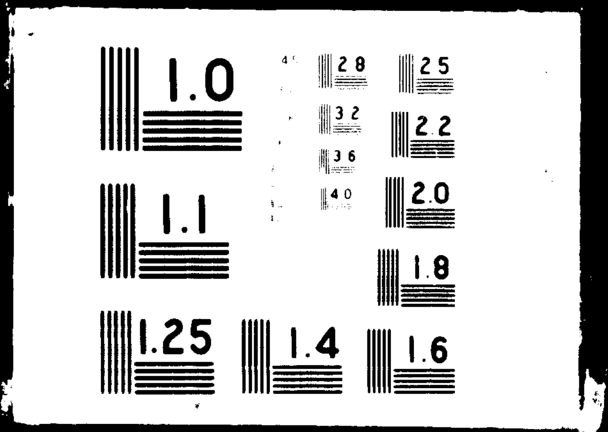


Table 4-I Percent Penetrations

Material	Penetrations, %
Al	60
Cu	55
Brass	50
Bronz	25
Steel (0.10C)	50 (Annealed) 38 (Cold rolled)
Steel (0.20C)	40 (Annealed) 28 (Cold rolled)

or fraction of the work material thickness (t). The pressure required for a shearing operation is a function of the shear strength and hardness and penetration of the work material, and the amount of shear; and is also affected by the clearance between the punch and die, the sharpness of the cutting edges, and the amount of shear on the punch or die.

The pressure (P) is then expressed by

$$P_o = \sigma_s L t$$

$$P_p = \sigma_s L p t = P_o p \quad \text{(when p is known and s = o)}$$

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

$$E_o = P_o t \quad \text{or} \quad E = P_p (pt) = P_{sp} (pt + st)$$

Where P_o, P_p & P_{sp} pressure required, lbs.

σ_s: shear strength of material, psi

L : perimeter of workpiece for shearing, in., for a round workpiece with a diameter (D); $L = \pi D$ in.

t : material thickness, in.

p & s: penetration and shear as a percentage of the material thickness, %

E : energy required, in-lbs.

After determination of the pressure (lbs. or tons) required for the operation, a die set with the necessary components should be selected or designed considering the following factors:

(a) Type and size of press

(b) Evaluation of the selected press

(c) Type of a die set for operation

(d) A tool steels and heat treatment required

(e) Feeding method and mechanism

(f) Stock-strip layout

(g) Stripping or ejecting method

(h) Shaving or trimming that may be necessary

(i) Standard die set

(j) Die space

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

Selection of Press:

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

(a) Capacity (rated tonage capacity, flywheel energy and motor hp)

(b) Type and size of the press (frame construction, bed opening and space, shut height, bolster plate size, etc.)

(c) Feeding method (direction and method)

(d) Speed of operation and length of stroke (crank velocity and ram stroke)

(e) Number of presses required (production quantity and production rate)

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

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

Punch Design:

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

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

Where E = modulus of elasticity

σ_s = shear stress, psi

D_p = diameter of punch, in.

$D_p/t \geq 1.1$

Stripper Design:

There are two types of strippers; fixed or spring-operated. The objective of stripper is to strip the workpiece from a die or punch. A stripper for a die is sometimes called a knock-out or an ejector.

The stripper thickness must be sufficient enough to withstand the stripping force required. The stripper spring must also be designed to perform the desired stripping action.

$$P_s = 3500\,Lt$$

Where P_s = stripping pressure, lb.

L = perimeter of shear, in.

t = stock thickness, in.

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

Where T = thickness of stripper plate, in.

W = width of stock strip, in.

t = thickness of stock strip, in.

Bending:

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

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

In designing a bending die the following items are essential and should be analyzed carefully: (See Fig. 4-4)

(a) Bend method

(b) Bend radii (R_b): minimum bend radii

(c) Bending allowance (A_b): length of bent metal

(d) Bending pressure (P_b)

(e) Spring back: (change in the bend angle after bending)

(f) Stock size and final dimensions

(g) Bend location tolerances

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

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

Where β = bend angle, deg.

R_b = bend radius (inside), in.

t = material thickness, in.

C = constant; when $R_b < 2t$, $C = 0.33$
$R_b > 2t$, $C = 0.50$

K = constant: 0.67

l = length of bent part, in.

σ_t = ultimate tensile strength, psi

W = width of die, in.

Also $L = a + b + A_b$

Where L = length of material required before bend

Drawing:

Various cylindrical, conical, spherical, square, rectangular and other shapes are produced by a drawing operation in which the metal is subject to extreme plastic deformation not exceeding its ultimate strength. In drawing operations the punch forces the metal down into the die to flow along the die face and through the clearance between the punch and die. The metal is subject to compression on the rim of the blank and tension on the cup wall (Fig. 4-5). The following basic relationships are essential for design of a drawing die:

$$P_d = \sigma_t \pi D t \left(D_0/D - 0.7 \right)$$

$$E_d = K P_d h$$

$$R_d = [(D_0 - D)/D_0] \times 100$$

$$R_f = (t/D) \times 100 \quad \text{or} \quad = (h/D) \times 100$$

$$c = 1.1t$$

$$D_o = \sqrt{D^2 + 4Dh} \quad \text{when } r = 0$$

$$= \sqrt{D^2 + 4D(h - 0.43r)} \quad \text{when } t << 0$$

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

Where P_d = drawing pressure, lbs.

σ_t = **tensile strength of work material, psi**

D = diameter of **finished shell, in.**

D_o = diameter of **blank, in.**

t = **thickness of blank, in.**

E_d = **drawing energy,**

K = **constant:**

h = **height of finished shell, in.**

R_d = **reduction in drawing, %**

R_f = **reduction factor, %**

C = **clearance**

r = **radius of finished shell, in.**

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

(a) **Volume** method

$$D_o = \sqrt{D_1^2 + (D_1^2 - D_2^2)(h/2)}$$

(b) **Weight** method

$$D_o = 1.1284\sqrt{\frac{W}{wt}}$$

Where D_1 = outside diameter of **finished shell, in.**

D_2 = inside diameter of **finished shell, in.**

W = **weight of finished shell, lbs.**

w = **weight of material per in^3**

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

When metal is deformed it is subject to strain hardening, i.e., the stress increases as deformation proceeds. Cold-working strain-hardens the metal to the limit of its plasticity and further working of the metal would cause fractures. Therefore, most drawing operations are performed in multiple steps with a varied reduction ratio at each step rather than a single drawing.

Standard Reduction %

1st draw:	40～45% reduction
2nd draw:	30～35% reduction
3rd draw:	20～25% reduction
4th draw:	15～20% reduction

For deep drawing operations the metal is treated by an annealing process between the successive drawing cycle to restore plasticity.

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

(a) Development of the approximate blank size

(b) Reduction factor (R_f): (for determining the amount of maximum single diameter)

(c) Reduction ratio (R_d): (for design of drawing cycle and intermediate flank sizes)

(d) Drawing pressure (P_d): (for selection of the press)

(e) Blank-holding pressure (P_h): (for design of pressure pad)

(f) Punch-die dimensions (clearance, draw radii, etc.)

(g) Lubrication method and lubricant

(h) Selection of a die material, tolerance and press

(i) Prevention of undesirable wrinkling and ironing

(j) Follow-up operations (redrawing, ironing, trimming, etc.)

The drawing process is seldom used economically when quantity requirements are small because of the complexity of die construction. For low quantities it is more economical to use some other production methods such as metal spinning, forming, machining, etc. Thus, economic justification along with technical feasibility is essential before utilizing the drawing process.

<u>Forging</u>:

Forging is a process by which metal is shaped into a desired form and size, refined structurally and improved in its mechanical properties through controlled plastic deformation in open or closed dies under compression.

The compressive forces may be applied by slow-speed squeezing (press forging) or by impact (drop forging). Forging operations can be performed in a wide temperature range, but usually at the range above the recrystallisation temperature of the metal. Typical forging operations are

(a) Open die forging (upsetting)

(b) Close die forging (impression or drop forging)

(c) Upsetting (closed-die)

(d) Roll forging

(e) Cold forging

(f) Hand forging

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

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

A good understanding of metal flow theory and basic concepts of forging metallurgy is essential for analyzing forging operations. Some basic relationships of the forging operation for a die design are as follows and also illustrated in Fig. 4-6.

Engineering Strain; $\varepsilon_e = \frac{\Delta h}{h_0}$

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

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

True Strain; ε

$$\varepsilon = \int_{h_0}^{h} \frac{dh}{h_0 h} = ln \frac{h_1}{h_0} = ln(1 - \varepsilon_e)$$

For sliding friction,

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

For sticking friction,

$$\sigma_x = \sigma_0 \left(1 + \frac{x}{h}\right)$$

Total Force (P_c) required for Compression:

$$P_c = pA$$

p : the average pressure

A : the cross-sectional area

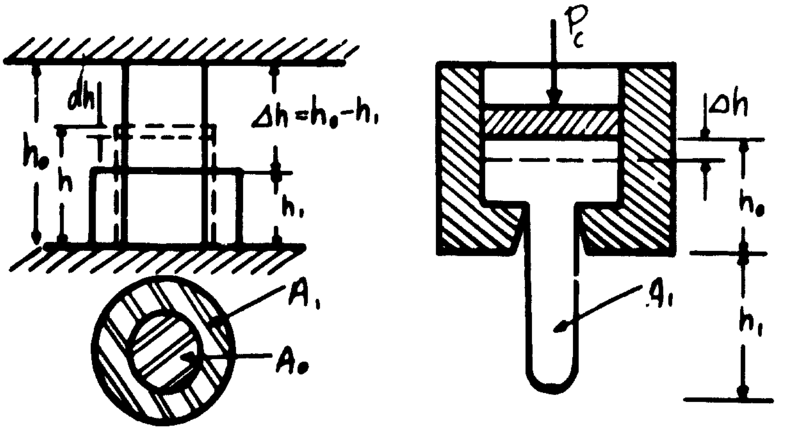
For sliding friction,

$$p = \sigma_0 \frac{h}{\mu b}\left(e^{\mu b/h} - 1\right)$$

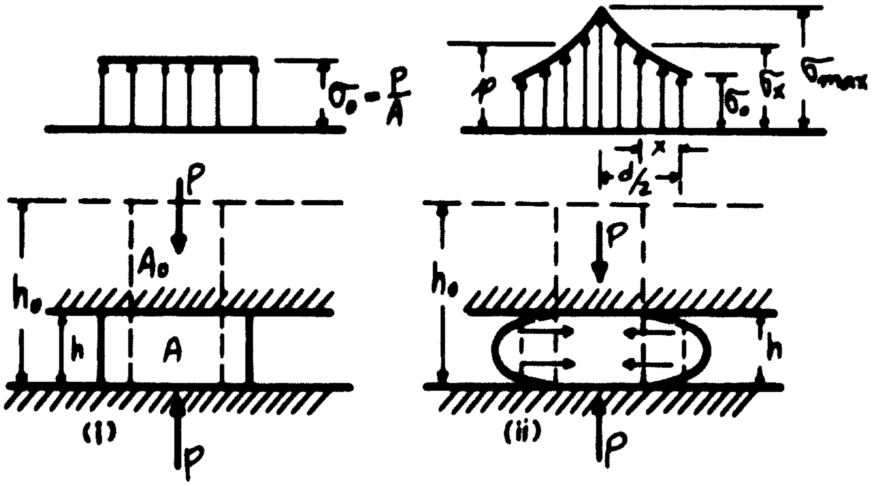
for a bar of (b) width

$$p = \sigma_0 \frac{2}{\left(\frac{\mu d}{h}\right)^2}\left(e^{\mu d h} - \frac{\mu d}{h} - 1\right)$$

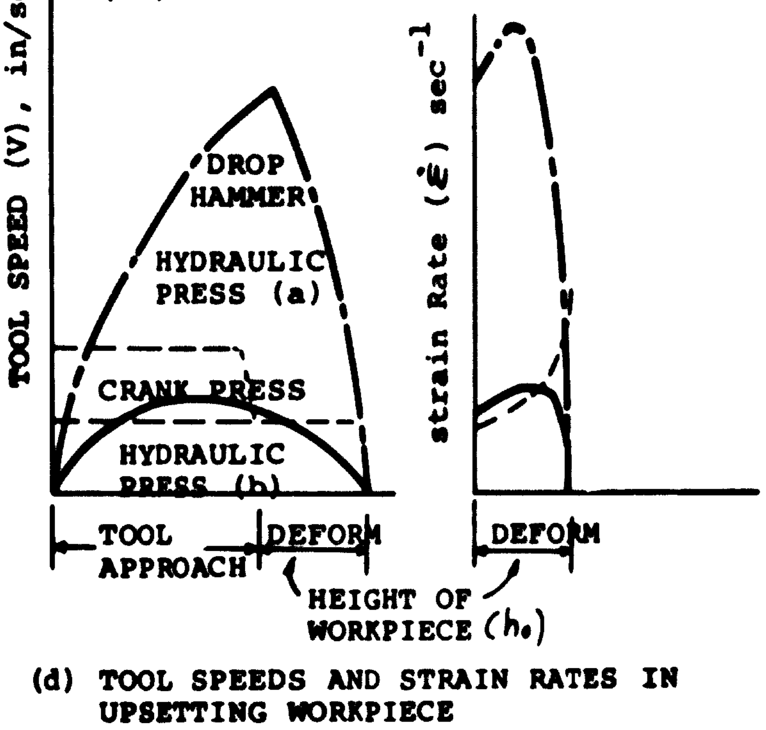
for a cylinderical workpiece of diameter (d)



(a) OPEN DIE FORGING (b) EXTRUSION



(c) THEORETICAL PRESSURE DISTRIBUTION
(i) without friction
(ii) with friction



(d) TOOL SPEEDS AND STRAIN RATES IN UPSETTING WORKPIECE

Fig. 4-6 Basic Relationships of Forging Operation

For sticking friction,

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

Total force required for Extrusion, (P_c)

$$P_e = pA_o = C\sigma_o A_o \ln\frac{A_o}{A_1}$$

c: constant

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

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

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

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

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

(c) To select a machine with sufficient capacity

A simple claculation of forging forces (P) can be made with the following formula:

$$P = C_1 \sigma_m A_t$$

$$\varepsilon = \ln\frac{V}{A_t h_o} \qquad \text{(Average strain)}$$

$$E = C_2 V \varepsilon \sigma_m \qquad \text{(Energy, in-lb)}$$

Where C_1 : a multiplying factor (see Table 4-I)

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

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

V : volume of the forging, in^3

C_2: a multiplying factor (see Table 4-I)

Table 4-II, Multiplying Factors for Estimating Force and Energy Requirements in Forging

Mode of Deformation		C_1	C_2
compression of cylinder between flat platens,	$\varepsilon_{\theta} = 0.8$ $\varepsilon_{z} = 0.8$	1.2 1.5 ~ 2.5	1.2 1.5
Impression die forging of single shape	without flash	3 ~ 5	2.0 ~ 2.5
	with flash	5 ~ 8	3 0
Impression die forging of complex shape	with flash	8 ~ 12	4 0

It is often necessary to consider forging for a new product or in the re-design of existing components. To select the most efficient forging method for a given job, there are two distinct approaches: (a) to design the part to meet functional and technical needs and (b) to design a forging sequence and die, considering the following factors:

(a) Part design

(1) configuration and tolerance

(2) size and weight

(3) specifications (properties and quality requirements

(4) material and forging stock

(b) Analysis of the forging operation

(1) forces and energy required

(2) design of the forging dies: direction of the fiber-flow lines, parting line and position of adequate draft, etc.)

(3) production quantity

(4) selection of forging press

(5) fabrication of forging dies

(6) friction, wear and lubrication

(7) design "in-house" or "sub-contract"

Planning for Press-working Tools:

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

(a) Design; shapes, maximum size, tolerances, weight, surface roughness, selection of material

(b) Production; tooling time, production time, quantity, deadline

(c) Economics; material costs, tool and die costs, presses, finishing cost, direct labor and overhead costs, inventory costs

Basic procedure of the process planning for pressworking tools include:

(a) Analysis of the product or part:

  (1) what is to be done?

  (2) list required operations and allied processes

  (3) determine manufacturing feasibility

(b) Determine the most economic process

(c) Plan the operation sequence:

  (1) determine critical specifications

  (2) select critical areas and operations

  (3) arrange the operations in best possible sequence

  (4) determine secondary or auxiliary operations

(d) Specify the necessary gaging for inspection

(e) Specify and select the necessary press equipment

(f) Determine material handling methods for stock and product

(g) Prepare the route or operation sheet

Design Procedure of Pressworking Tools:

Preliminary Planning:

(a) Develop the blank with special reference to

  (1) best grain direction

  (2) bending, forming, drawing strain

  (3) available press equipment

(b) Decide a tentative sequence of operations

(c) Lay out the stock-strip

(d) Consider the press accomodation of the die set

(e) Establish center-line of pressure

(f) Establish location of pilot hole punches

(g) Selection of die type

(h) Check material specification

(i) Make the route sheet

Steps for Die Design:

(a) Lay-out scrap-strip

(b) Design die block

(c) Design punches

(d) Design punch plate

(e) Locate and design pilot, gages and stops

(f) Design stripper

(g) Select or design suitable fastners

(h) Select standard die set

(i) Assign dimensions and material specifications (bill of materials and drawings)

(j) Select a suitable press

Die-making Operations:

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

(a) Cut off blocks

(b) Rough machining and grinding

(c) Machining screw and dowel holes

(d) Layout of die

(e) Machining die opening

(f) Finishing die opening

(g) Machining and fitting punch to die

(h) Machining punch holder, stripper, stops, etc.

(i) Machining clearance holes in die shoe and stripper slot

(j) Heat-treatment and grinding

(k) Assembling die and stripper to die shoe

(l) Assembly of punch and punch holder

(m) Assembly of auxiliary parts

(n) Try out

(O) Inspection

Relationship with Product Design:

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

(a) Flat surface are preferable to formed surfaces

(b) A rectangular outline is preferable to a curved outline

(c) On drawn forms, a round or circular shell or cut is preferable to rectangular one

(d) A symetrical design is preferred

(e) Any form should, if possible, be made of straight bends

(f) On formed surfaces, tolerances or dimensions affected by part thickness should not be closer than expected variations in the stock thickness

(g) Dimensions from edges should be assigned with tolerances within the tolerances available on stock width

(h) Bends should be ar right angles to the grain or as close thereto as possible

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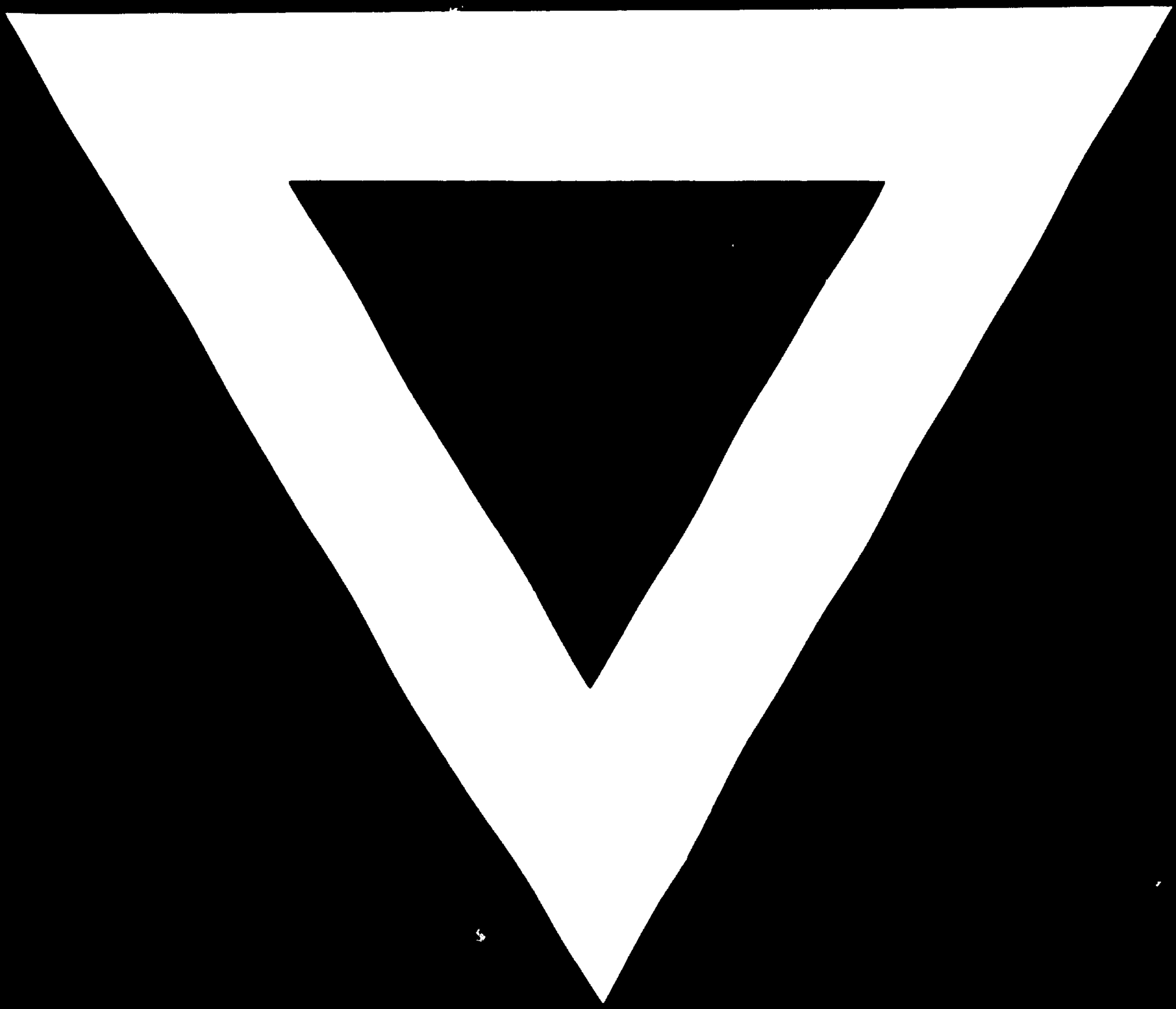

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