

INTRODUCTION TO TOOL ENGINEERING

By

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A Thesis

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in fulfillment of the requirements
for the degree of

PROFESSIONAL DEGREE IN MECHANICAL ENGINEERING

Department of Engineering

1953

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CHAPTER I

I. OBJECTIVE OF THESIS

The objective of this thesis is primarily to introduce tool engineering and its work in the modern manufacturing industry; secondly, to discuss the purpose, function, and some of the "know-how" of this technical profession.

From many definitions, the tool engineering group would seem to have two major objectives:

1. To devise means and equipment to achieve and maintain a desired level of quality in a manufactured product
2. To accomplish the results in the most economical manner.

The discussion of tool engineering, its work and the manner in which it accomplishes its major objectives will be interesting to both the technical student and the practicing engineer. To the technical student it will offer a background of industrial information that will give a better understanding of modern industry. To the practicing engineer it may present a new approach to some old problems.

II. DEFINITION OF TOOL ENGINEERING

The definitions set forth for tool engineering are many and varied but there are valid reasons for the lack of agreement on the inclusion of certain activities within the classification. Tool engineering is a rapidly expanding field and in each organization the department has been set up to suit the size of the organization, the product, production requirements, and in many cases has been influenced by the available manpower.

The following definition by a prominent tool engineer is quite authoritative: "The Tool Engineer is a specialist in the design and application of tools, jigs, fixtures, and other manufacturing equipment, which are important factors in determining the end cost of the product."¹

In other definitions will be found the inclusion of the words: analysis, planning, construction, application, processing and estimating. Thus, along with the development of large mass production industries, the tool engineering classification has acquired many ramifications. In general, the term has been recognized as meaning the design and selection of the necessary tools and machinery for the economical production of a given quantity of parts or assemblies.

¹ C. E. J. Brickner, "The Tool Engineers Place in the Industry", Tool Engineer, July 1946 p. 37.

III. TOOL ENGINEERING

Background of tool engineering. In modern industry the experience and knowledge of tools, machines, and processes, together with the "know-how" of low cost production, is found a group whose function within an organization was not clearly defined until recent years.

The work performed in this field has existed in industry for many years, but the complexity of modern production has brought about the grouping of the various kinds of work into a common functioning department. This group is designated by different companies as manufacturing engineering, production engineering, process engineering, and tool engineering. Many other designations are used but the foregoing are the most common. Of these the terms "tool engineering" is the most nearly universal.

Although the tool engineering group is a comparative newcomer in the industrial world, this does not mean that under such conditions that tool activities did not exist. The tooling functions were assumed by the shop supervisors, foremen or mechanics. This practice still exists in many small shops.

With the coming of mass production, standardization and interchangeability in manufacturing, the tool engineering took its place in the industrial field. The continuing expansion and enlargement in the size of industrial enterprises brought forth more complex and extensive problems, thus presenting opportunities for a more specialized and concentrated study of them. This entrance into the manufacturing field of many technically trained engineers brought the influence and viewpoint of specialist. This brought about a new analytical and scientific approach to attacking manufacturing problems. Among concepts introduced was that all manufacturing personnel or persons engaged directly in production should be relieved of all planning, preparation, and calculations and those functions should be assigned to specialist capable of applying the utmost of skill and knowledge.

Place in organization. Upon examination of the organization chart of many leading manufacturing companies, it would be noticed that there are as many variations as there are establishments, and that all the charts differ somewhat as to the key positions. This is as would be expected for each company has grown through the manufacture of a wide and varied range of products, and each company has only those executives and departments necessary to produce the finished product. In

one company the tool engineering department perhaps would be under the jurisdiction of the plant manager, in another under the plant superintendent, in another it might be under the guidance of a chief engineer or general engineering department. The work of this department falls between that of product engineering and the production departments. The term "tool engineer" has been applied to the head of the department in the sense that he symbolizes its character. In some plants he may be known as the master mechanic, chief tool engineer or the chief tool designer. The tool engineering division may be divided up into various groups designated by their particular specialties, such as, process engineers, tool engineers, or estimators. Any of the engineering employees specializing in any department of the tool engineering division can be termed "tool engineers".

Responsibilities and objectives. The tool engineering division is committed to the ideal of the most economical production possible under existing conditions of available equipment, financial considerations and quality requirements. These things are their responsibilities either directly or indirectly.

Always foremost is the desire for greater economy. The selling cost depends on many factors. Some of these, such as the cost of raw materials, interest rates, marketing expenses, patents, taxes and tariff rates, do not involve tool engineering

directly. In others, such as the correct design of the product, the choice of raw materials, the selection of manufacturing methods, tool engineering shares the responsibility with other members of the organization. Actual manufacturing costs, however, are the direct concern of tool engineering. This group is always endeavoring to lower the factory cost on every article fabricated. This is accomplished by the design of labor saving tools, machines and devices to fill the need where the usual standard tools cannot be used economically to produce quantities of the product to be made.

Tool engineering is charged with the responsibility of cooperating with the product engineers so that the design will be economically producible as well as functional. Tool engineering selects the best manufacturing methods, indicates the proper equipment to be used, establishes the proper sequence of manufacture, designs, estimates tool costs, procures the required machines and tools, and supervises their installation, and generally consolidates these items into a smooth working plan of production.

No matter what the product is, or where it is going to be used, the objectives of executives, engineers, and salesmen and the other members of a manufacturing concern is to produce a product of the highest quality at the lowest possible selling price. Through the design of efficient tools and the selection of proper machines, tool engineering is able

to achieve reduction of manufacturing cost, accuracy of parts, and the elimination of the need for operational skill.

An increase in the accuracy of the part means a uniform product of higher quality. This is an important factor in sales and future orders.

The other two items are very closely related. If the need for operational skill is reduced or eliminated, the labor base is broadened, which is to say that the range of intelligence of the men required to run the plant is broadened. The man of high operational skill can be used on an operation requiring his skill, while a semi-skilled worker can do a job to suit his ability. Even those workers possessing a minimum of intelligence can be employed. This means more employment for more workers. Thus, by the transfer of the skill from the worker to the tool, the high degree of operational skill once demanded of a worker is no longer needed; therefore, one of the two main manufacturing costs - direct labor - has been reduced.

Tool engineering is also aware of the other factor of manufacturing cost; that is, investment cost on the tools and machines. Both must be as low as possible and both influence each other. It is always possible to lower labor cost by investing in tools. Likewise a savings in investment cost generally means higher labor cost. In all cases a compromise must be made and as much ingenuity and skill as possible

should be used to insure the best tools for the least expenditure.

The cost of the product is further reduced by planning the flow of production according to a fixed time schedule, increasing the rate of production to the maximum economical output of the machine and to reduce waste time and material.

These are some of the more important responsibilities and objectives of the tool engineering division.

Tooling up for production. There are many different types of "tooling up" methods and we cannot study all of them thoroughly here. Only a general view of the part tool engineering plays in modern industry can be presented. Tooling programs are often undertaken with a view to provide new tools for a product that has been steadily increasing in sales for some time or for a new product. In addition, tool designers are often called upon to redesign tools that are not quite satisfactory in service, or to improve tools where operators, foremen and others offer worthwhile suggestions. Of course, the biggest "tooling up" program of all is the preparation to produce a part or assembly never before manufactured.

After the sales department has made contact with the customer concerning a new product to be manufactured, all of the available information is passed on to the product engineer. The part or assemblies will be designed by the product engineers. They will be primarily responsible for the proper functioning

of the part or assembly. They should, however, have given some consideration to economical manufacture, but since they are not connected with detailed shop processes as the tool engineer is, they may have overlooked a few factors.

Consequently, tool engineering first considers the possibility of design changes in the part for easier production. Under no circumstances are they allowed to make any changes themselves, but suggest the necessary changes to the product engineer.

When the design of the product is released by the engineering department, blueprints of all of the parts are sent to tool engineering division. The tool engineers and factory executives then begin the study of the manufacturing program. The tool engineer must be familiar with the equipment and the resources of the factory. They must learn the approximate number of units to be made to be able to estimate the amount of money required for investment in new tools. The general manager has the final decision as to the expenditure. Sometimes the general manager requests an estimate of the proposed cost of new tools which he approves or modifies; or he may tell the tool engineer how much will be allowed for the tooling program.

After careful consideration has been given to the items, tool engineering starts to break down the manufacturing process into individual operations. At this time tool engineering

begins the selection of the proper production machinery and starts to design the necessary jigs, fixtures, gages, etc.

In the foregoing pages tool engineering has been introduced showing its history and background. In another section tool engineering's place in the industrial organization was discussed, and also the division of the tool department into various specialist groups.

Some of the tool engineer's responsibilities both direct and indirect were considered, and also his major objectives in connection with his work.

In a section on "tooling up" for production, it was shown how the tooling process proceeds from the sales department down through the design to the tool engineer.

In the following chapters will be discussed the two major problems of tool engineering; that is, tool design and production machinery.

In the chapter on tool design, the all-important work of the tool engineering department is taken up in some detail. The design of jigs, fixtures, and gages is one of the more important parts of the engineer's work. In line with the design work, the objectives of good fixture design from the standpoint of motion economy will be considered.

In the last chapter on production machinery the reader will become acquainted with production machinery and its

purpose. This will include the reasoning involved in the selection of the proper machine.

Special emphasis has been placed on the ultimate production of manufactured goods by the most economical means and the necessary procedures by which that end is attained. The text of the thesis does not cover all the ramifications of tool engineering, but it does describe major points supplemented by illustrations and tables, the problems encountered and the need for a knowledge of jigs, fixtures, gages and machines by the tool engineer.

CHAPTER II

TOOL DESIGN

The essential purpose of the tool design department is to furnish designs and drawings of the necessary jigs, fixtures, dies, tool layouts and gages for the complete tooling of any desired part. The design of practical jigs, fixtures and gages constitutes the greater part of the tool designer's work. This chapter will be confined to the basic principles of design of these items and the objective of good jig and fixture design from the standpoint of motion economy.

I. THE TOOL DESIGNER

The first work the young designer, or detailer as he will be known, is called upon to do is usually that of making detail drawings of the individual parts of a jig, fixture or gage, the assembly or general plans of which have been developed by his superiors. As the detailer increases his experience and knowledge of the basic principles of jig, fixture, and gage design he will be advanced through the steps of senior detailer, junior designer to senior designer. More and more he will be allowed to develop his own ideas. For the designer to efficiently design all the various jigs and

fixtures used in a modern manufacturing establishment, he must be virtually a storehouse of ideas. While the basic principles of jig and fixture design are not too many in number and comparatively simple, the true worth of the designer depends upon his ability to apply basic principles in an original and ingenious manner.

The fact that the tool designer spends a great deal of time at that drafting board often leads to the erroneous impression that designing is a form of drafting. At first glance this impression may seem justified, but drafting actually is only indirectly related to tool design. The relationship of drafting to tool design is similar to that of writing to thinking. Drafting is a descriptive method of expressing ideas beyond the limitations of the written or spoken word. There is every reason to believe that the real work of the designer may be completed while the proposed tool is still in the form of an idea. When the designer starts to draw he must have already visualized the tool he wishes to put on paper. He has to lay out the tool, often changing minor details and proportions, but this is only a recording process for his ideas. In other words, the work of the designer is largely mental and is essentially a process of visualization.²

²J. I. Karash, Analysis of Drill-Jig Design, New York: McGraw-Hill Book Company, 1944, preface.

As the discussion continues the reader will realize more and more the multiplicity of items of knowledge and ideas the designer must have at his command.

While every tool designer is confronted by different problems, there are certain fundamental principles which can be modified to meet the existing conditions and apply in most cases. While all the devices used by the designer will not be exhausted by any means, it will be endeavored to show some of the general principles which are helpful in design work.

II. JIGS AND FIXTURES

Jigs and fixtures have become such a necessary part of modern manufacturing in a large percentage of the work done that an understanding of the principles involved is a necessity in every shop. The two most important reasons for jigs and fixtures are reduced cost and interchangeability of manufactured parts.

The use of jigs and fixtures is primarily to reduce the labor cost of performing machining operations by transferring the required skill of the operator to a machining device, thus making it possible for an unskilled worker to perform the operation. The advantages of commercial interchangeability has probably proven more important in many cases, however. Jigs and fixtures provide a very accurate method of locating holes and surfaces in relation to each other and to size within very close tolerances. This means lower cost of assembling parts without fitting and the possibility of supplying replacement parts for machines already in use. Even when the number of pieces is rather small and the cost of a jig or fixture does not seem warranted, they may be necessary for a saving in assembly time, duplication of the part and machine performance.

Many items enter into the proper design of jigs and fixtures that are not apparent to the casual observer. A

finished jig or fixture may seem to be nothing more than rough castings or built-up pieces of steel with a few rest buttons and clamps to hold the part in place. The time and care which the tool designer has taken to lay out the jig or fixture and the accuracy with which the toolmaker has made the tool cannot be seen, but the real value can be easily determined when the tool is put into use. A careful study of the various suggestions for jigs and fixtures of different kinds as well as the principles involved will help in designing tools that are both sound in design and economical.

Difference between jigs and fixtures. There is more or less confusion regarding the terms used in describing jigs and fixtures. The terms jigs and fixtures are often used interchangeably, although there is a fairly well defined difference, generally agreed upon, between them. Most shop men are apt to use the term jig to describe most work-holding devices.

This seeming lack of universal definition probably is due to two reasons:

1. An attempt is often made to form an all-inclusive definition to include devices actually misnamed in the shop. A tool with a guide bushing to hold the work and drill is called a jig. An apparatus to

hold the work while welding, assembling, and polishing are often also called jigs. Although these devices are very dissimilar they are often called by the same name.

2. Often an attempt is made to create the impression that jigs and fixtures are vastly dissimilar, which is not true. Actually there are any number of hybrids having the outstanding features of both.

A jig is generally defined as a device for holding the work and guiding the tool while the operation is being performed. In the true sense the term "jig" is applicable only to contrivances used in those processes in which the tool rotates and is guided to the work as in drilling, reaming, boring, and similar operations. A jig is seldom fastened to the machine on which it is used, but is movable so that the tool can be aligned in the guide bushing.

Fixtures are generally defined as devices for holding the work while an operation is being performed. They differ chiefly from jigs in that they do not guide the tool. Fixtures are usually fastened to the machine, thus establishing the proper relationship between the work and the tool. Fixtures are principally for work being performed in milling, broaching, or planer machines. The term also may be correctly applied to welding or assembly devices that hold parts in the proper relation to each other while a fastening process is being performed.

Elements of jig and fixture design. There are many more things to consider in the design of jigs and fixtures than seems apparent from the simple definition. The purposes that these devices serve can be broken down into many separate functions and each must be given careful design consideration. It will be found that the purpose of a fixture may be any except the first and fourth items in the list below. The jig may have any or all of the following purposes;³

1. To guide the tool
2. To locate the work
3. To clamp the work
4. Secondary operation features
5. Chip control
6. Coolant control.

Guiding the tool. Contact guiding of the tool is used only in a jig. Such guiding of the tool is used in drilling, reaming, countersinking, counterboring and similar operations. The guide for the tool is called a jig bushing. It, however, not only guides the tool but also keeps the tool in proper relationship to other holes to be drilled or reamed.

Although jig bushings are made of hardened steel, they are very often subjected to severe wearing conditions and do become unserviceable in time. Consideration should be given

³ J. I. Karash, Analysis of Drill-Jig Design, New York: McGraw-Hill Book Company, 1944, p. 2.

to the necessity to replace these bushings when the jig is designed, since some types of bushings are much easier to replace than others.

Jig bushings have been standardized and can be purchased from any number of manufacturers who specialize in these items. Bushings are made in many types, the most common of which are the press fit and the renewable types.

Press fit bushings are assembled permanently into position and when worn out cannot be readily replaced. Therefore, they should be used only in low volume production or where the service is not severe. There are two types of press fit bushings: the plain or headless and the shoulder bushing. The plain type of bushing does have certain advantages. Besides being slightly less in cost and being flush with the top of the jig, they can be set closer together than the shoulder type. The main disadvantage of the plain type is that they are apt to work out of the jig plate either by the drill and pressure or because they are bumped with the drill press spindle.

Renewable bushings are made in two parts, the liner or outer sleeve which is pressed into the jig plate, and the inner slip bushing used to guide the tool. There are two types of renewable bushings, the plain and the slip. The plain bushing is used where several bushings are required during the life of the drill jig, but are intended to be kept in place until worn out. The slip type can be pulled out to

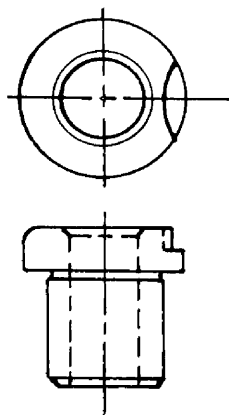
facilitate multiple operations such as drilling, reaming, and spotfacing, or where the same jig is used for different drill sizes. Renewable bushings are used where the drilling action is severe and the bushings are apt to wear out before the jig becomes obsolete. When the wear is such as to cause inaccuracies, the operator can easily replace this type of bushing.

Bushing clamps or lock screws are used on all renewable bushings to hold them in place and to prevent rotating. If the bushing is not clamped it will be drawn out by the drill. Clamps are intended for use in places where removing is infrequent. The lock screw type is the one to use where quick removal and replacement is desired.

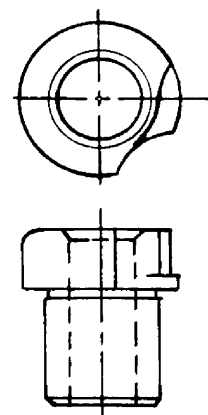
Typical jig bushings, liners, lock screws and clamps are shown in Figure 1.

A number of typical bushing, liner, lock screw, and clamp installations are illustrated in Figure 2.

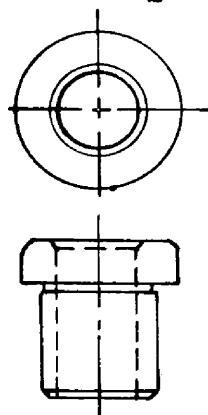
Locating. A sound understanding of the principles of locating is a most important point to the designer. The fundamental purpose of the jig and fixture is to establish a desired relation between the work and the cutting tool within predetermined limits. If the jig or fixture fails in this one respect, the work produced will be scrap. Most important are that good facilities are provided for locating the work and that the part to be machined may be easily



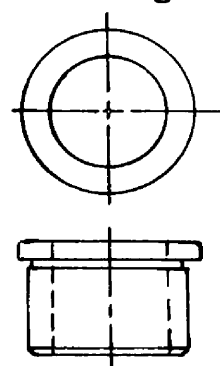
Plain renewable
bushing



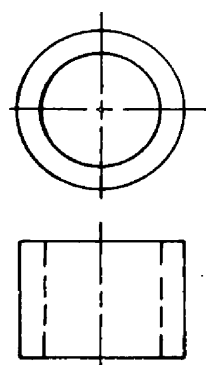
Slip renewable
bushing



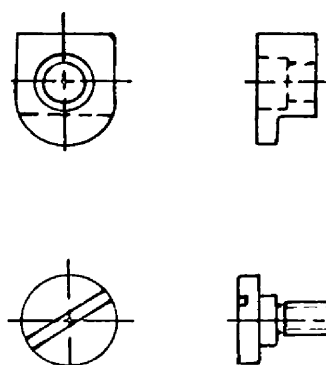
Press fit bushing



Head type liner

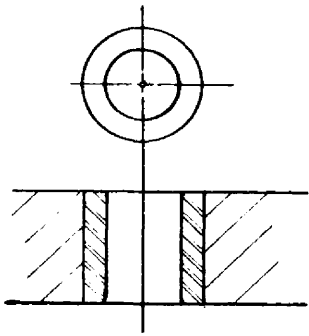


Headless type liner

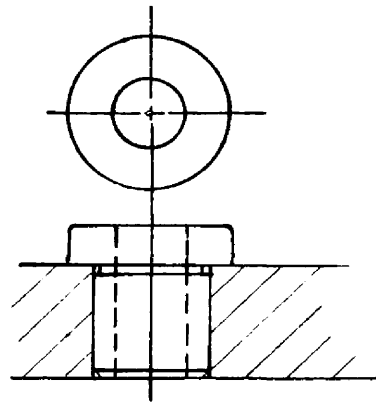


Lock screw and clamp

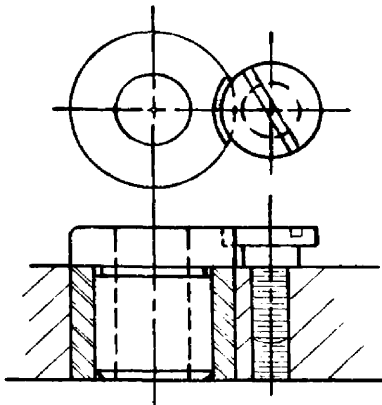
FIG.1- TYPICAL JIG BUSHINGS, LINERS,
LOCK SCREWS AND CLAMPS



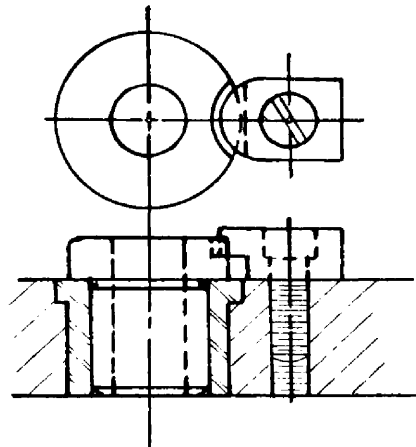
Press fit headless
bushing



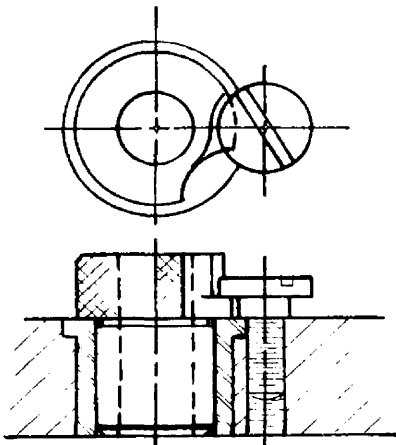
Press fit head
type bushing



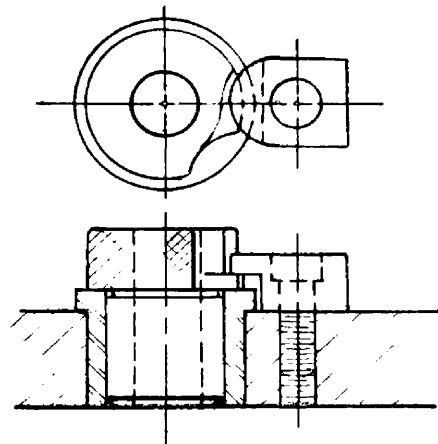
Screw lock
Headless liner
Flush mounting



Round end clamp
Shoulder liner
Flush mounting



Screw lock
Shoulder liner
Flush mounting



Round end clamp
Shoulder liner
Projected mounting

FIG.2- TYPICAL JIG BUSHING, LINER,
LOCK SCREW AND CLAMP INSTALLATIONS

located and quickly taken out of the jig or fixture. By all means, jigs and fixtures should be made foolproof so that it is impossible to insert the part except in the correct way. This is important to prevent errors, especially where a great deal of unskilled labor is used. The locating points should be visible to the operator so that it can be seen that the work is properly seated before it is clamped in place. Since locating points in the jig or fixture may wear from contact with rough surfaces, they must be hardened steel and made conveniently replaceable by some means by the designer.

There is no one best way to locate work in a jig or fixture. The method to be selected depends primarily on the piece that is to be machined. On some work, such as castings or forgings, work rest buttons would probably be used. In still other cases, as in partially machined blocks, rest buttons or relieved strips or plates may be the best selection.

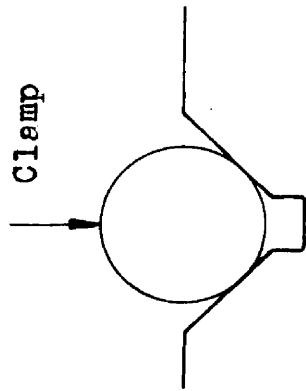
One of the most useful means employed in jig and fixture construction for locating or centering the part is the "V", its construction varying to suit conditions. The term "V" block includes a wide variety of forms but is confined to the use of two surfaces in contact with the work. This type of locator is especially useful on cylindrical shaped work. It can also be used on castings and forgings of cylindrical section, but in this case the "V" should be machined with knife edges or a short "V". The reason for this is that as

small an area as possible of the part should come in contact with the locator. Better yet, when a "v" is to be used on castings or forgings, is to use an adjustable "v" as shown in Figure 3. This type of locator will allow adjustment to fit the casting, because castings or forgings often vary in size in different runs.

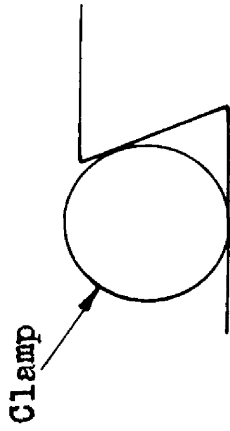
If the work has not been previously machined, locating must be done from a rough or unfinished surface. In this case, not more than three fixed points of support can be used. Other supporting points or "jacks" may be used but they must be adjustable to compensate for the rough surface and are usually brought into contact with the work after clamping. The rest buttons and locating surfaces on which they rest should be either cone pointed or knife-edged.

If the part has undergone a machining operation and has a finished surface, it may be wise to take advantage of this surface and locate on it. This part should rest on four buttons all the same height or on a relieved flat surface as illustrated in Figure 4. If the part, when located on the four buttons, does wobble or rock, this is an indication that there is a chip or dirt on the locator or the part.

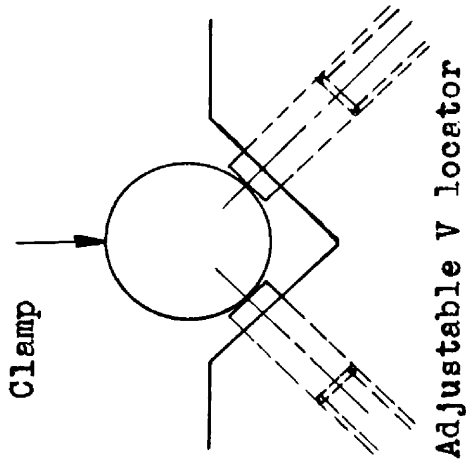
In Figure 5 is shown two simple fixed or non-adjustable stops, the type which are usually used on work that has been previously machined. In Figure 6 are adjustable stops that can be moved to compensate for variations in finish stock



Plain V locator

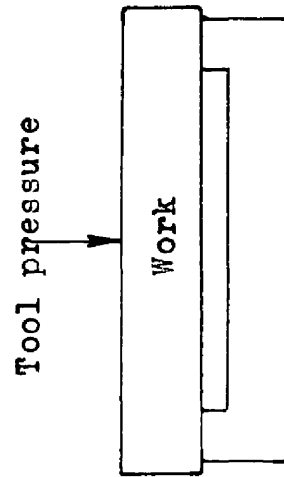


Modified V locator

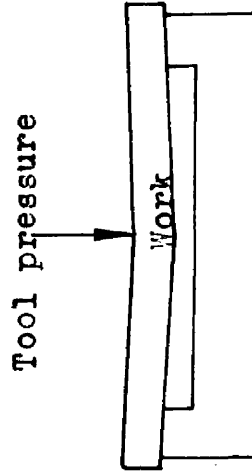


Adjustable V locator

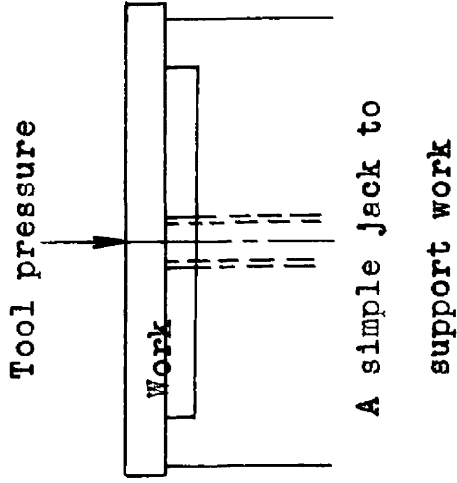
FIG.3- EXAMPLES OF V LOCATORS



Relieving locator to
establish working plane



Insufficiently
supported work



A simple jack to
support work

FIG.4- EXAMPLES OF RELIEVED LOCATORS

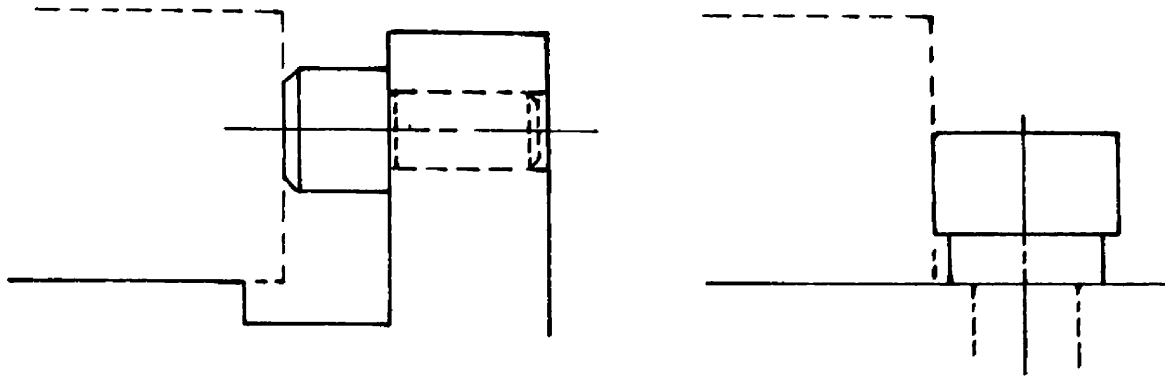


FIG. 5- TWO SIMPLE FIXED OR NON-ADJUSTABLE STOPS

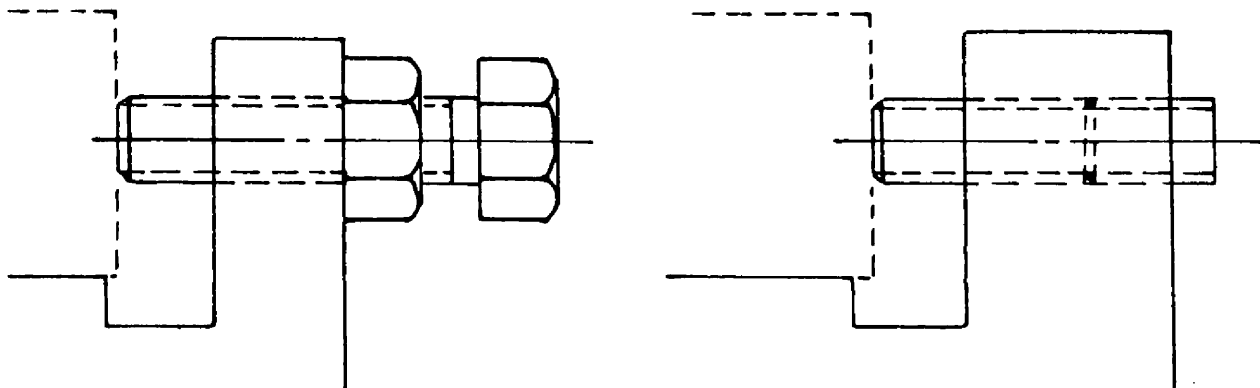


FIG. 6- ADJUSTABLE STOPS THAT CAN BE LOCKED IN POSITION

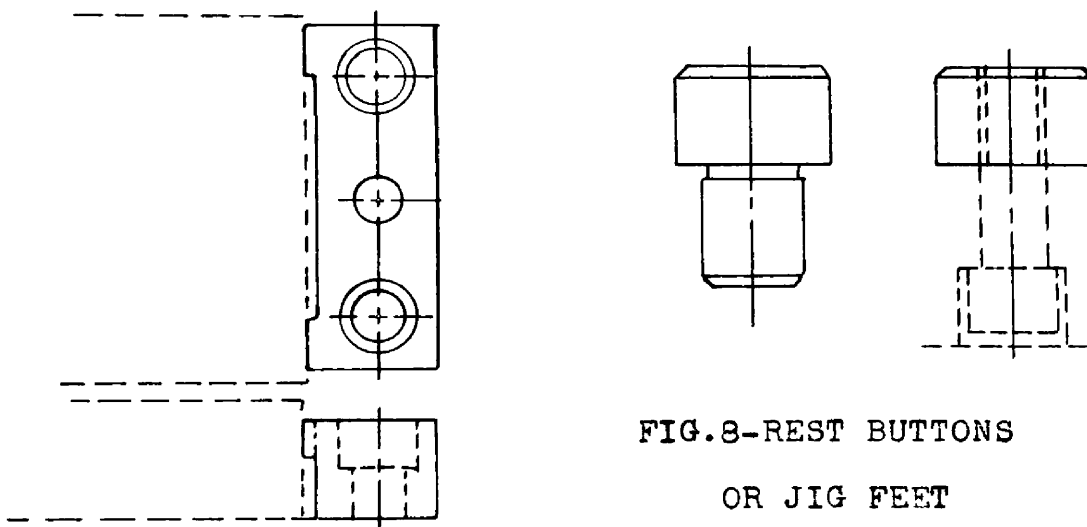


FIG. 7- FIXED STOP WITH TWO POINT BEARING

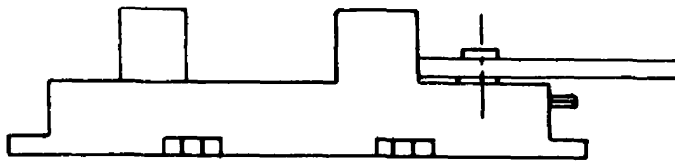
FIG. 8- REST BUTTONS
OR JIG FEET

left on castings or forgings. Many times the stop is used to square up the work piece by having contact at two separated points such as the stop illustrated in Figure 7.

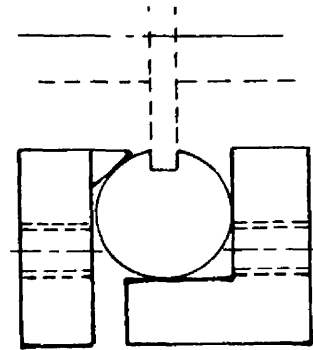
The rest buttons should be of sufficient height to allow room below the locating surface for chips. In Figure 8 is shown two common types of buttons which can be used either as rest buttons or as feet on jigs.

There is one very simple and efficient way in which to design a milling fixture. There are many cases where simple vise jaws can be designed to fit a standard milling machine vise either of the screw or quick clamp types. These vises are usually of substantial design and rigid construction and are very useful when supplied with properly designed jaws. These fixtures can frequently be used in place of expensive milling machine fixtures which, in many cases, are nothing more than special vises. In Figure 9 is illustrated a typical milling machine vise and some production type jaws.

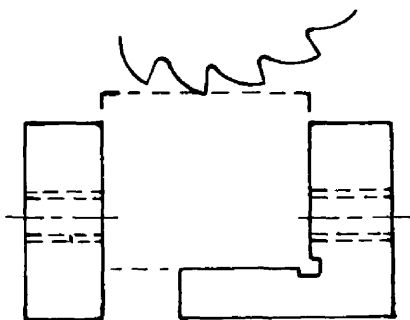
Clamping. After having the part correctly located, the next consideration is the question of how it is to be clamped in position in an efficient manner. The proper designing of the clamps is a very important part of the designer's work. Faulty clamps may easily cause much defective work as well as injury to the operator due to broken tools and uncontrolled motion of the work piece. A clamp according to one dictionary is something that holds or binds things together. The



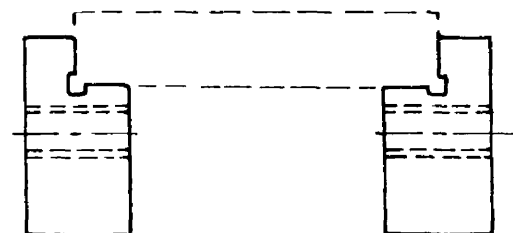
Cam operated milling
machine machine
vise



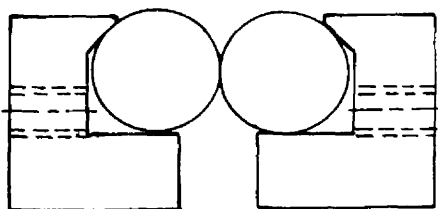
Vise with one
wedge jaw



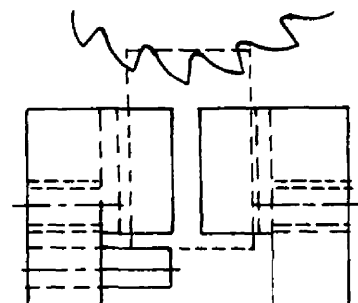
Vise jaws for
square parts



Vise jaws for
flat parts



Clamping two bars
at once



Round part clamped
in vertical V jaw

FIG.9- MILLING MACHINE VISE AND TYPICAL JAWS

application of the clamp in jig and fixture design is to hold parts in position during machining. This holding of the work piece for machining must be a complete restriction of any possible motion during the work operation. This means a restriction of movement in the vertical as well as the horizontal plane, and also preventing of any possible rotation of the part. In designing a clamp to do these things, the designer must take into consideration the operation being performed. The force exerted on the work by the tool and the direction of the force must be determined. More ingenuity and originality can be displayed by the designer in devising clamping means than in any other phase of jig and fixture design.

A good clamping device must fulfill these requirements. First, it must hold the work piece rigidly while the tool is cutting. Second, it must clamp and unclamp with a minimum of effort in the shortest length of time possible. Third, the clamp must be positive regardless of vibration, tool chatter or heavy pressure. Fourth, the clamp must not damage the work piece in any way.

The work must be held firmly in the jig or fixture without distortion or springing and each succeeding piece must be held in the same position. To this end, the gripping and holding must be done nearly above or opposite the locating point and as near as possible to the machined surface.

The clamping means must be positive and rapid, yet simple in construction and operation. Screw clamps are very positive in action but are usually too slow for general use. When it is found necessary to use screws they should be operated with hand wheels or knobs. Often screw clamps on large jigs and fixtures are operated with power wrenches. Cams and eccentrics are very satisfactory clamping means; both are positive and rapid acting. The most used of all clamps is the plain screw and strap, and their combinations. Four of the simpler clamping devices are shown in Figure 10. Other clamping principles are illustrated in Figure 11.

Several other types of clamping devices used in jig and fixture design are:

Quick acting screw	Cross-head screw
Hook bolts	Toe clamps
Swing hook clamps	Wedge clamps
Lever clamps	Cam locks
Straps	Spring pins
Latch clamps	Toggle clamps
Eccentric pins	Rack and pinion

Many of the various forms of clamps and jig and fixture details have become standardized and can be purchased from companies who specialize in this type of equipment. There are many advantages to be derived from such standardization. Mass production of these items greatly lowers cost. The use

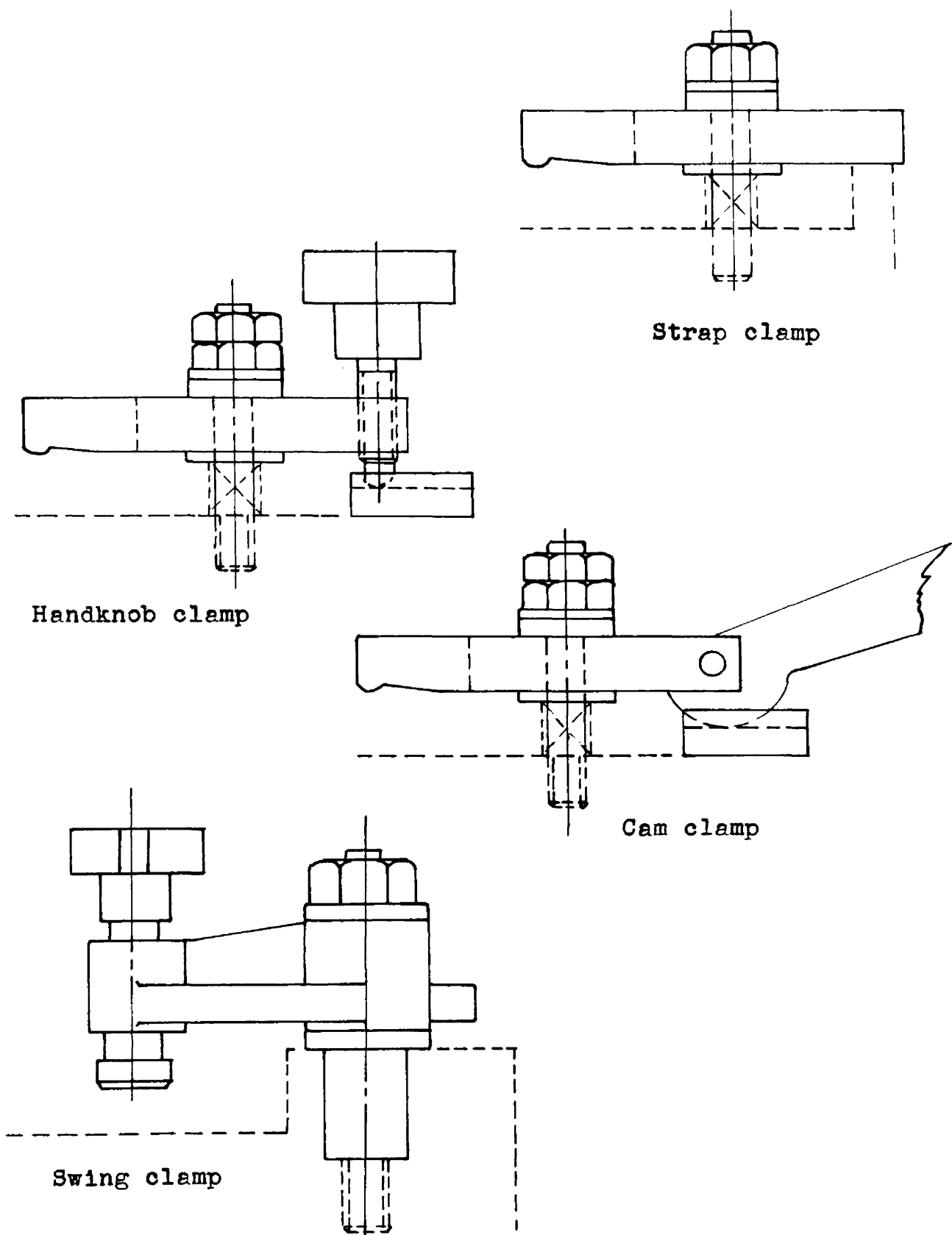
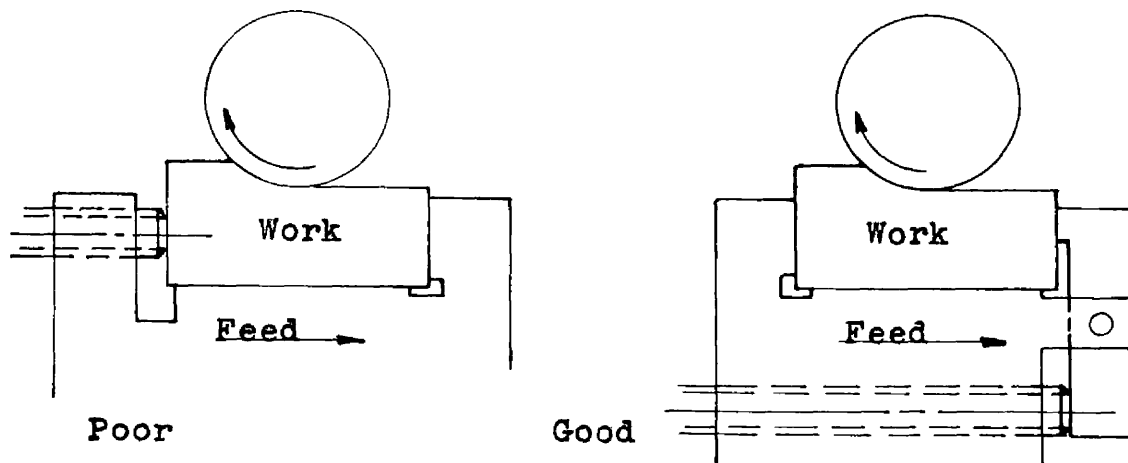
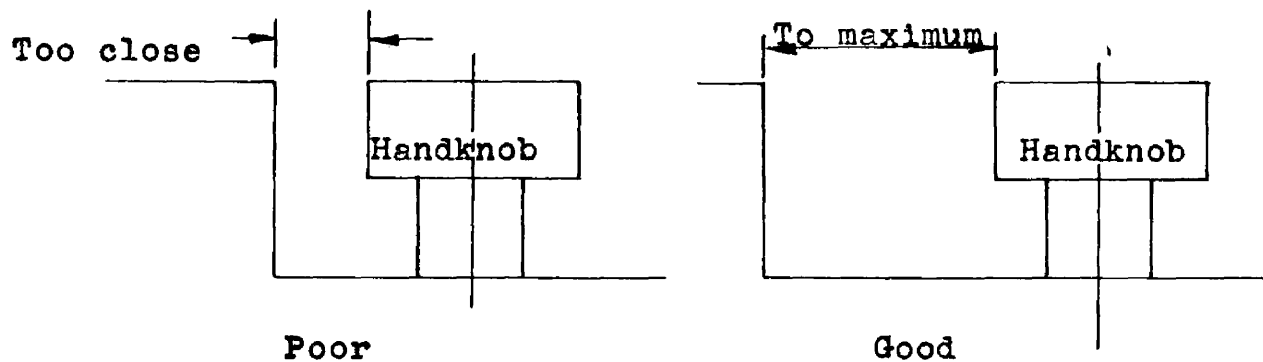


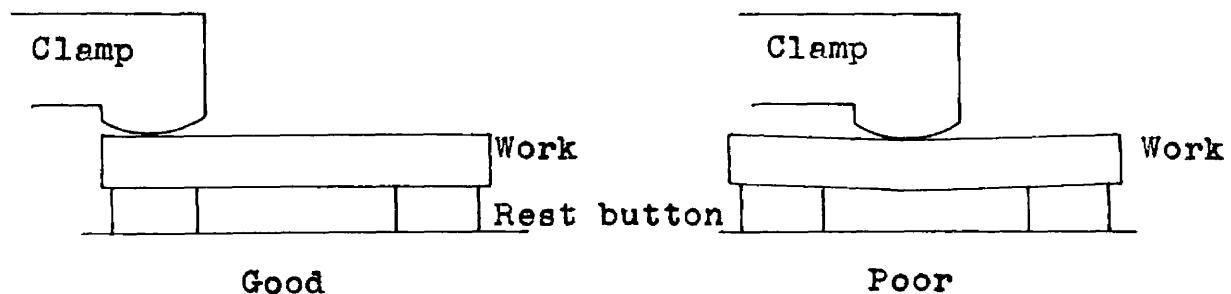
FIG.10- FOUR STANDARD TYPES OF JIG AND FIXTURE CLAMPS



Cutting pressure against solid stop



Allow sufficient hand room



Clamp over rest button

FIG.11- CLAMPING PRINCIPLES

of these items also greatly simplifies the design and making of jigs and fixtures. Standardized items include various types and sizes of clamp assemblies, jack locks, flanged nuts, handknobs, keys, hardened washers, clamp rest, cams, spherical and "C" washers and rest buttons.

The designer should be well acquainted with these items available and select the correct ones for the particular design whenever possible.

Secondary operation features. When it is necessary to perform secondary operations, that is, drill, ream, tap, counterbore, countersink, or spotface, there are certain mechanical features that can be built into the jig that will greatly facilitate the performance of this type of work. The jig will probably offer no special secondary operation features unless the designer has deliberately built into the jig such features. For example, many times after drilling a hole some second operation may be needed, such as reaming, tapping, or counterboring. In many cases there may be several operations to finish one hole as drill, countersink, and tap. In this case some special consideration will have to be given to guiding these tools or providing the necessary clearance for the tools.

The use of a liner and slip bushing in drilling is one way of providing for a secondary operation. After drilling,

the bushing can be removed and a different size inserted to guide a reamer, counterbore, or a drill used as a counter-sink. Quite often the second operation tool can be used unguided, but consideration must be given to the internal diameter of the liner bushing to insure that the tool will pass through it. Three typical secondary operation setups are shown in Figures 12, 13, and 14.

It may even be necessary to make the bushing plate movable to facilitate use of the second tool. In Figure 15 are shown four operations which often are done in succession. By the use of flipper bushing plate the casting can be drilled, reamed, spotfaced, and chamfered all in one jig. There are many variations and combinations of tools and jigs features such as these which, if properly designed, prove very useful.

Chip control. Of all the factors involved in the process of jig and fixture design, that most overlooked or neglected is the subject of chips. A jig or fixture may be well designed from the standpoint of locating, clamping, etc., but the operation of it is inefficient because minor construction details pertaining to chips had been overlooked. This creates a most trying and tedious job for the operator.

It probably has been noted some time that in some drilling operations much time is often spent in breaking up

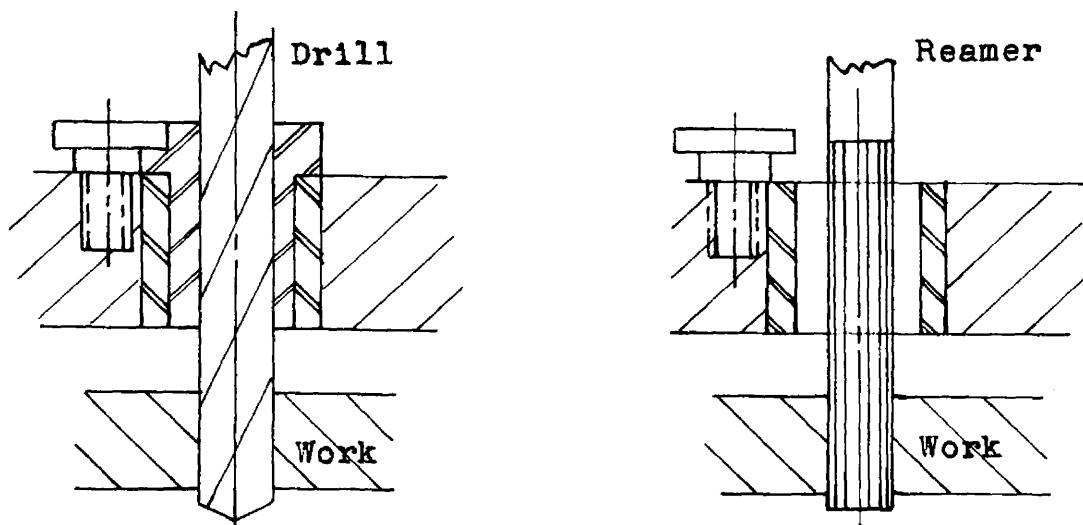


FIG. 12- DRILLING AND REMOVING SLIP BUSHING FOR AN UNGUIDED SECONDARY OPERATION

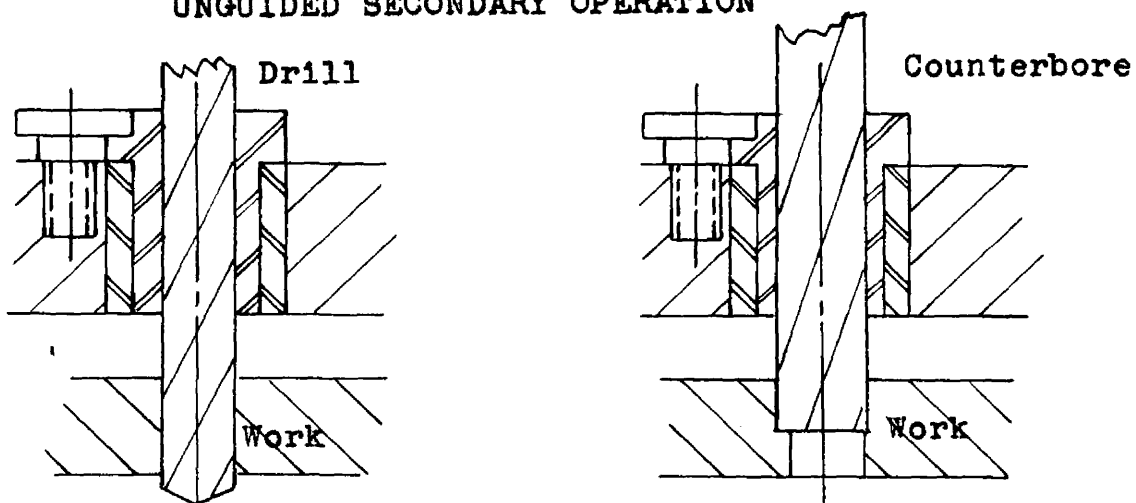


FIG. 13- USING TWO SIZES OF SLIP BUSHINGS FOR DRILLING AND COUNTERBORING WITH FLAT POINT DRILL

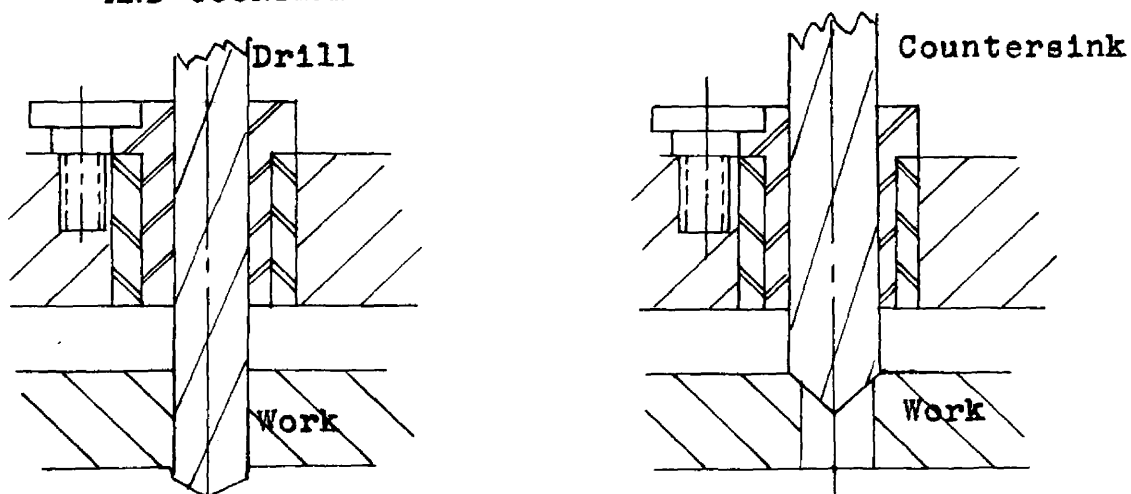


FIG. 14- USING TWO SLIP BUSHINGS TO DRILL AND COUNTERSINK WITH THE END OF BUSHING GUIDED DRILL

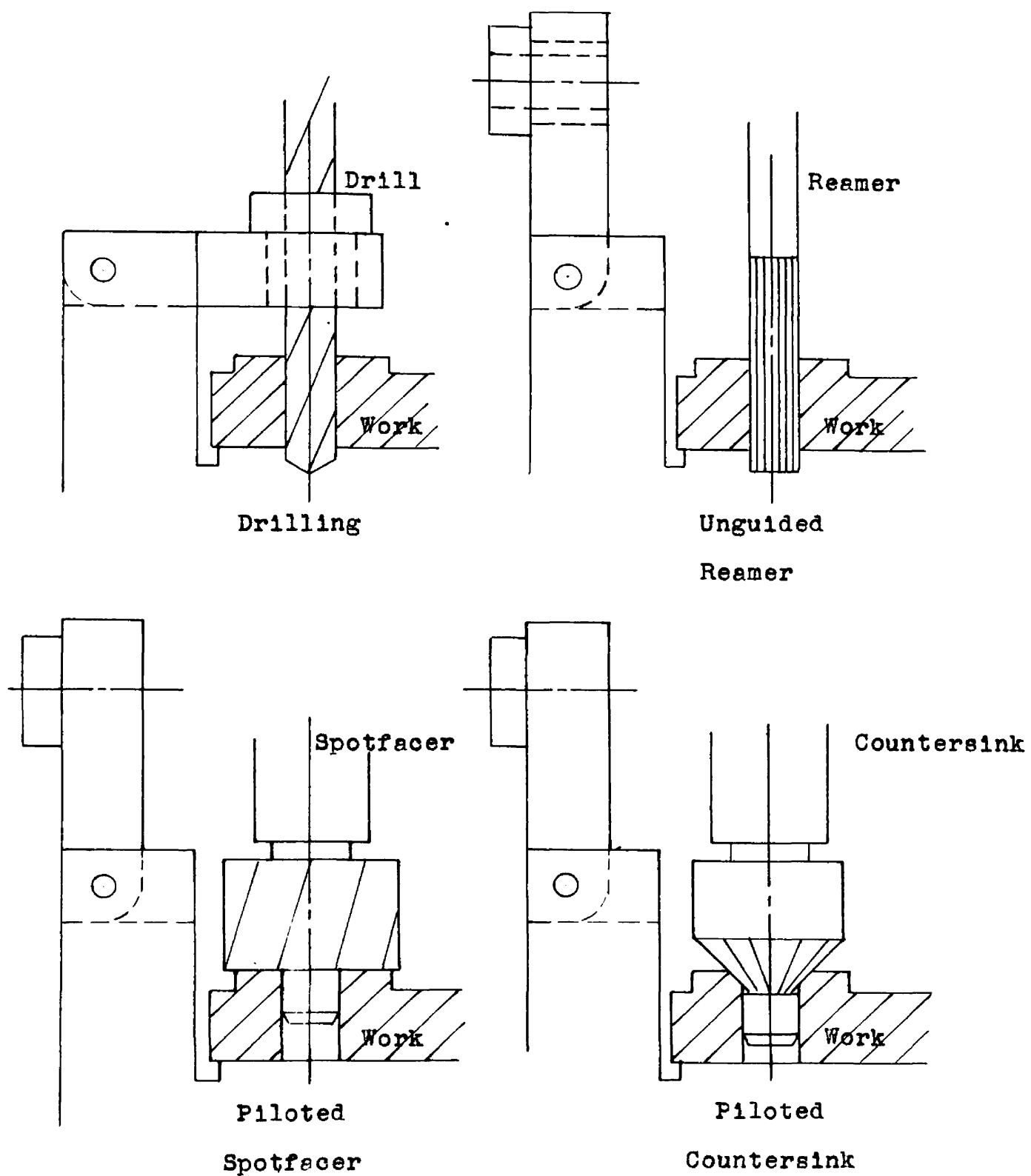
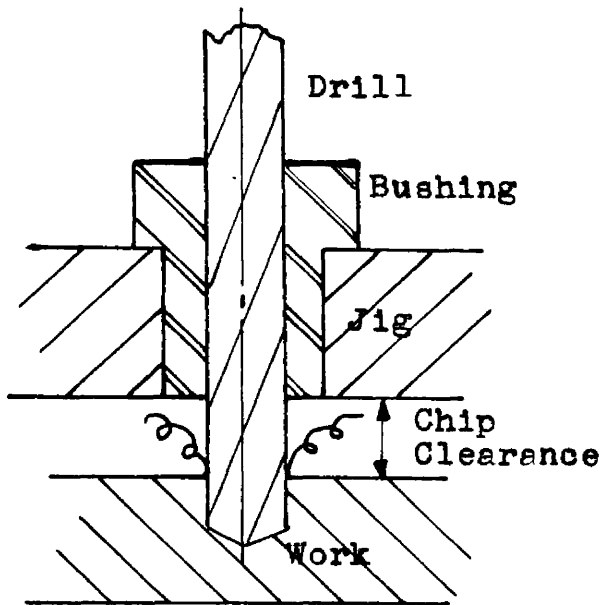


FIG. 15- AN EXAMPLE OF THE USE OF A FLIPPER BUSHING
TO FACILITATE THE SECONDARY OPERATION

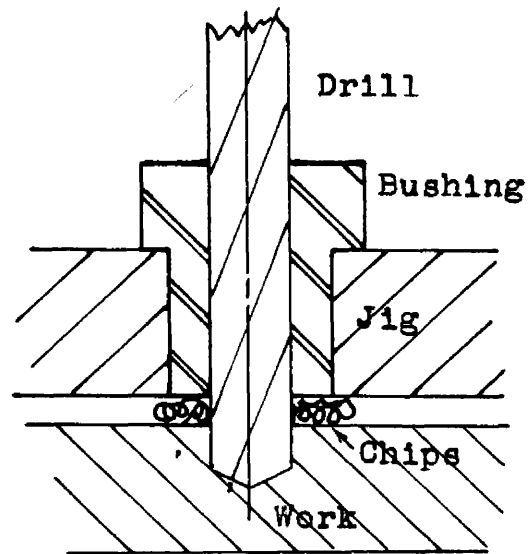
and removing chips to allow continuation of the operation. A drill jig can be so designed as to minimize or even eliminate the time that would ordinarily be required for this purpose. Much of this chip trouble is caused by an improper relation between the bushing and the work. In Figure 16 is shown some examples of the different placements. If the bushing is at the proper distance from the work, the chips will have ample room to get out and not tangle the work. If the bushing is improperly placed, as in the other views of Figure 16, it is quite obvious that the chips are going to pack up and cause considerable trouble.

In the designing of jigs and fixtures it is at times advantageous to provide grooves or troughs in the locating corners so as to avoid locating misalignment that might be caused by chips. There are some examples of what is meant by "corner relief" in Figure 17.

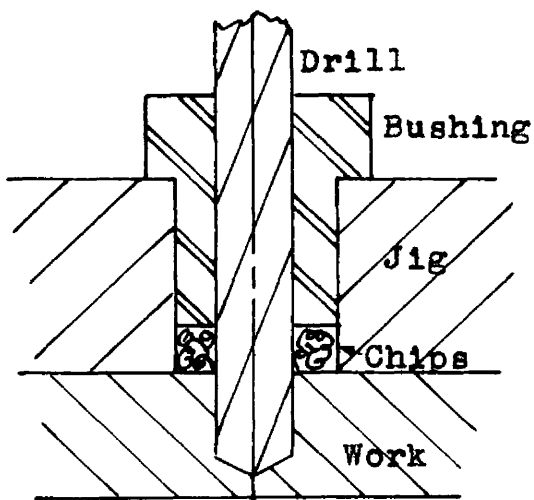
Often serious chip interference can be avoided by using the proper contact area relief on the locating surface. When two flat surfaces come together, a single chip between them will prevent them from coming into full contact. The entire area of these contact surfaces is vulnerable to a single chip. If the locating surface is relieved or cut away except for narrow strips so that the contact area is small, the probability of a chip being on this area would be greatly reduced.



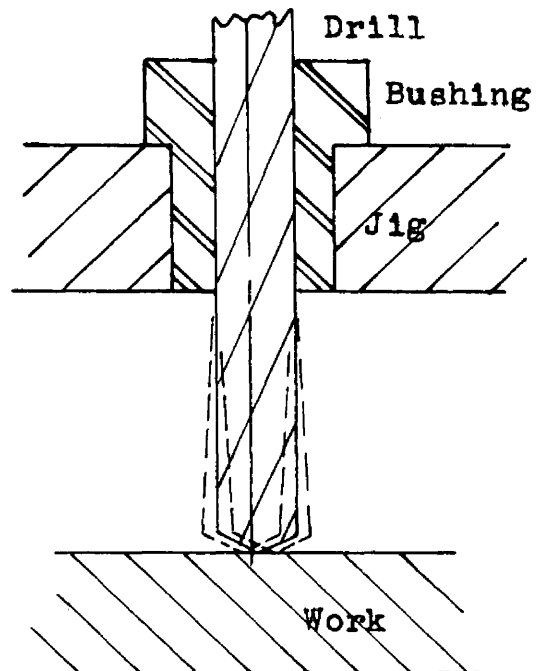
Proper placement
of bushing



Bushing too close to work

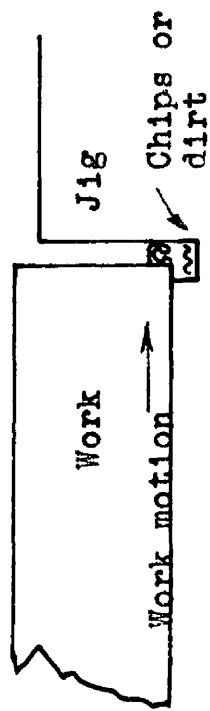


No chip clearance



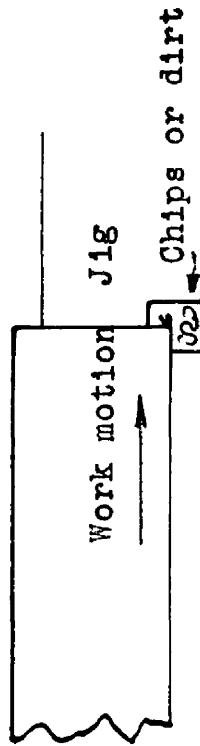
Inaccuracy caused by excessive
chip clearance

FIG.16- PLACEMENT OF THE BUSHING

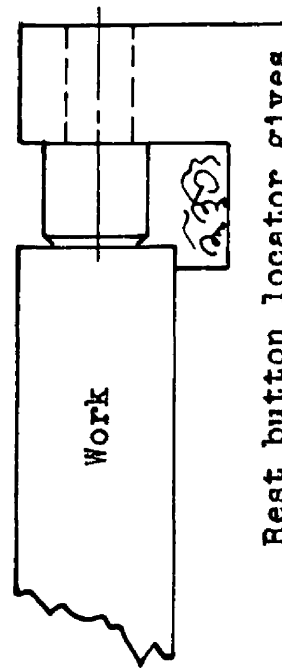


Chip gathering caused by
unrelieved locating corner

Improperly relieved corner



Properly relieved corner



Rest button locator gives
good corner relief

FIG.17- EXAMPLES OF CORNER RELIEF FOR CHIP CONTROL

There is another chip problem that is often neglected; that is what is known as a burr. A burr is really a chip that has not been completely severed from the work piece and is a result of the machining operation. If it is not properly or completely removed, it may cause considerable locating trouble. It is often necessary to cut away or relieve locating section of the jig or fixture in order to clear burrs caused by a previous machining operation.

The jig or fixture should be designed with ample clearance for chips. If possible accumulated chips should fall away from rather than on to the locating surface when the work is removed. If possible, the locating surface should be completely covered by the work so that chips cannot collect on it. The locating buttons should be sufficiently above the surrounding fixture base so that the chips may fall below them. It is good practice to make the jig or fixture as wide open as possible so that chips can be blown or brushed out.

Coolant control. The use of coolants in jigs and fixtures can sometimes be greatly facilitated by designing with the purpose in mind. Oftentimes if no thought is given, after a jig or fixture is built and in use it will be found that the cut is in such a relation to a part of the fixture or clamp that very little coolant gets into the tool.

It might be remembered that the coolant flow from the tool also is an excellent means of keeping locators free of chips and to dispose of chips. With a little thought during design many of the chip control problems can be solved by the proper coolant control.

General considerations. The most economical design that will perform the desired function correctly is usually the best design for the purpose. Tools are expensive mostly because of the high quality of workmanship put into them; thus, their design should always be considered in light of the expense involved.

Jigs and fixtures should always be as simple in design as is consistent with their function. The simpler the design, the fewer the parts there are to wear out or to get out of order and the lower will be the maintenance cost.

All tools must be designed with the thought of the safety of the operator in mind; that is, the jig or fixture must be foolproof as possible and must not in any jeopardize the person involved in the operation. The operator must be thought of as having a minimum amount of skill, and safety must be designed into the tool.

Although the foregoing principles discussed should be adhered to in the designing of jigs and fixtures, there are

no definite rules. The judgment of the designer is usually a sufficient rule, if that judgment has been acquired through experience.

III. OBJECTIVE OF GOOD JIG AND FIXTURE DESIGN FROM THE STANDPOINT OF MOTION ECONOMY

In any discussion involving mass production industries, the first and most important element which applies to all jigs and fixtures, tools and processes is the economic one. The preceding articles discussed the purpose of jigs and fixtures and points the tool engineer has to consider in designing for these purposes. Another important point of view to tool engineering is the objective of good jig and fixture design from the standpoint of motion economy; that is, how to produce a work piece in the least possible time. Since the tool engineer's main objective is to produce work of the highest quality for the least cost, the following may be considered a summary of all the principles of good jig and fixture design. The designer plays a very important part in the amount of time required for the operator to complete a work piece in a jig or fixture. From the standpoint of motion economy these are items that the designer must consider in the design of an efficient jig or fixture:

1. To eliminate barriers
2. To provide sufficient chip clearance
3. To provide sufficient fixture relief for burrs

4. To provide for quick and easy clamping and unclamping of parts
5. To provide for as much mechanical assistance as is practical to aid in the loading and unloading of parts
6. To provide for the processing of as many parts at one time as may appear practical
7. To provide for minimum material cost for both original and maintenance factors.

Eliminate barriers. The first way to save the operator time is to eliminate barriers, obstructions, or handicaps.

Some of the more common ways used by the designer follow:

1. Provide clamps that move out of the way of the loading area; that is, design the jig or fixture so that the operator is free to move directly in and out of the loading position.
2. Provide visible locating points so that part can be directly placed in the fixture with one movement. This will eliminate fumbling, hunting and re-positioning by the operator.
3. Relieve jig or fixture where necessary to allow the operator to get fingers around the part for removal.
4. Consider the direction of flow of material, if known. The loading, clamping and disposing can be

very much simplified if it is known from which direction the operator is to receive his stock and in which direction it is to be disposed.

5. Avoid existing barriers in the machine in designing a jig or fixture. Always keep clamps away from arbors, arbor supports, operating handles and guards when loading and unloading. The operator's hands must be well clear of the cutter during the insertion, clamping and removal of the work piece. Always give due consideration to the stroke of the machine.
6. All exposed screws, nuts and lugs the motion of which might catch the operator are to be avoided and sharp corners and edges should be removed.

Provide sufficient chip clearance. From the previous discussions of jig and fixture design it will be remembered that improper chip clearance causes improper location and alignment of the part and poor clamping. Insufficient chip clearance can also cause considerable time loss by the operator due to having to load, unload, brush or blow out fixture, reload and clamp because of chips on the locators. From the standpoint of motion economy certain steps can be taken to avoid this:

1. Keep locating surfaces to a minimum size.
2. Keep locating surfaces projected well above background surface and provide sloping surfaces and

openings on background to facilitate flow of chips.

3. Provide for maximum chip clearance around moving parts of jig and fixtures including clamps, moving locators, ejectors, cams, etc.
4. Consider position of cut (vertical or horizontal) to chip disposal with relation to selection of machine.
5. When liquid coolant is used build in lines, where practical, to cool cutting tools and if possible to wash away chips.
6. When liquid coolant is not used, build in air lines where practical to cool cutting tool and to blow away the chips.

Provide relief for burrs. Burrs on the work piece cause the operator considerable difficulty in clamping and locating. A few minutes consideration by the designer can eliminate this trouble by doing one or both of the items below:

1. Provide relief for burrs from the previous operations on locating and clamping surfaces.
2. Provide relief for burrs from operation being performed to facilitate unloading of work.

Provide for quick and easy clamping and unclamping. Since clamping and unclamping are two of the motions that the

operator must perform on each and every work piece, this would seem to be an excellent point at which motion economy would show a just reward. There are many ways that the designer can speed up this necessary task:

1. Locate clamp handles in position most convenient for the operator and provide sufficient clearance around handles, open, closed, and during stroke to prevent interference.
2. Use quick acting clamps such as cams, toggles, air or hydraulic cylinders, bayonet locks, etc., where practical.
3. Clamp at as many points as possible with one clamping motion.
4. Provide suitable leverage on manually operated clamps along with properly designed handles to avoid use of lead hammers or makeshift extensions and to avoid distortion of part and fixture.
5. Provide foot operated clamps where practical.
6. Use machine movement for clamping whenever practical.

Provide mechanical assistance in loading and unloading.

Mechanical assistance is always a good way in which to make an operation more efficient and less fatiguing to the operator. Some of the methods used by the designer are listed below:

1. Use slides, rolls, or magazine feeds; guides, chutes, and dial or indexing feeds; machine actuated where practical.

2. Chamfer or bullet nose all pins or holes to aid in the positioning of the part.
3. Provide for ejection of the part by mechanical knock-out, air, or gravity where practical. Provide knockout for pushing work off of locating pins or other locating members.

Provide multiple station fixtures. This consideration is usually for high production setups only. Provisions should be made for processing as many parts at one time as appears practical. There is one caution, however; always consider the nature of the cut and setup time involved.

Provide for minimum material and maintenance cost. Since jigs and fixtures usually cost considerable to design and build and are subject to severe wear conditions, thought should be given to material and upkeep cost. There are several points to be considered in this respect in designing a jig or fixture:

1. Consider welded construction and use of structural shapes.
2. Make all parts subject to wear readily replaceable. Provide master bushings for tool bushings, pilots, etc. Provide keys in place of dowels where practical.
3. Use cheaper material on other than locating surfaces-- use tool steels only where necessary.

To be completely successful in the accomplishment of these objectives, the factors of safety and sound engineering principles must be incorporated.

IV. GAGES AND GAGING

The tool engineer is responsible for the design or purchase of all the necessary gages for the production of a work piece manufactured by the factory. If this task is to be done efficiently, it is necessary to have a complete knowledge of gages and gaging methods. Since it would take many volumes to fully cover the subject of gaging and gages, only a general discussion will be attempted.

The prime purpose of an industrial gage is to determine the dimensional fitness of a given work piece for subsequent machining operations or to function in the assembly of which it is to become a part. Gages provide the ultimate means of assuring interchangeability.

The tool engineer must realize that in actual production exact dimensions never exist. The variation in the size of parts may be restricted but they never can be avoided, and a certain amount of variation always exists. For example, when two mating parts are to be machined, such as a shaft to fit in a bearing, a certain allowance must be permitted to allow the type of fit desired. The prescribed difference between the mating parts to attain a specific class of fit is called the "allowance". In the case of the shaft and

bearing, where the shaft would be smaller than the hole, the minimum clearance is called the "allowance". If the shaft were larger than the hole, necessitating a press fit, the maximum interference is called the "allowance".

In order to hold this allowance each part of an assembly must have dimensions with tolerances. The tolerance is the extent of variation in a dimension which may be permitted or tolerated without impairing the functional fitness of the part in the assembly. The limiting dimensions of this tolerance are called the "limits".

Tolerances should always be given for a decimal dimension and are often given to fractional dimensions as well. It is important, however, never to give a tolerance closer than is absolutely necessary. The closer the tolerance the greater the cost, and the rate of cost to fineness of tolerance is not a direct ratio. Each slight decrease in tolerance is accompanied by a greater increase in cost.

All tolerances should be based on a functional consideration of the part in question. In many assemblies the majority of elements do not have critical surfaces and comparatively large tolerances are permissible. Gages for these dimensions may and should have large tolerances from the standpoint of economy. Extreme accuracy should only be maintained when necessary.

There are many ways to classify gages. For example, in Figure 18 are shown several classifications of measuring instruments used in manufacturing. All measuring instruments could probably be classified under any of the various groups:

1. Linear - angular - plane surface
2. Fixed gages - adjustable gages
3. Direct reading - indirect reading - non-reading.

There are many more possible classifications. In these groups in Figure 18 are shown many of the common measuring instruments with which the tool engineer must be familiar.

Another way to classify gages is that used in most manufacturing plants, that is, into three groups by their use as manufacturing gages, inspection gages, and reference gages.

MANUFACTURING GAGES

Manufacturing gages are those used by the operator on the machine for gaging the particular operation being performed. These gages are usually of the fixed, adjustable, and the non-reading type. These gages are often what are known as "go" and "no go" gages. These gages are adjusted by the inspection department and sealed. The operator runs the work piece to the tolerance between the limits of the gage. This type of gage greatly reduces the possibility of error that would probably result if an unskilled worker were

<u>LINEAR</u>	<u>ANGULAR</u>	<u>PLAIN SURFACE</u>
Scale	Square	Surface gage
Caliper	Protractor	Profilometer
Divider	Sine bar	Level
Micrometer	Dividing head	Optical flat
Vernier caliper		Straight edge
Depth micrometer		
Telescoping		

<u>FIXED GAGES</u>	<u>ADJUSTABLE GAGES</u>
Plug gage	Micrometer
Thread plug gage	Surface gage
Feeler gage	Vernier caliper
Gage block	Dial indicator
Steel scale	Protractor
Ring gage	Indicator snap gage

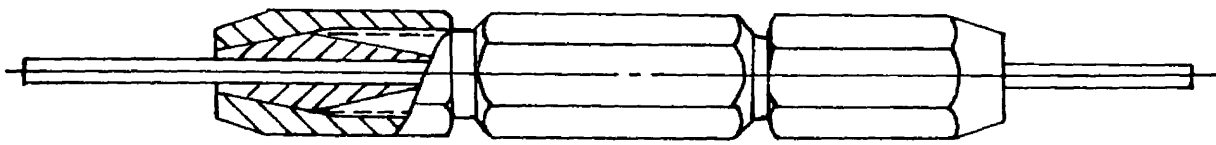
<u>DIRECT READING</u>	<u>INDIRECT READING</u>	<u>NON-READING</u>
Micrometer	Telescoping gage	Snap gage
Vernier	Surface gage	Plug gage
Protractor	Sine bar	Ring gage
Scale	Caliper	Optical flat
Depth micrometers	Planer gage	Optical comparator

FIG. 18 - CLASSIFICATION OF MEASURING INSTRUMENTS

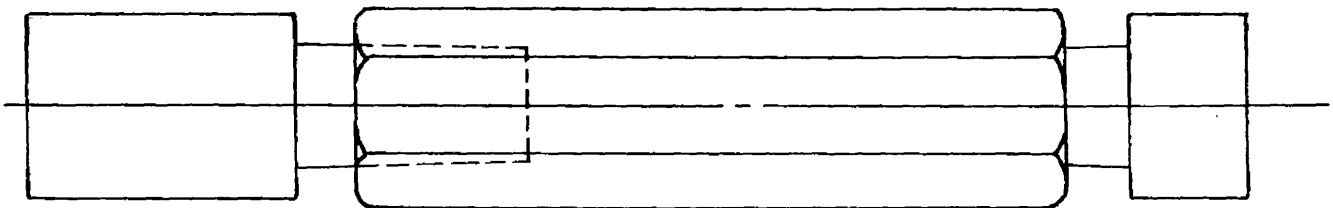
required to use an indirect or direct reading measuring instrument, such as a micrometer, telescoping gage or vernier. The most common types of manufacturing gages are plug, snap, flush pin, thread gages, and indicator gages.

Plug gages. The plug gage is a fixed type gage and is good for one size and purpose only. It consists of a handle either round or hexagonal-shaped with an accurately ground and lapped cylindrical plug at one or both ends. If it is double ended it is termed a "go - no go" gage. The ends are of different lengths. The long end is the "go" plug and corresponds to the lower limit of a hole. If the hole is large enough, the "go" plug will enter the work piece to be tested without forcing or twisting. The "no go" plug is larger than the "go" plug and corresponds to the high limit of the hole. If this plug enters, the hole is too large.

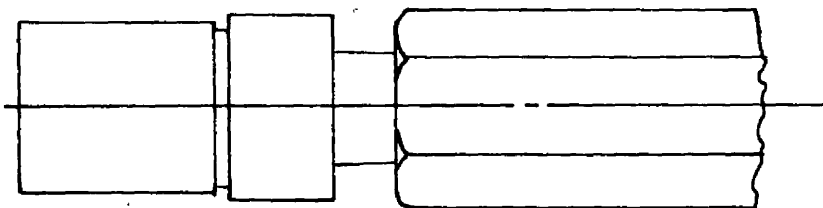
The standard double end plug gage is made in many designs, two of which are shown in Figure 19. One has plugs that are straight and held into the handle with a small collet. This type of gage ranges up to one-half inch in diameter. The other type of double end plug gage has the plugs attached to the handles by means of tapers. This type ranges up to about one and one-half inches in diameter. Plugs of a larger size than this do not have tapers, but are fastened to the handles by screws through the center.



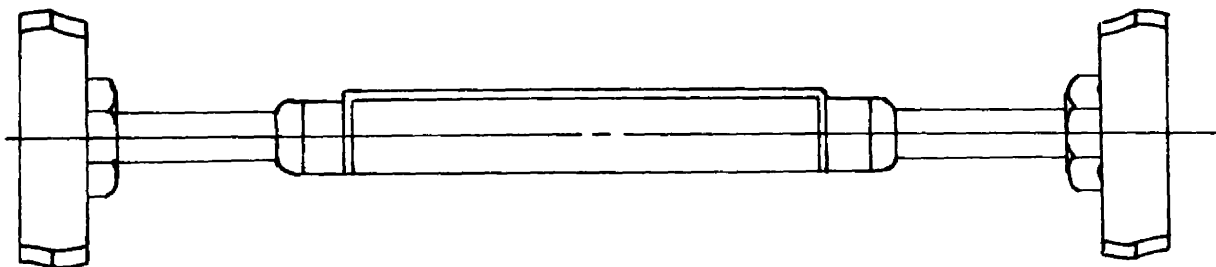
Go and no go pin type plug gage



Go and no go plug gage



Go and no go progressive type
plug gage



Go and no go disk type plug gage

FIG.19- VARIOUS TYPES OF PLUG GAGES

If the plugs are made in large sizes, each of the plugs will have a separate handle due to the weight of two, were they both attached to the same handle.

Another type of plug gage shown in Figure 19 is the "go - no go" progressive type plug gage in which the two limits are on one plug. The advantage of such an arrangement is the "go" and "no go" can be tried in the hole without turning the gage end for end. The disadvantage of this arrangement is that if it is desired to change the one limit on the hole, a new plug with both limits would have to be made.

The other type of double end plug gage shown in Figure 19 is known as the "go - no go" disc type plug gage. The plug has specially ground disc with the sides cut away to give a small area of contact. The advantage of this type gage is that it will detect taper and out-of-roundness in excess of the limit whereas a cylindrical plug gage will only check the smallest diameter of the hole.

Snap gages. Snap gages are also known as "go" and "no go" gages. These gages are used to measure diameters, lengths, thickness and similar dimensions. They are adjustable to within narrow limits by setting the anvils. These anvils are adjusted to size for a particular job and locked.

The work piece is supposed to pass through the first set of anvils and not through the second, to be acceptable.

Two common designs of snap gages are illustrated in Figure 20. One of these snap gages has a rather wide anvil and is meant for the measurement of straight cylindrical or lengths and widths of flat work. The other is used where some particular shape of narrow anvil is desired. This gage is very efficient in measuring such things as diameters of ring grooves and undercuts.

In many cases due to limitations or restrictions in the part, a standard snap gage cannot be used. A special snap gage may have to be designed for this particular part. In Figure 21 are shown three non-adjustable snap gages often used. These are made in one, three, and five piece construction. The design selected will depend on the number of pieces to be manufactured. If a very limited amount are to be produced, the one piece would be adequate. If the production is to be large, the three or five piece gage would be used because these can be reworked to compensate for wear.

Flush pin gages. The flush pin gage or feeler pin gage is one of the most useful and adaptable type of gages used in manufacturing. The old saying that the sense of touch is keener than the eye probably had something to do with the

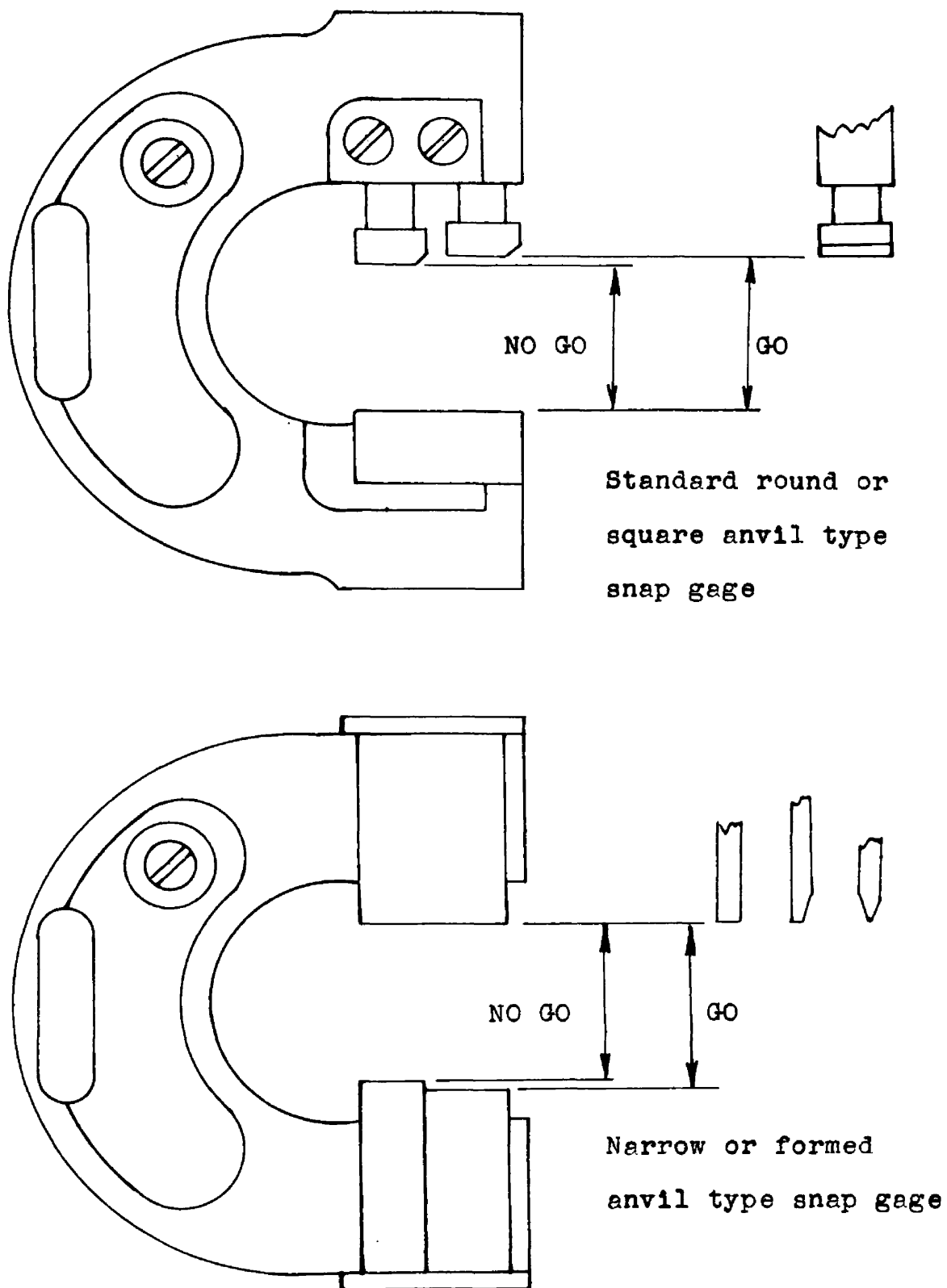
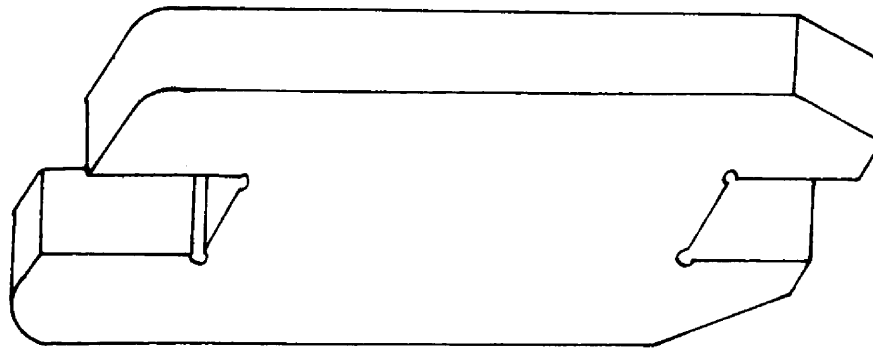
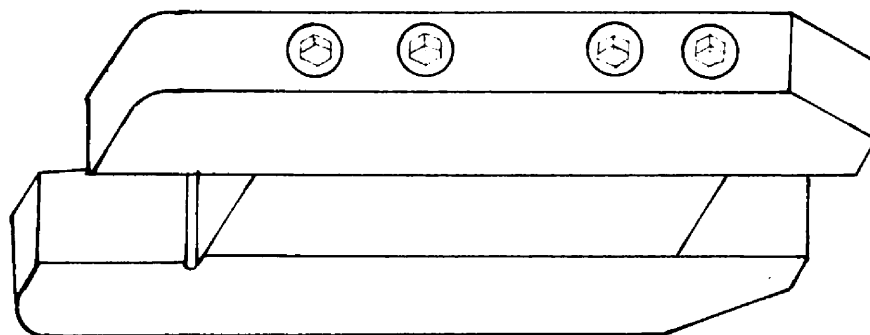


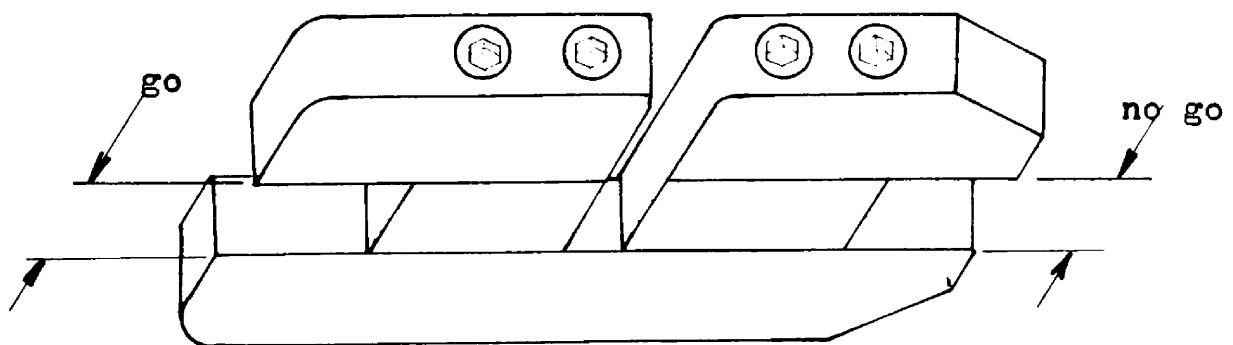
FIG.20- TWO TYPES OF ADJUSTABLE SNAP GAGES



1 piece snap gage



3 piece snap gage



5 piece snap gage

FIG. 21- NON ADJUSTABLE SNAP GAGES

designing of the flush pin gage. With the flush pin gage, the touch is relied upon more than the eye. These gages are usually used in gaging such dimensions as are too difficult to gage in any other manner. This type of gage is particularly useful for gaging the distance between surfaces that are not opposite each other. Examples of many uses for the flush pin gage are illustrated in Figure 22.

The flush pin gage consists of a round barrel or body with a plunger through the center. The plunger projects from a face of the body a distance equal to the minimum dimension to be gaged when the opposite end of the plunger is flush with the opposite face of the body. In this face of the body is ground a step equivalent to the limit of the work piece.

This type of gage is simple, foolproof, easy to read, and cheap to make.

Thread gages. External and internal thread gages are as essential to checking threads as plug and snap gages are for checking internal and external surfaces. The thread gage used in manufacturing is a "go - no go" gage the same as the plug gage. The gaging members are plugs with precision ground plugs. The pitch diameter of the "go" plug corresponds to the lower limit of the thread while the pitch diameter of the "no go" plug corresponds to the high limit of the thread. In checking a threaded hole the "go" will enter while the "no go" will not if the thread is within the limits.

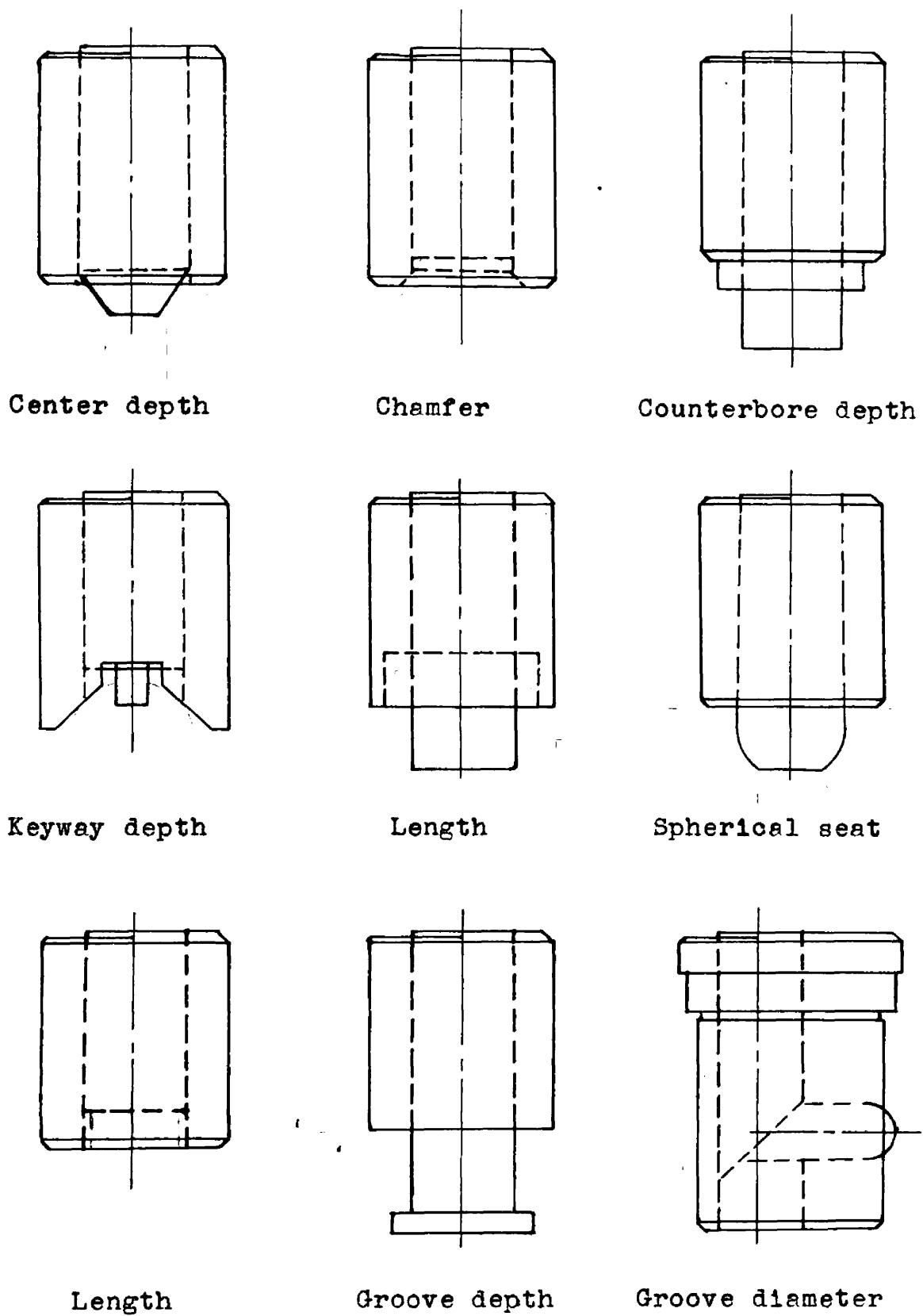


FIG.22- VARIOUS TYPES OF FLUSH PIN GAGES

The thread ring gage or external gage consists of a "go" ring, a "no go" ring and two setting master plugs. The thread ring gage is adjustable and must be set and checked to the setting plug which is similar to the "go - no go" thread plug gage.

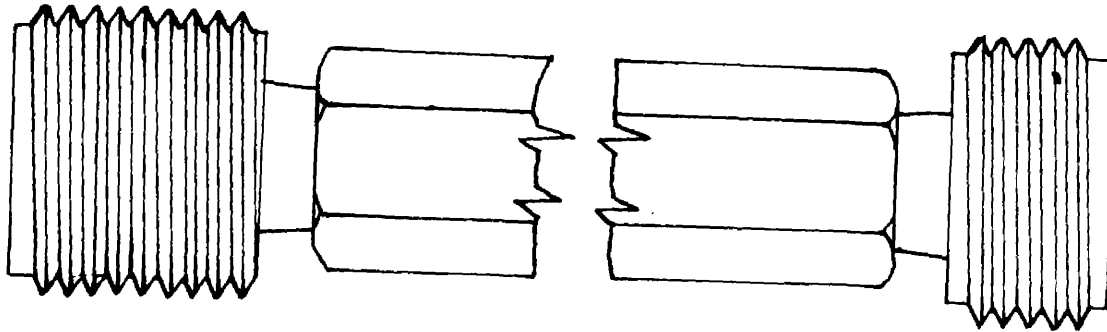
Illustrations of the thread plug gages and thread rings and setting plugs are shown in Figure 23.

Indicator gages. Indicator gages can be defined as an instrument for accurately and quickly indicating on a visual scale one or more dimensions of a work piece. A dial gage or dial indicator is a very sensitive instrument used to compare heights or distances between narrow limits. Some dials are graduated in thousandths, half thousandths, and tenths of thousandths.

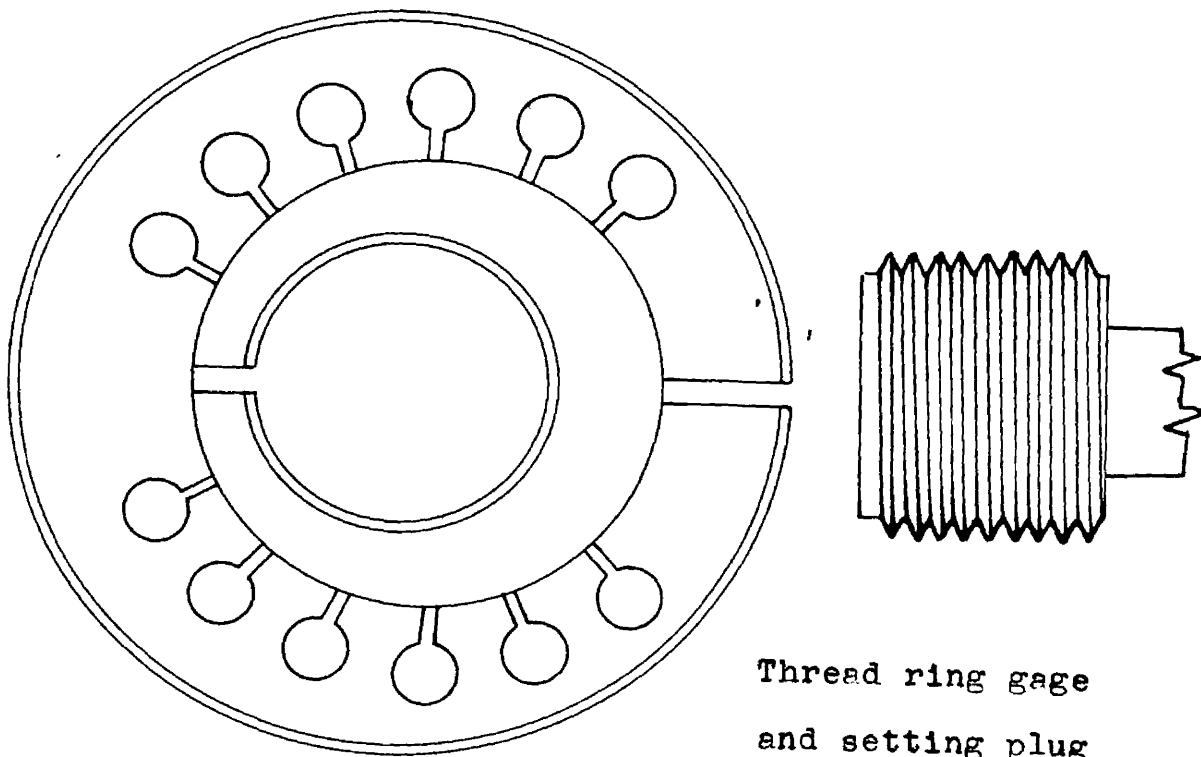
Indicator gages are only used in manufacturing when a very high degree of accuracy is required and some form of fixed gage is not sufficiently accurate. When an indicator gage is used a master part to the mean thickness or length is furnished with the gage for setup. The master part is put in the gage, the dial set at zero, and the limit read as so many thousandths plus or minus from the zero point.

An indicator gage can be used to check such things as lengths, thickness, squareness, concentricity and parallelism.

In high volume manufacturing, an indicator gage is often designed to check many dimensions on the part at one



Double end go and no go thread plug gage



Thread ring gage
and setting plug

FIG.23- THREAD GAGES

checking by having several indicators in contact with the work piece at various points.

INSPECTION GAGES

Inspection gages are those for determining the accuracy of work after it has been machined. The dimensions on a work piece are rechecked by the inspection department after the operator has completed his work. They seldom use the same gage as does the machine operator. Their gage may be identical, but it is checked very carefully and kept in fine adjustment. Usually many more adjustable and direct reading gages are used in this work. Such gages as micrometers, verniers, calipers, surface gages, gage blocks, and optical comparators can be used by the skilled inspection personnel, whereas such measuring instruments in the hand of machine operators would probably result in many dubious measurements.

In checking a hole a telescope gage and a micrometer may be used in place of the plug gage. A visual comparator may be used instead of a snap gage. External threads may be checked with pitch wires and a visual comparator instead of with a thread ring gage as the machine operator would use.

In nearly all cases the inspection gages are capable of far greater accuracy than the manufacturing gages. In cases of difference between manufacturing and inspection gages both are immediately checked to reference gages.

REFERENCE GAGES

Gages used only for determining sizes of other gages or for setting instruments are called "reference gages". These gaging instruments are used only to measure the accuracy or to adjust and set the manufacturing and inspection gages.

The reference gages are instruments which are the ultimate in measuring equipment. These gages do not read in thousandths or tenths of a thousandth, but more often are capable of measuring in millionths of an inch.

Reference gages include such instruments as gage blocks, optical flats, optical comparators, profilometer, microscope and various mechanical and electronic magnifiers.

CHAPTER III

PRODUCTION MACHINERY

The personnel of the tool engineering division must have a complete knowledge of all types of production machinery, both standard and special. In any "tool up" program it is the responsibility of the tool engineer to select or purchase the necessary machinery. To do this the function, purpose, operation, the advantages and disadvantages of each type must be taken into consideration.

Although manufacturing methods vary greatly from one industry to another, within an industry they are more or less similar. In the metal machining industry manufacturing methods are applied as nearly as possible to standard machines and their modifications. These machines naturally fit themselves by function into some form of the five basic machine groups,⁴ that is, drilling, milling, turning, grinding, and the planer-shaper group.

The work of turning, facing, boring, and threading is usually performed by the lathe group. Surface finishing other than cylindrical may be done by the milling machine or

⁴ Herbert D. Hall Foundation, The Machine Tool Primer, Newark, New Jersey, Herbert D. Hall Foundation, 1943, p. 111

the planer-shaper group. The grinder group does cylindrical, internal, and other surface grinding. The function of the drilling group is limited to drilling, reaming, tapping, counterboring and similar types of work.

In many cases a machining operation may involve principles of several groups; for example, as in gear cutting. The gear hobber employs the milling procedure, whereas the gear shaper or generator uses the reciprocating tool principle of the shaper group. However, some work is associated consistently with just one group. Turning, for example, is definitely associated with the lathe group, the production of holes with the drilling group, and the machining of flat surfaces is associated with the milling machine and shaper group. All machines of a basic type have the same functions. They differ largely in detail of construction, however.

If there is a good understanding of the principles of the basic types, then the various modifications can be easily identified. The inexperienced engineer should study the basic elementary motions of each type of machine and become thoroughly familiar with all the fundamental motion in each production machine; this will enable him to grasp the characteristics of the various types of machines. Particular attention should be noted to the motion of the cutter, the motion of the table and the relation of one to the other. A complicated mass production machine that apparently has no

resemblance to any of the so-called standard machines can be easily identified as a special form of drilling, turning, milling, grinding, or shaper type machine.

I. SELECTION OF MACHINES

The selection of the proper machine depends on many factors. This is evident when one considers that there is always a choice of several manufacturing methods for producing any piece of work. The decision as to which method to use will influence directly the selection of the machine. In many cases, the length of run and the volume of production may be such that the method may be altered to suit an available machine. The machine selected will depend on several factors, the principal ones being:

1. The type of production
2. Volume of production required
3. Manufacturing equipment available
4. Required quality of finish.

Type of manufacturing.⁵ Manufacturing can either be classed as the intermittent or the continuous type. The intermittent type is usually associated with production of short runs or in small quantities. For example, a manufacturer may produce universal joints or companion flanges of many sizes and shapes, but the production is not great enough on any one model to run full time. This type of

⁵ Halsey F. Owen, Introduction to Tool Engineering, New York: Prentice-Hall, Inc., 1948, p. 8-9

manufacturing is representative of the largest number of manufacturing establishments, all of which are rather small in size.

The continuous type of manufacturing is representative of a small group of very large establishments that produce a limited variety of parts in large quantities. Continuous manufacturing is synonymous with mass production. The best example of this type is the automotive industry. Every automobile requires certain common parts, such as propeller shafts, universal joints, steering gears and linkage, engines, wheels and transmissions. Production is so great that some factories may manufacture nothing but steering gears or propeller shafts.

It is evident that the methods used in the two types would differ in many respects, and that the methods used in one might not be satisfactory in the other. From this it might be logical to conclude that the machinery selected for a long run, one setup job would be different from that where the production was small and the changeover was frequent. However, there is some misconception as to the type of machines used in the continuous type of production. It is generally thought that a large percentage of the production machines would be special, single purpose machines. This is not necessarily the case, although it is true in a few plants. Even in the automotive industry, only a part of the production

is on a continuous type setup, while a part is of the intermittent type. Nearly all of the production machines used in the continuous type production are the same standard types as used in the intermittent production establishment, with the exception of special single purpose machines in the production line as required.

Volume of production.⁶ The volume of production will materially affect the selection of the machine to be used. When the volume of production is small, the tools and the machines are, of necessity, as simple and inexpensive as possible. As volume of production increases, more elaborate and specialized equipment may be justified. In either case, the machine must be capable of the required production rate and and able to give the desired quality. The machine must not only meet the present needs, but must be adaptable to future requirements and to quick changeover to other work pieces.

Manufacturing equipment available.⁷ Regardless of the volume of production the product must be manufactured on the equipment available, if at all possible. Many times the method or the sequence of operations must be altered to use

⁶ Halsey F. Owen, Introduction to Tool Engineering, New York: Prentice-Hall, Inc., 1948, 8-9 pp.

⁷ Ibid., p. 10

this equipment in the most economical manner. This is particularly true of the intermittent type of manufacturing. This type of general purpose machinery can be adapted to a number of different situations and a large variety of jobs, and the expense of setting up such machines is not excessive. In most cases they can produce at a satisfactory rate, although not at as high a rate as a special machine built for the specific job. If the available machine can be used a large capital investment is saved, but if the production is sufficiently high, new machines may be justified at key points in the process and the available machines used to fill in as best they can.

Quality of finish required.⁸ The quality of finish desired in a product will definitely influence the selection of the machine to be used on the individual parts. Where close tolerances and refined finishes are required, those machines capable of producing such a tolerance must be selected. If the tolerances are more liberal and the finishes are not required a much greater selection of machines is available to do the job. The finishes and tolerances are usually not held any closer than the function and finish requires, even though modern machines are capable of extreme accuracy at high rates of production.

⁸ Halsey F. Owen, Introduction to Tool Engineering, New York: Prentice-Hall, Inc., 1948, 21-22 pp.

For the engineer with a limited amount of experience, it is often difficult to select the proper machine with any degree of confidence due to the lack of knowledge of a machine's capabilities. In the chart Table I are given approximate microinch values obtainable by various machining methods and also some values for natural finishes.

FINISHES OBTAINABLE BY VARIOUS MACHINING METHODS ⁹

	MICROINCH VALUES									
MACHINE FINISH	1000	500	250	100	40	20	10	5	2	1
	very rough							very fine		
Cutting torch, Chip and Saw										
Hand Grind										
Disc Grind or File										
Lathe, Shaper, Mill										
Radial Cut Off Saw										
Bore										
Drill										
Ream										
Surface Grind										
Cylindrical Grind										
Hone or Lap										
Polish or Buff *										
Superfinish										
NATURAL FINISHES: **										
Sand Casting										
Forging										
Perm. Mold Casting										
Rolled Surfaces										
Die Casting										
Extrusions										

* Dependent on previous surface finish and grade of abrasive

** For reference only- Not called for on drawings

TABLE I

II. DRILLING MACHINES

The drilling machine, or the drill press as it is more commonly called, is probably used to greater extent than any other production tool, yet they do not always receive as much attention as their importance warrants. This is probably due to the fact that the drilled hole is seldom depended upon for the finished hole, but is more often the roughing operation for reaming, broaching, grinding, or lapping.

The drilling machine's duties, as in other types of machines, are not limited strictly to the operations its name implies. Auxiliary drilling operations include boring, counterboring, countersinking, spotfacing, reaming, tapping, trepanning, polishing, light milling, and even light surface grinding. In the machining of wood the drilling machine is used for shaping, mortising, routing, plug cutting, and sanding. It is often used for such tasks as mixing liquids.

The drilling machine consists, in all cases, of any adjustable table for holding the work, an iron frame to which is mounted a vertical rotating spindle that carries the necessary drills and mechanisms to drive the drill at varying rates of speed, and feeds that are required for any specific job.

Drill presses are classified into several general types as sensitive drilling machines, power feed, automatic multiple spindle, and radial drilling machines. Of these types the sensitive and the power feed drilling machines are probably the most used.

Sensitive type drill press. The sensitive type drill press is a light machine built in both the bench and the floor models. It is usually used for operating small twist drills at high speeds. This type is a machine on which the drill feeding is manually applied by the operator by means of a feed lever. The feed, then, is not a powerful mechanical force but it is rather an elastic pressure which is sensitive to the resistance of the work. A skilled operator has a distinct "feel" of the cutting action of the drill and feeds the drill into the work accordingly. This type is not necessarily operated by hand; a foot pedal arrangement is sometimes used to feed the drill, the advantage of such an arrangement being that both the operator's hands are free to perform some useful work.

Small diameter drills often require sensitive feeds to avoid drill breakage. The small drill cannot stand much pressure and must be eased along by the "feel" of the operator. Such drills also require intermittent withdrawal to avoid chips packing into the flutes and thus prevent drill

breakage. Drilled holes of different depths can usually be drilled easier on a sensitive drill press than on a power feed where some special power feed stop arrangement or constant operator attention may be required.

Although sensitive drill presses are usually thought of in connection with small drills, the sensitive type of drill feed may be found on almost any type of drill press. These machines range in size from extremely small drill capacity to approximately one inch drill size. Holes as small as .005 inches diameter may be drilled with such a machine. The spindle is driven at a high rate of speed in order to create a sufficient cutting speed. They can be used in straight line production in any number of combinations, as auxiliary tools to augment some other machine, or for special setups to eliminate costly special purpose machines.

Another of the features of the small sensitive drill press is portability. It can be moved instantly to any part of the plant or shop where it will be most effective. In many plants making a wide variety of products, it enables a different layout or setup to be made for any sequence of operations. It is possible, in many cases, to set up one of these portable machines alongside another machine on which the cutting operation is slow. The operator may then perform one or more operations on the hand feed machine while waiting for the completion of a power feed cut on a heavier machine.

To suit production needs, both the bench and column types of sensitive drill press are often arranged in gangs of two or more.

Power feed drill press. A power feed drill press is one in which the machine itself provides the drill pressure. This mechanism may be a feed screw, cam feed, pneumatic feed, hydraulic feed, or almost any kind of mechanism for transmitting force to the drill. Power feed drill presses invariably are capable of being operated manually as sensitive drill presses. This type of drilling machine is really a double purpose machine because it can be used both as a sensitive or a power feed machine.

The above statement might bring up the entirely reasonable question -- why should there be sensitive type drill presses; why not have only power feed machines and use them manually when the machining conditions demand? The power feed drill presses are often used in this manner. However, there is an appreciable difference in the cost between the two types of machines. If a machine is expected to be used almost entirely as a sensitive feed, it would be an economically sound idea to purchase the sensitive type for the purpose.

The power feed machine is used for medium duty and for general purpose drilling. It is the type of machine most commonly used in all machine shops and is used for many kinds

of drilling operations. It is the basic machine from which all of the other drill presses have been developed for specialized work.

In Figure 24 is shown such a drill press along with the type of drill head and multiple station jig that is often attached to the power feed drill press to convert it to a special purpose machine.

When required the power feed drill press can be purchased with several spindles in one machine. This machine is called a multiple spindle gang drill. In the gang drill the spindles are arranged in a straight line and usually it has a long table which extends the length of the machine. An example of the gang drill press is illustrated in Figure 25.

Multiple drill press. A multiple drill press is simply a machine capable of drilling two or more holes at the same time. This type should not be confused with the multiple spindle gang drill. There is a distinct difference between the gang drill and the multiple drill. This difference lies in the arrangement of the spindles.

There are several types of multiple drill presses, differing from each other in the degree of flexibility. Some multiple drill machines are single purpose machines built for the production of a certain part with a set pattern of holes and are not easily adaptable to another job.

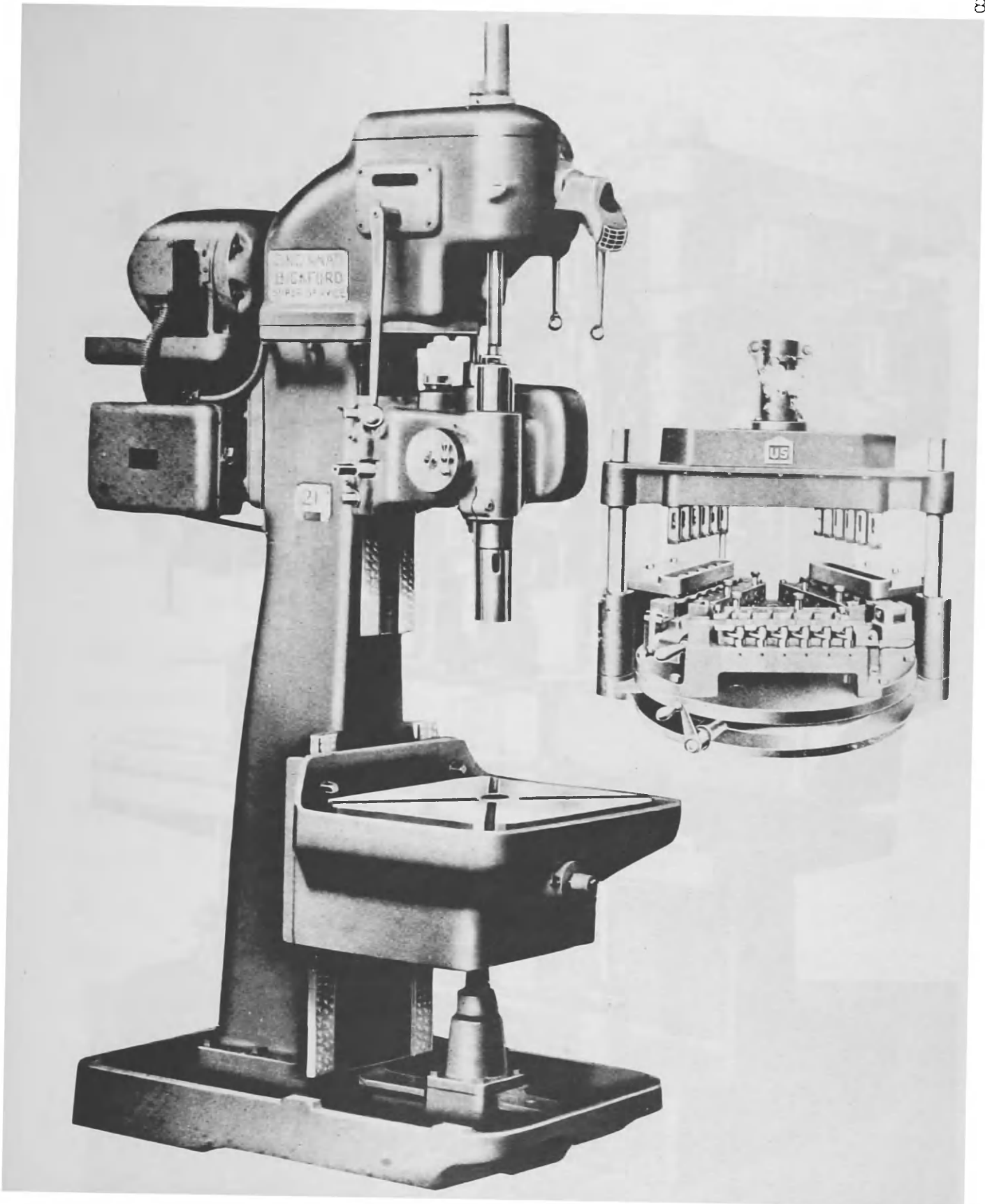


FIG. 24-A SINGLE SPINDLE POWER FEED DRILL PRESS WITH A TYPICAL
MULTIPLE SPINDLE HEAD AND INDEXING JIG OFTEN USED WITH THIS
MACHINE

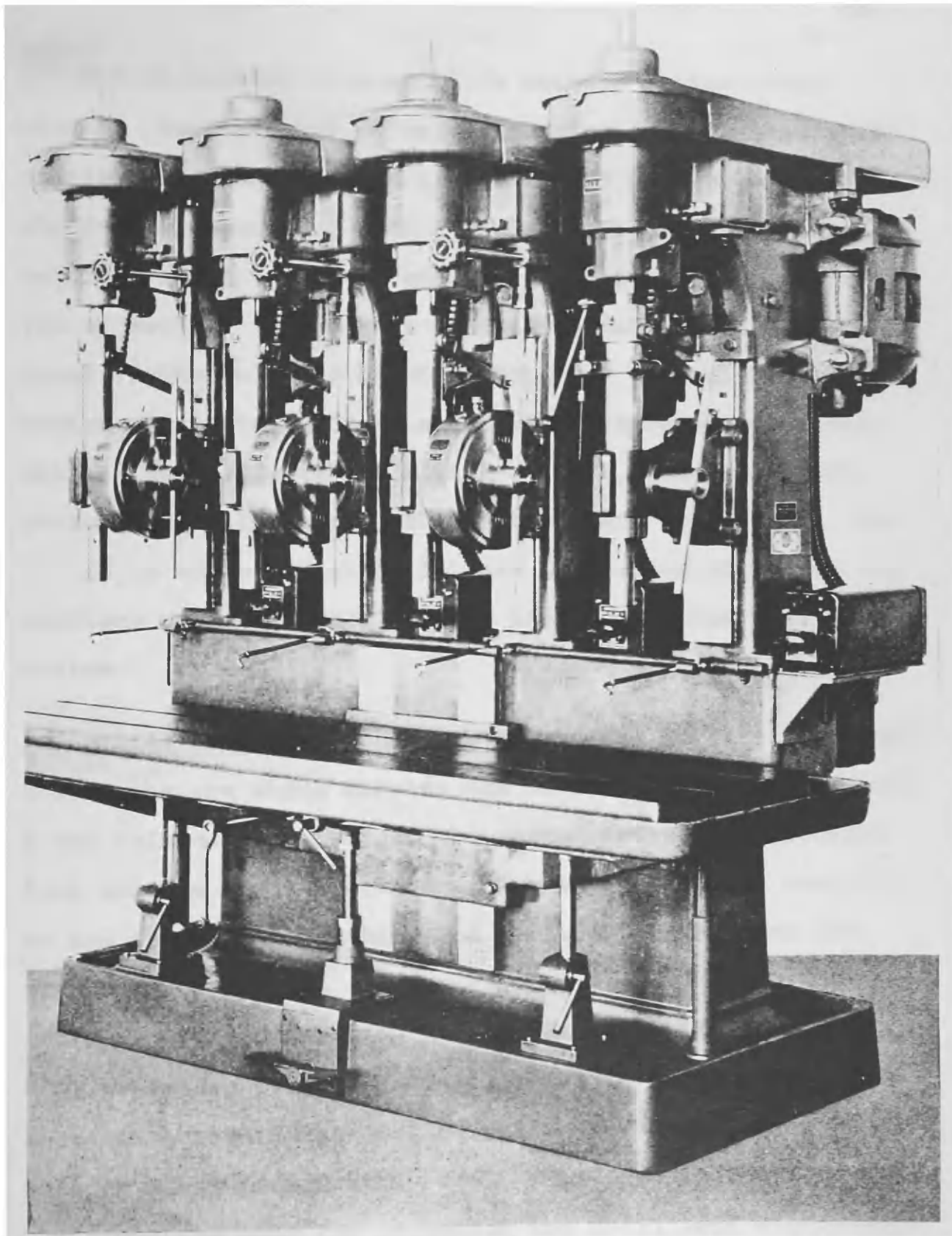


FIG.25-A MULTIPLE SPINDLE POWER FEED DRILL PRESS

The adjustable type multiple machine is the other extreme. In this type of multiple spindle arrangement, the spindles are arranged in a circular head with provisions made for adjustment of each spindle horizontally to any position within the range of the respective spindles. This type of machine is somewhat special in nature and is used almost exclusively for jobbing shop work or semi-high production industries. These machines all have spindles with vertical tool adjustment in each spindle, and the number, spacing, and relationship to the table are to suit the job.

It is common practice in mass production plants to use auxiliary multiple spindle heads instead of this type of machine.

Radial drilling machines. The radial drill is so named because the arm which carries the head of the machine swings on the column. The head of the radial drill is adjustable along the arm and the arm can swing to any desired position. The arm is also adjustable in a vertical position on the column.

This type of drilling machine is extremely useful when it is necessary to drill several holes in a large or heavy piece, such as a heavy casting which cannot be lifted to a table or moved around with ease. With this type of machine provisions are made for adjusting the drill head with respect

to the work, which is much easier than to move a heavy work piece. The construction of this machine enables it to drill pieces which, due to their size, cannot be drilled in any other machine. This machine is used more frequently in heavy industries, tool rooms, and on low production items than in the small production shop.

It might be interesting to note that this type is classified as to size by the length of the arm.

III. TURNING MACHINES

The metal cutting turning machine or lathe is the oldest, most adaptable and most widely used of all standard machines. In the average machine shop there are usually more turning machines or lathes than any other type of metal cutting machine with the possible exception of the drill press.

In this type of machine, the work piece is revolved or turned by power and the cutting tool is brought to bear against it removing metal in the form of chips.

From the lathe, various modifications have been developed to meet the needs of the manufacturing industries. Of the turning machines used in the production shop the most common in use are the engine lathe, turret lathe, automatic screw machine, multi-spindle automatic bar machine, the automatic chucker, and the multi-spindle vertical lathe.

Engine lathe. In the engine lathe, the work is held between centers or in a chuck which rotates against a fixed tool to form a cylindrical section.

By the use of attachments and special cutting tools, the machine will form tapers, thread holes with a tap, knurl or imprint variegated patterns in the surface of the work, and cut off a completed piece from a bar of metal. The

single point type of cutting tool is usually employed for the operation of turning, boring, facing, and threading, while standard twist drills are used for drilling holes in the work done on the lathe. Standard reamers are used to ream the holes smoother. For drilling and reaming, however, unlike the way these operations are performed on the drill press, it is the work that is revolved and the tool is fed into it but not revolved. Besides the basic operations of turning, facing, drilling, reaming, and threading, it can also do milling, shaping, gear cutting, flute cutting and tool grinding. For continued use, however, best results can be obtained only by use of a machine for the purpose for which it was intended.

One thing is common to all these operations on the engine lathe. In each and every case, the engine lathe operator must direct the action of the tool throughout the job. There are other forms of lathe or metal cutting machines that vary in their ability to perform work automatically but these will be discussed later. A typical modern engine lathe is shown in Figure 26.

Any engine lathe would have these principal parts: the bed, headstock, tailstock and the carriage.

The bed of the lathe is the essential framework of the machine, onto which is mounted the headstock, the tailstock,

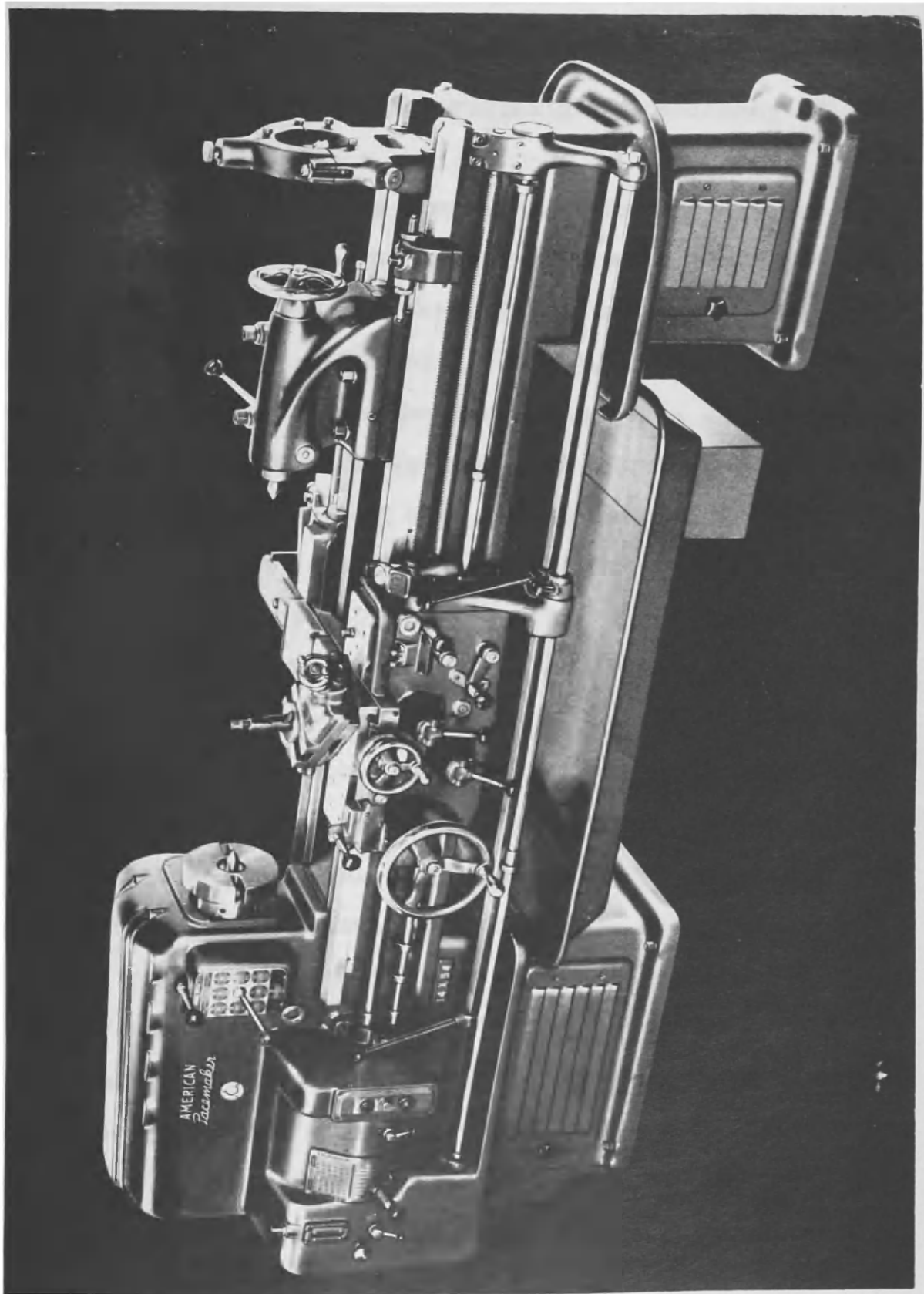


FIG. 26-A MODERN PRODUCTION TYPE ENGINE LATHE

and the carriage. It supports the tool and the work and contributes to the strength, rigidity and accuracy of the machine.

The headstock is the source of power for the work and for the tool. Through the center of the headstock is the main spindle to which the workholding unit, such as centers, chuck or collet, is attached. The headstock also contains gears or pulleys to give the desired spindle speeds and to drive shafts to the carriage and lead screws. Many of the large and powerful lathes have geared headstocks which are equipped for a wide speed range. A typical lathe may have 24 speed changes from 30 to 1200 RPM.

The chief function of the tailstock is to contain the dead center which supports one end of the work. The tailstock is adjustable along the ways of the machine and can be locked in any position desired. The tailstock can be used to support and drive cutting tools such as drills, reamers, counterbores, countersinks and taps into the work.

The carriage support moves and controls the tool. It is made up of several parts: the apron, saddle, compound rest, and the tool post. The apron is the vertical portion of the carriage and contains controls for tool movements. The saddle bridges the ways and supports the apron, and also contains the cross feed mechanism and supports the cross slide and the compound rest.

The compound rest is constructed similar to the cross slide but has a movement somewhat shorter and is adjustable to feed at any desired angle to the work. On top of the compound slide is mounted the tool post.

The size of the lathe is classified by the swing in inches and the length of the bed in inches. The swing is the maximum diameter of work which will clear the ways and the maximum diameter of work which will swing between the centers. The length of the bed is the over-all length of the ways or bed, and not the length of work which the machine will support between centers.

As can be seen the engine lathe is a very versatile production machine. Listed below are typical operations performed:

Turning	Thread cutting
Facing	Spring winding
Drilling	Polishing
Reaming	Spinning
Boring	Milling
Counterboring	Grinding
Countersinking	Knurling

Turret lathe. The turret lathe is a modification of the engine lathe. It takes its name from the fact that the tailstock of the engine lathe is replaced by a multiple

faced rotating tool holder, called a turret, which can be indexed to various positions about an upright pin or axis. The cross slide tool post is replaced by a square turret giving four working tools instead of the usual one. The rear end of the cross slide is adaptable to still another tool post if desired.

The operator controls all movements of the tool either by hand or power, but the tools mounted on the turret are so set as to bring each to a fixed stop to size the work without the high degree of concentration of operation attention as is required in operating the turret lathe. With the turret lathe, a number of tools can be working on the work piece at the same time.

The work can be held in a chuck on the end of the headstock spindle and revolved just as it is on the engine lathe. Also face plate fixtures can be attached to the spindle to chuck castings or forgings. Bar stock of any shape can be fed through the spindle and held in a collet. After the bar has been machined to the desired shape it is cut off and the bar is again fed out to the stop and the operation can be repeated.

This type of machine is an excellent example of a general-purpose machine, readily adaptable for production setups. It can perform faster and more accurately all the work that can be done on the engine lathe, and with less

skill required of the operator. Once the tooling setup is completed, it will reproduce parts accurately and at a rapid rate. Changing the tool setup, which requires comparatively little time, permits it to machine an entirely different piece of work. A typical turret lathe is shown in Figure 27.

Automatic screw machine.¹⁰ The single spindle automatic screw machine can best be described as a modified small automatic bar turret lathe. The machine differs from the turret lathe in that the tool holding turret revolves about on a horizontal pivot pin instead of about on a vertical axis.

The work is made from long rod or bar stock which is fed into the machine through a collet. Small pieces, such as capscrews, bolts, pins, or plugs, are completely machined and cut off automatically. The automatic feed of the bar stock makes the machine cycle continuous. As soon as one piece has been completed and cut off, the bar is fed forward automatically to the stop and the next part is started. This operation continues almost unattended by the operator until the bar is used up.

Work done by this automatic is usually rather small, in most cases one inch in diameter or less and approximately two and one-half inches in length being the maximum. Special

¹⁰ Herbert D. Hall Foundation, The Machine Tool Primer, New Jersey: Herbert D. Hall Foundation, 1943, p. 137, 174, 175

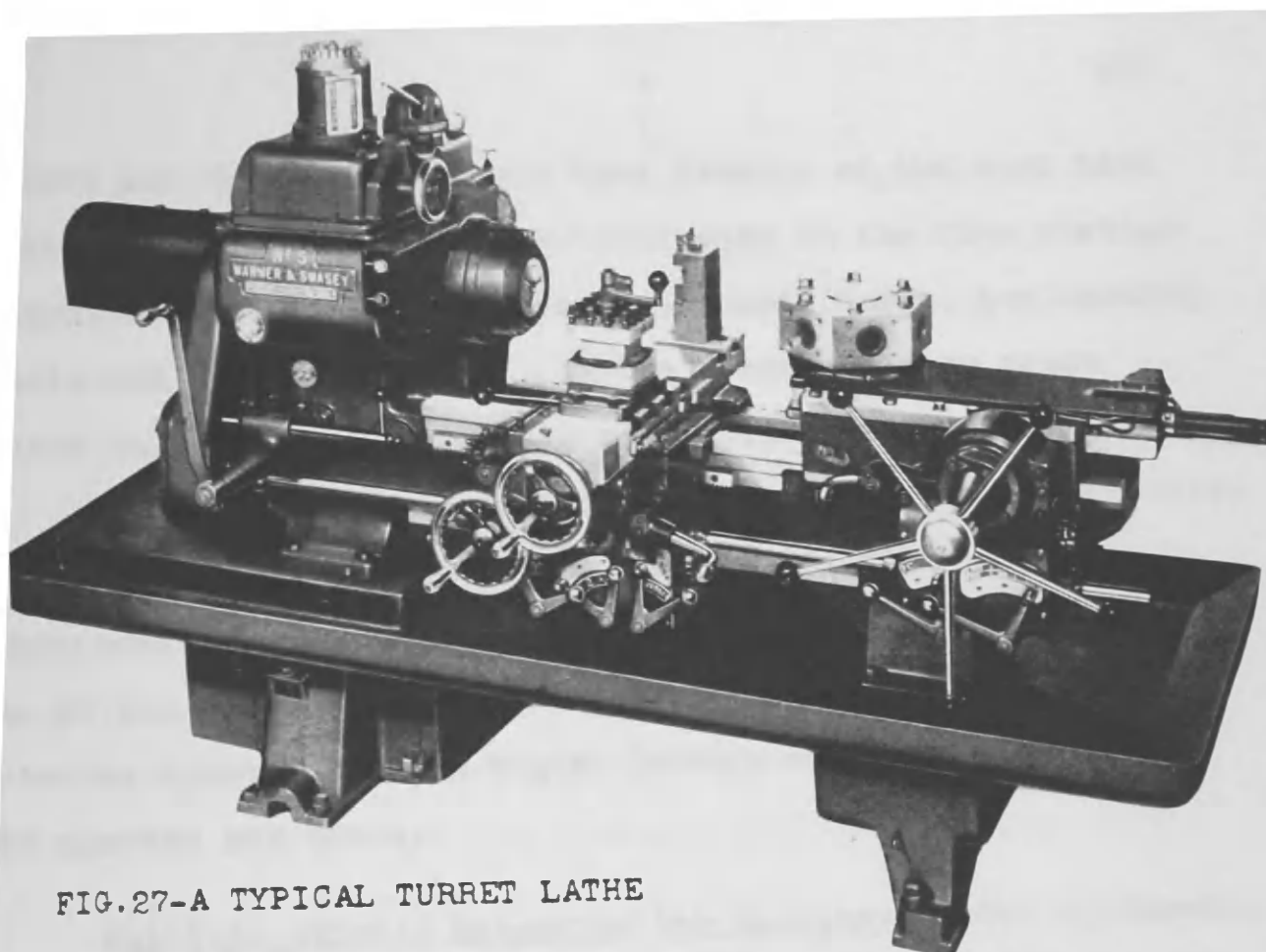


FIG.27-A TYPICAL TURRET LATHE

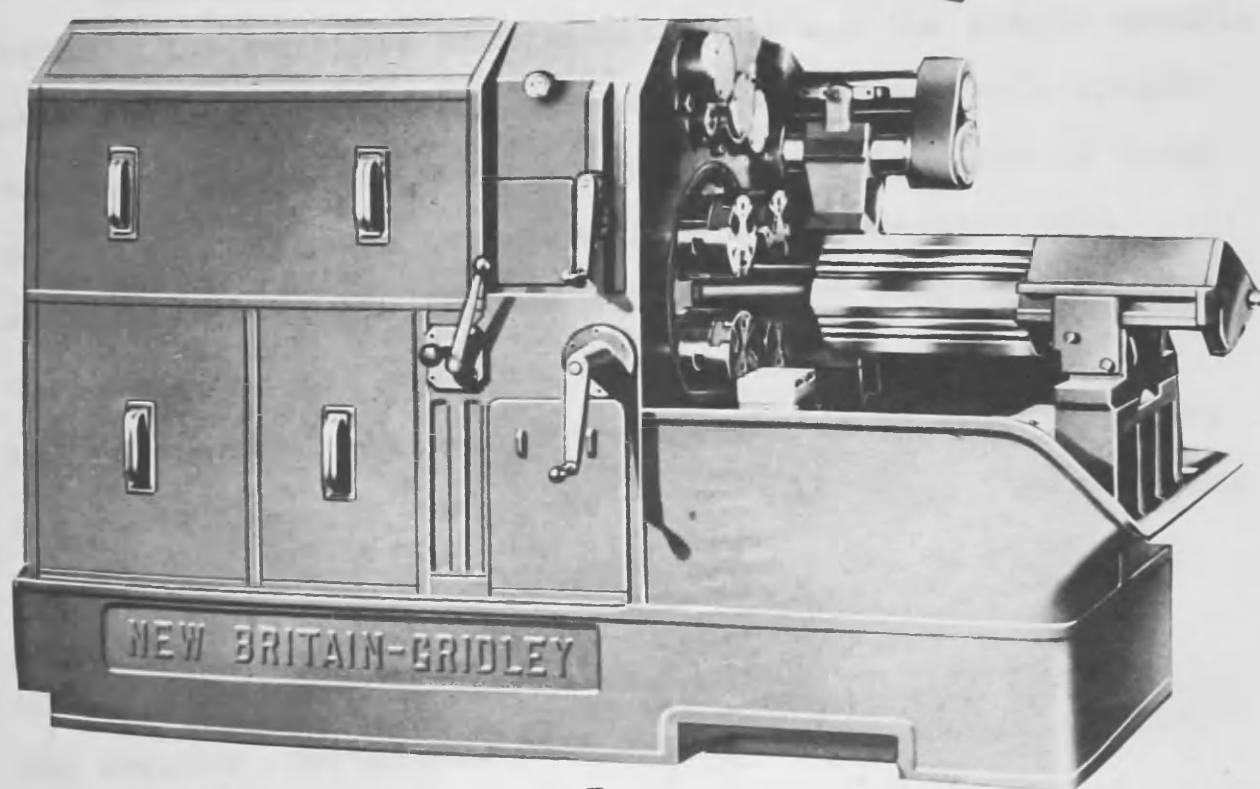


FIG.28-A MULTIPLE SPINDLE
AUTOMATIC CHUCKING MACHINE

screws and headed pins are a good example of the work best suited to this machine. The tools used in the five station turret consist of drills, reamers, counterbores, box turning tools and threading tools. In the front and rear cross slide holders, form tools are almost invariably used.

Small parts can be produced in this machine in a fraction of the time that would be required on most other turning machines. An average machine cycle may be 3 to 10 seconds, or at the rate of 360 to 1200 pieces per hour. To do a similar operation on an engine lathe would take from 3 to 20 minutes per piece.

Multiple spindle automatic bar machine.¹¹ The difference between the multiple spindle automatic and the single spindle automatic is that in the former the different tools operate simultaneously. At every station or spindle, work is being performed, although the operations are successive ones whereas in a single spindle automatic the tools follow in succession to the one work station. Many more operations can be combined and production speeded up because more than one piece is being worked on at the same time. The multiple spindle automatic may have four, five, six, or eight work spindles.

¹¹ Herbert D. Hall Foundation, The Machine Tool Primer, New Jersey: Herbert D. Hall Foundation, 1943. p. 173-181

There are several types of automatics but all have certain fundamental principles of operation in common. In this fully automatic bar turning machine, the bars are loaded into the hollow spindles or feed tubes and held into position by the collet. The bars are worked on simultaneously by the various tools. The operations are not duplicated at each spindle, instead they are progressive. The tools in one station work on the bar; when they have performed their function all the spindles index and the next station of tools do their work, until the bar has indexed completely around the machine and has been cut off as a finished part. This means one finished piece per index.

The choice of the number of spindle machine to use would depend on the simplicity or complexity of the operations involved. If there are a few operations a four or five spindle machine would be sufficient, but if the part were complex and involved many operations, the six or eight spindle machine may be required. Of course, the quantity of pieces required would have to be sufficient to justify setting up one of these complicated machines.

Chuckers. The multiple spindle chucking machine or chucker as it is called is quite similar to the automatic except it is semi-automatic in operation. In these machines, the various operations are performed on pieces like castings or forgings instead of on bar stock. Workholding chucks are

provided at the end of the spindle. Each time the main spindle indexes, a piece is released and it must be removed and replaced with another piece. A multiple spindle chucking machine is shown in Figure 28.

Vertical turret lathe. Of the vertical turret lathes used in production, the two most common are the single spindle and the multiple spindle types. The single spindle turret is exactly what its name implies. It is exactly like the turret lathe except that the center line of the work spindle is in a vertical position. Such a machine is shown in Figure 29. From this picture the principal parts, such as the work spindle, turret, and cross slides, can be easily distinguished.

This type of machine is not meant for high production, but is a rather low production machine. A good example of the type of work this machine can perform would be some kind of large housing or transmission case which should be rotated to face, turn, or bore various diameters in line. Such a part could hardly be chucked on a regular lathe faceplate, not only because it would be bulky, but the overhang would probably make accurate machining impossible.

In the single spindle vertical, the work piece could be hoisted onto the table, located and clamped there and machined. In this case all the weight would be down on the spindle and not affect the accuracy of the machining.

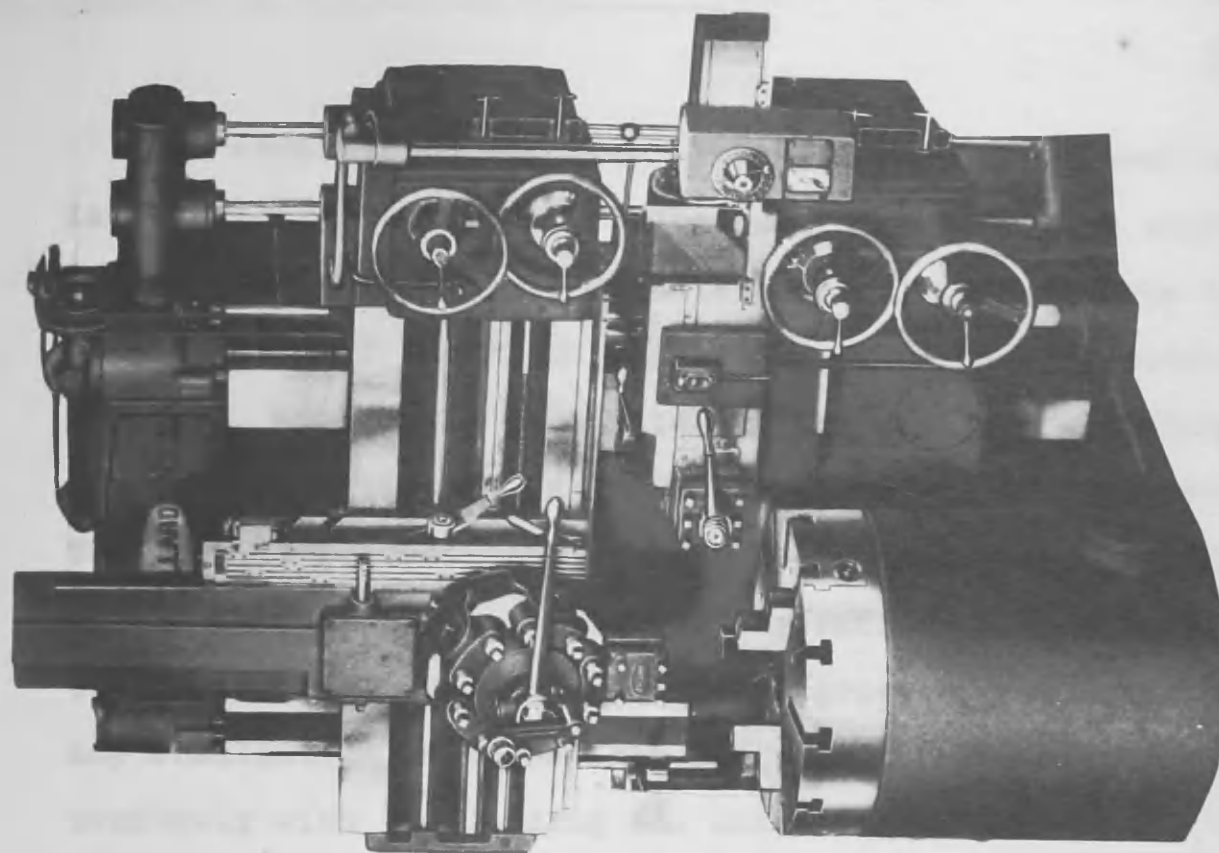


FIG. 29-A VERTICAL TURRET LATHE

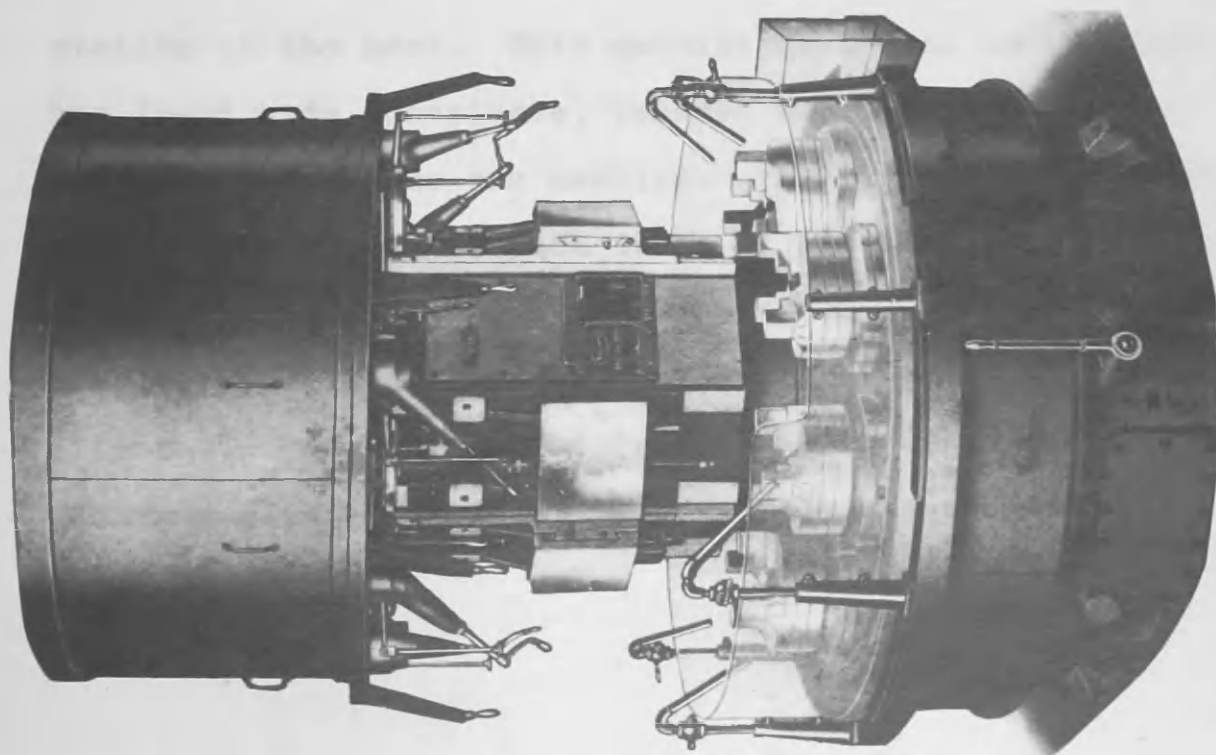


FIG. 30-A MULTIPLE SPINDLE VERTICAL
TURRET LATHE

In contrast to the single spindle vertical turret lathe is the multiple spindle mass production counterpart shown in Figure 30. The multiple spindle vertical turret lathe is a good example of the high production, high accuracy modern machine. Within the capacities of the machine, all classes of castings, forgings, and cut bar stock can be machined. The work is secured into a chuck or special holding fixture on the spindle of the machine. Operations may include boring, turning, facing, threading, grooving, drilling, or any combination of operations performed in sequence simultaneously with the loading and unloading of the work. This produces a completely finished piece in the time consumed by the longest single operation, plus a few seconds required for the indexing of the carrier with its spindles from one station to the next. This machine used with double indexing has found wide acceptance, because two chuckings can be accomplished on the one machine. This produces a finished piece, both sides, at each index of the machine. This type of machine is made in various sizes and numbers of spindles. The larger will swing work up to approximately 24 inches in diameter. The number of spindles varies from 6 to 16 and machines may be single or twin spindle arrangement.

IV. MILLING MACHINES

Milling is a machining process in which cutters provided with a number of teeth are rotated rapidly while a work piece is fed under the cutter slowly. Thus, a surface can be machined much faster than with a single point tool and often with a better finish. The milling machine can produce either flat or formed surfaces. It provides one of the fastest means of producing surfaces on a large number of parts. For high production work, milling has almost entirely displaced the planer and the shaper. The miller is also flexible enough to do odd jobs such as tool room work.

The extreme versatility of the milling will be more fully realized from the list of jobs it can perform. With very little in the way of extra equipment, the miller can produce or perform the following:

Milling cutters	Flat surfaces
Splines	Convex surfaces
Keyways	Bevel gears
T-slots	Contours
Racks	Spur gears
Dovetails	Dies
Twist drills	Cams

Straddle mill	Face surfaces
Tangs	Concave surfaces
Grooves	Bolt heads

The size of a milling machine may be designated by the dimensions of the table, in inches, or the manufacturer number. The horsepower of the driving motor is also another measure of capacity.

There are many classes and types of milling machines from the small and simple hand operated type to the completely automatic type. In millers there are many varieties which would be very difficult to catalog properly; therefore, only the most important production types will be discussed. To satisfy the variety of requirements, milling machines are made in a wide range of types and sizes. The most common are:

- Hand mill
- Manufacturing mill
- Plain horizontal
- Plain vertical
- Special types of millers

Hand mills. The simplest of all milling machines is the floor or bench type hand mill. This machine is relatively small and has hand operation of both the knee and the table. The head has a vertical movement by means of the one handle

while the other handle controls the table movement. The same handle can be applied for the cross movement of the table on the saddle and the vertical movement of the knee.

The simple hand miller has a wide field and can handle a wide variety of work. The lever operated table makes it possible to take short milling cuts as fast as the pieces can be clamped and the lever moved.

A few examples of the type of work for which this machine could be used would be as follows:

Milling slots

Milling woodruff keyways

Straddle milling

Milling chamfers

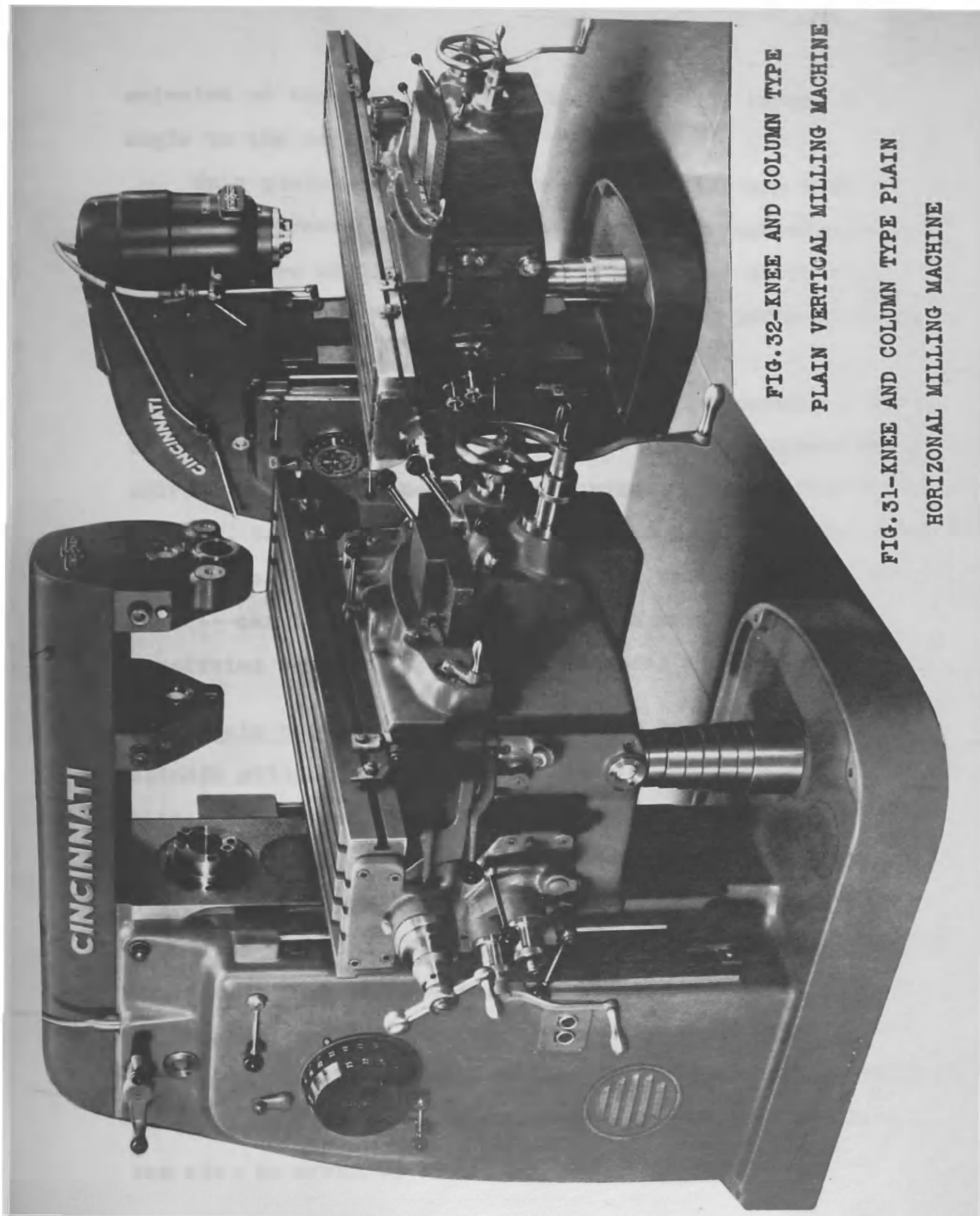
Milling oil grooves

Manufacturing type. As the name implies, the manufacturing type miller is widely used in mass production shops. This is a horizontal spindle miller with a fixed bed. The table is mounted on a solid bed, much like a planer table, and is fed back and forth under the cutter spindle either by the action of a power driven screw or by hydraulic cylinder. Having a fixed bed, the vertical adjustment is secured by moving the head that carries the milling spindle. The table is adjustable both up and down, and in and out perpendicular to the table.

The work is clamped to the table generally by a work-holding fixture or vises especially designed for rapid location and clamping. For more effective use of the machine in high production shops, two sets of fixtures are employed, one on each end of the table. During the time that one piece is being milled, the operator can be removing the finished part from the other fixture and reloading with an unfinished part.

Plain horizontal mill. The plain horizontal mill is also known as the knee and column mill. It differs from the manufacturing type in that not only is it possible to traverse the table back and forth by power, but also it is possible to feed the table in and out parallel to the spindle axis, and also to feed the table up and down vertically. The spindle is in a fixed position. The knee, that is the bracket that supports the saddle and the table, may be raised or lowered on the column which is true of all column and knee type mills. The various slides and operating handles can be seen in Figure 31 which shows a dial type plain milling machine.

Without close examination the plain and universal mills might be mistaken one for the other. The only difference between the plain and the universal mill is that the table of the universal has an additional movement. It can be



**FIG. 31-KNEE AND COLUMN TYPE PLAIN
VERTICAL MILLING MACHINE**

**FIG. 32-KNEE AND COLUMN TYPE
HORIZONTAL MILLING MACHINE**

swiveled on the saddle so that the table will travel at an angle to the column.

On a plain knee and column type machine, any type of straight traverse milling can be performed, such as slab milling, form milling, and straddle milling. It is also possible to mill a vertical pad or slot in a piece of work with an end milling cutter.

With special attachments on the milling machine a host of toolmaking jobs can be performed. Milling cutters themselves are made on the milling machine. So are twist drills, reamers, taps, dies, broaches, and even gears. In fact, any kind of gear -- straight spur, helical tooth, bevel or worm gear -- can be cut on a mill, although when production quantities warrant, special gear cutting machines are used.

Plain vertical miller. There are two types of vertical spindle milling machines: one with a fixed bed and the other with a knee and column. The knee and column type of machine is by far the most common type in use; therefore, the discussion will be limited to this type. This machine is much like the plain mill, except the spindle is in a vertical position. The feed movements of the table are the same as in the horizontal as can be seen in Figure 32 in which the dial type knee and column vertical mill is shown. In addition to the knee, saddle and table movements the vertical head can also be moved up and down.

Vertical mills are, in general, chiefly used for end milling operations. Certain operations like milling grooves, and slots, dies and mold making, and other cavity work lend themselves to the vertical spindle machine. If an end mill is inserted in the spindle nose of a horizontal miller, it is difficult to mill surfaces, because the cutter operates on the rear side of the work where it cannot be readily seen from the operator's position in front of the machine. However, in the vertical spindle machine, the working surface is facing upward rather than inward, giving easier visibility for working and gaging.

Special types of mills. There is no limit to the kinds of special milling machines that can be designed for performing specific milling operations. Listed below are some of the machines used in industry which are modifications of the milling machine and are special or semi-special in nature:

Die sinking machines	Hobbers
Thread mills	Planer mills
Rotary table mills	Profilers
Drum type mills	Gear hobbers
Duplex mills	Gear cutters

Other highly specialized kinds of milling machines might be mentioned, such as planetary and roto mills, which are especially designed for only one type of work.

One of these special types of mills is shown in Figure 33. This machine is a thread mill. In the picture Figure 34 can be clearly seen exactly how the cutter and the work come in contact. The cutter in the rear revolves rapidly while the work held in the collet and supported on the outboard end by a center, revolves very slowly. The milling cutter or hob cuts the required tooth form into the work. Since the hob teeth have no lead as say have taps, the cutter advances along the work one lead of the thread each one revolution of the work. Since the hob has many teeth and is a little longer than the work, the work only revolves one and a fraction turns to complete the thread milling operation. This is only one of the many machines which use the milling action to do a required cutting operation.

V. GRINDING MACHINES

The operations done with the grinder are fundamentally the same as for many of the machines previously described, except that a finer or smoother finish can be produced. With a grinder, for example, nearly all the operations can be done that can be accomplished on the lathe, except that the high speed grinding wheel replaces the single point lathe tool. Fundamentally the cylindrical grinder does the same operation as the lathe during turning. Internal grinding and face grinding may be compared to boring and facing on the lathe. Thread grinding is a similar operation to single point threading.

On flat surfaces, the grinder refines the surface as planer or milling machine would rough machine it. Cup wheels correspond to the end mill cutter. Almost all metal cutting operations except drilling holes can be duplicated by grinding.

Grinding was originally only a finishing operation, but it has developed to the point where it is competing with other machining operations in the rough machining of surfaces. For example, in many cases the surface grinder is replacing the planer or shaper; grinding with a crushed wheel from the solid may replace lathe operations; and thread grinding from

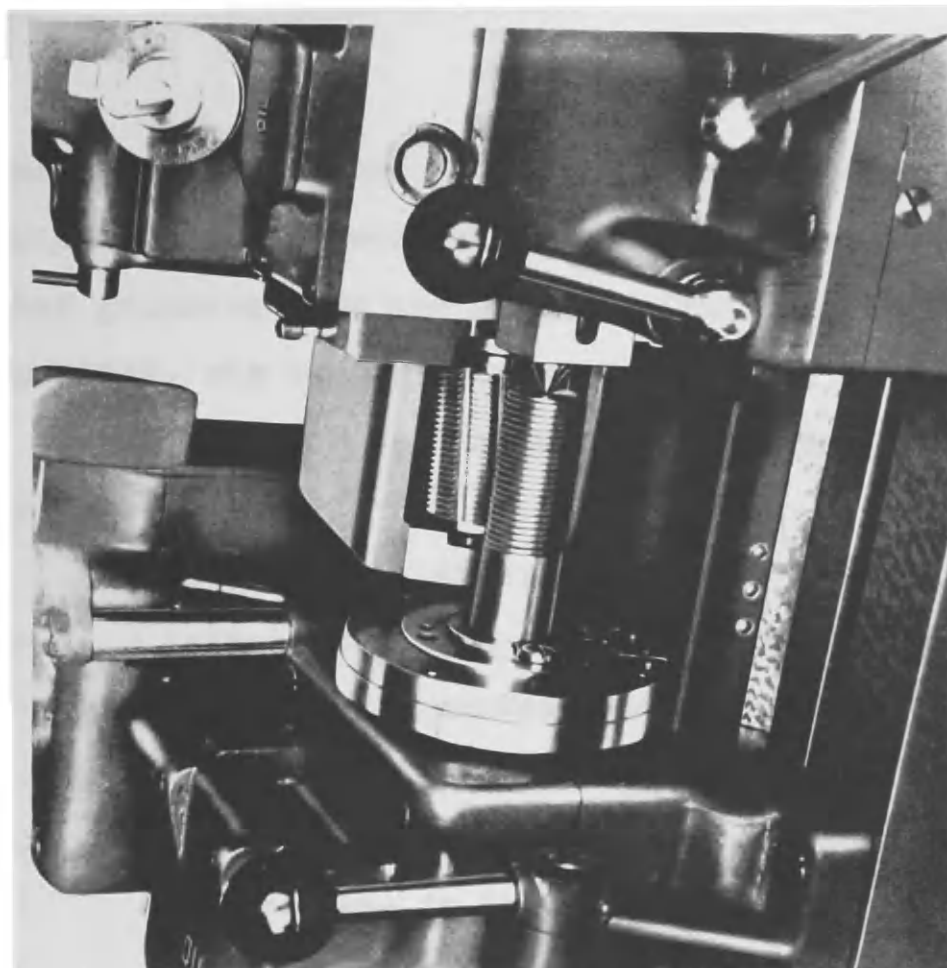


FIG. 34—SHOWING RELATION OF CUTTER
AND WORK IN THE THREAD MILL

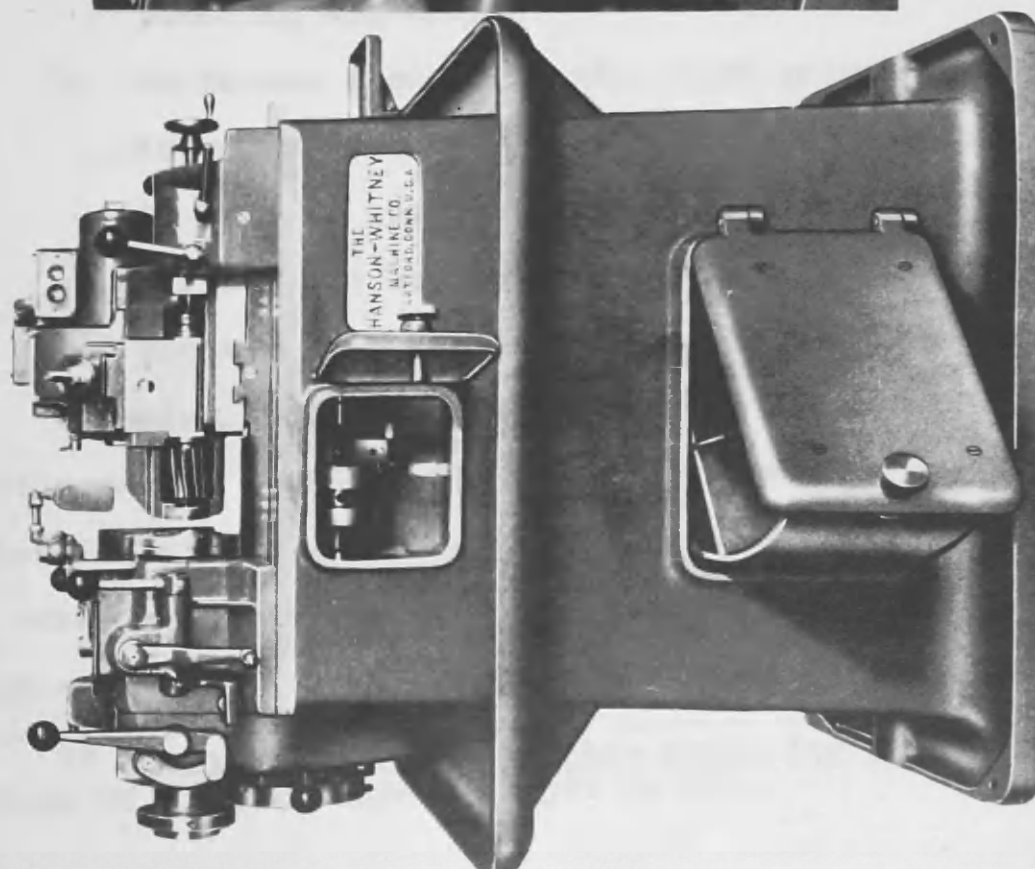


FIG. 33-A THREAD MILLING MACHINE

the solid may replace the die or single point threading tool. Grinding is different from any other machining operation in that grinding runs the gamut of finishes from the roughest possible, say snag grinding of castings, to superfinishing.

There are three functions which are basic to all grinding operations:¹²

1. To generate size; that is, to remove sufficient stock to finish the part into the desired tolerance.
2. To generate surface; that is, to produce a good finish or luster on the part. Grinding often does not involve the holding of close tolerances, but in many cases it is used only to produce a luster or pleasing appearance.
3. To remove stock. In this case grinding may be used to remove stock or true up a surface. Snag grinding is only to remove undesirable stock, while another surface may be ground to true up for locating with not too much regard for finish or tolerance.

Grinding ordinarily is used to remove comparatively little metal, usually .010 to .020 inches for most work. Its chief object is to remove irregularities and tool marks left by other machining methods and to produce a fine finish with high accuracy. Grinding can produce surfaces of 0.5 microinches

¹² Charles R. Hines, Machine Tools For Engineers, New York: McGraw-Hill Book Company, 1950. p. 201

finish and accuracy within 5 millionths (.000005 in.). As compared to other machining operations, grinding is a very high speed operation. The grinding wheel travels at a speed of 5,000 to 10,000 surface feet per minute.

There are probably more different types of grinding machines than any other one type of metal cutting machine. In many cases, it is almost impossible to draw a clear line between many of the different types of grinders. There will be no attempt to establish standards of classification, but to promote an understanding of the common production machines and their functions.

The most common types of production grinders are:

Cylindrical

Centerless

Surface

Internal

Thread

Cylindrical grinder. The cylindrical grinder is the most common grinder used on production. Work that is round in cross section is usually ground on a cylindrical grinder. This type is used to grind such pieces as plain cylinders, contoured cylinders, tapers, faces, shoulders, fillets, and even cams and crankshafts.

The cylindrical grinder is shown in Figure 35. As in any other machine, there are certain essential movements



FIG. 35-A CYLINDRICAL GRINDER

involved. In the cylindrical grinder, the work must revolve, the grinding wheel must revolve, and the work must pass the wheel, or the wheel must pass the work. Also there must be some method of feeding the wheel into the work, or the work into the wheel.

If the work piece is long, it is mounted between centers and driven by a dog much as in an engine lathe. Short work, castings or forgings can be mounted on a faceplate or held in a chuck or suitable fixture. Provision is made to traverse the work back and forth in front of the wheel. This movement is accomplished manually or automatically by dogs which cause the table to reverse at the end of each stroke. In this type of operation the work is mounted between centers in the headstock and tailstock which are mounted on a table which reciprocates in much the same manner as the milling machine table travels. A separate motor is provided in the headstock to rotate the work.

The grinding wheel is mounted on a spindle and driven by another motor through belts so that it is isolated from vibrations of any kind, particularly from the drive motor. The whole motor and wheel spindle assembly is carried on a slide, which is adjustable in and out to suit the diameter of the work. The infeed of the wheel to the work is done automatically on many machines, so that a predetermined diameter can be reached and repeated without hand adjustment.

Even compensation for grinding wheel wear is built into many machines.

As with many machines of the turning and milling machine groups, the cylindrical grinder can be set up with a completely automatic cycle so that one operator can tend several machines. Automatic sizing is an important feature in this type of arrangement. After one part has been completed the wheel retracts and is redressed as required to hold size. Continuously reading gages are often used by this type of grinder. In this arrangement dial gages are supported on a holder above the work and near the wheel. This gage is set up with a zero. When the work is being ground the gage has contact with the work and the amount of stock to be removed can be read instantly without stopping the work. When the dial reads zero the work is the size of the master, thus to the proper size.

The grinding wheel is dressed with a mounted diamond. In the cases where two to five wheels are used for the purpose of producing several stepped or contoured sections in the part at the same time, the diamond dresser may also be used. If a contour is desired the wheel can be crushed or dressed with a hardened steel roll of the desired shape.

The speed of the grinding wheel should be from 5500 to 6500 surface feet per minute, or a shop man likes to remember it slightly over one mile a minute. The speed of the work

is usually from 30 to 100 surface feet per minute depending on the hardness of the material. In general, the work speed is reduced for the harder steels.

The modern cylindrical grinder is a heavy, rigid, accurate machine capable of producing part diameters accurate to approximately .0001 inches. The parts are also equally accurate in roundness and straightness.

Centerless grinders. Centerless grinding machines make possible the finish grinding of pieces without supporting them at their end with conical centers. The distinguishing feature of this machine is the two wheels, one the grinding wheel and the other called the regulating wheel. Between these is the work rest blade. The piece to be ground is supported on the work rest blade, which has a top surface sloping away from the grinding wheel, and against the regulating wheel rotating at slow speed. The speed and friction of this wheel keeps the work rotating uniformly as it is ground. A modern centerless grinder such as this is shown in Figure 36.

There are two methods of centerless grinding; that is, either by through feed grinding or by infeed grinding. In through feed grinding the work pieces are fed straight through the space between the wheels. To impart endwise motion to the piece, the regulating wheel is tipped on its axis at a

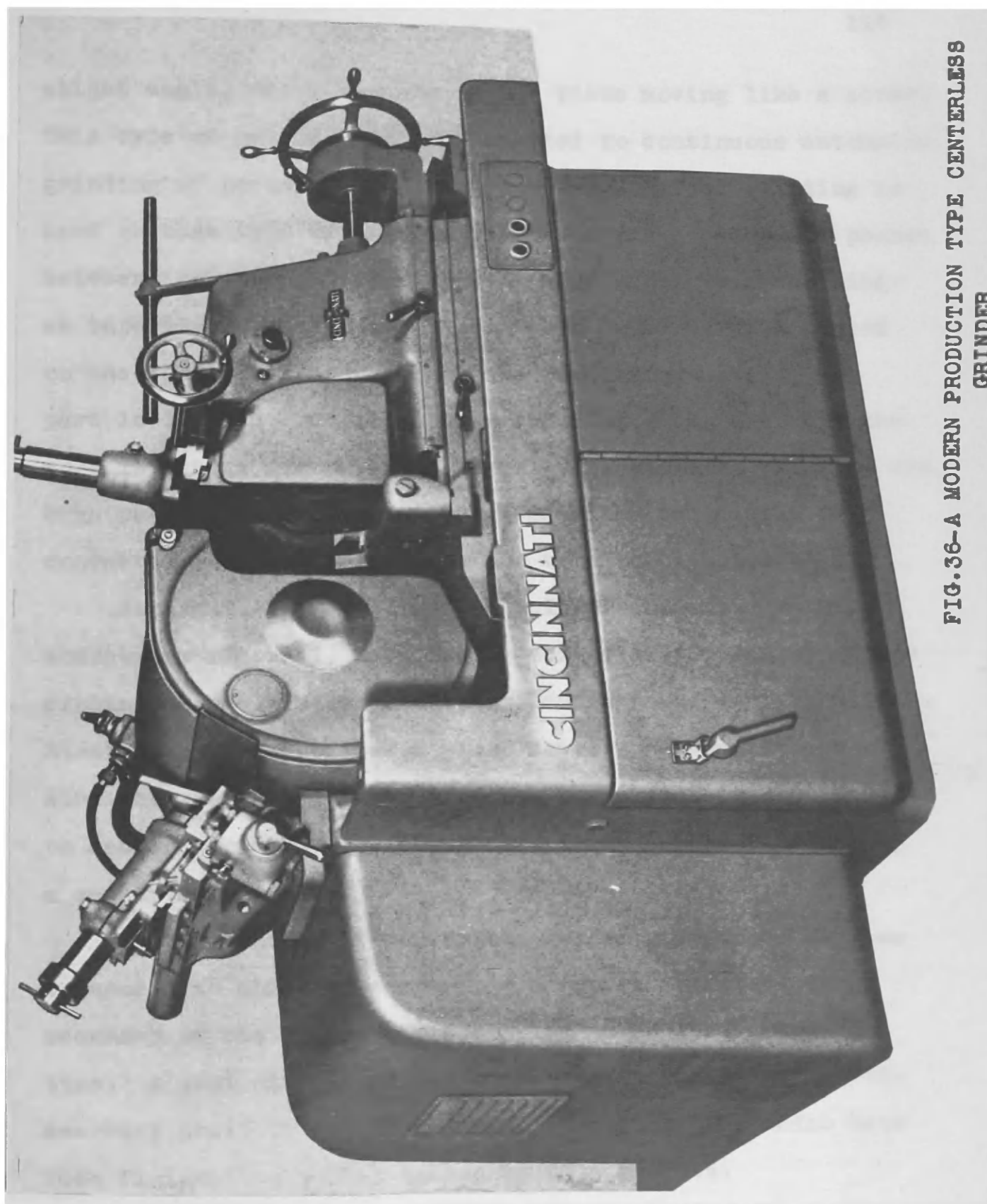


FIG. 36-A MODERN PRODUCTION TYPE CENTERLESS
GRINDER

slight angle, which results in the piece moving like a screw. This type of grinding is best adapted to continuous automatic grinding of parts of constant diameter. Infeed grinding is used on that type of work in which the piece cannot be passed between the wheels. This type of work might be such things as tapered, formed or shouldered work. The work is placed on the rest blade and against the regulating wheel. The part is located endwise with an end stop. In this case the work is plunge ground. Both types of centerless grinders are high production machines. These machines can easily be converted back and forth from one type to the other.

Straight, taper, formed or multiple diameter work of almost any material, metallic or non-metallic, can be ground within extremely close limits of accuracy and surface finish. Straight cylinders, piston pins, dowels, valves, tubes, and straight shafts and other hardened parts that cannot be held on centers or chucked without difficulty can be finished on a centerless grinder.

The advantages of centerless grinding are that no time is needed to chuck or center the part, it increases the accuracy of the grinding process and takes less grinding time. A good example of the type of work performed and the accuracy possible is the grinding of piston pins which have been finished to .00005 inches by this process.

Surface grinders. Surface grinders can be distinguished by the position of the grinding spindle and the shape and movement of the workholding table. There are two types of spindles in surface grinders; that is, a vertical and horizontal spindle. The table motion can either be reciprocating or rotary. The motion of the table is usually in a horizontal plane, an exception being in the case of a disc grinder which is usually considered a special purpose machine.

On the horizontal spindle reciprocating table machine the grinding is done on the periphery of a straight wheel. Small fixtures can be fastened onto the table to hold the work. These fixtures can be bolted down in the one or more keyways. This machine is often used with a magnetic chuck on the table. With this fixture many small parts can be placed on the table and ground at once. Small fixtures can also be held with the chuck. Besides being used on production, this machine finds wide usage in the tool room.

The vertical spindle, reciprocating table machine uses a cup or segmented wheel and cuts with the side or end of the wheel. This machine is capable of removing a great deal of stock rapidly whereas in the horizontal spindle machine the cut is rather light. This is a heavily built, large machine and is used almost exclusively on production and very seldom in the tool room. This is partly because this machine cannot equal the accuracy of the horizontal spindle

machine. The vertical spindle, rotary table machine uses the same grinding wheel as the reciprocating table machine. This machine is the most adaptable of all the surface grinders to mass production methods. Because of the rotary motion of the table, work can be ground continuously and automatically. Automatic hoppers or loaders and take-off devices are often fitted to the machine.

The horizontal spindle, rotary table machine grinds with the periphery of a straight wheel. The spindle can usually be tilted to grind concave or convex surfaces. This is not a machine that is used in general shop work, but is usually adapted to a special application.

Internal grinders. Internal grinding as the name implies is the process of grinding the interior of a cavity or hole. The internal cylindrical surface is completed by reciprocating a rapidly rotating grinding wheel back and forth in the hole as the work piece revolves slowly. The grinding wheel diameter does not correspond to the diameter being ground, but is smaller. The wheel center is offset with respect to the work center and size is controlled by a lateral cross feed movement of the work head slide. A typical internal grinder is shown in Figure 37. Note the position of the work head and the grinding spindle. The work is held in a chuck or a workholding face plate fixture and in some cases in a collet. Quite often the chuck or fixture is air or



FIG. 37-A TYPICAL INTERNAL GRINDER

hydraulically operated. The grinding wheel is driven by an electric motor belted to a high speed grinding spindle by an air spindle or by a high speed electrically driven spindle. The speed of the grinding wheel may vary from approximately 10,000 to 100,000 RPM. Any type of work piece requiring an internal diameter to be held to exacting tolerances or finish can be done on this type of machine.

Thread grinders. The thread grinders are used for a wide range of small lot work as well as for long production runs. Continuous and multiple internal and external, right and left hand, straight, tapered, and relieved threads can be ground in any pitch in standard threads, or special thread forms can be ground on internal or external work. Thread grinders are for the grinding of internal and external threaded parts requiring high commercial accuracy. These machines can be made to run completely automatic except for the three simple manual steps of loading, shifting start lever and resetting grinding wheel. Automatic functions include wheel dressing, wheel size compensation after dressing, wheel feed, retract, backlash compensation and work speed control for roughing, finishing, and rapid traverse.

Making threads "from the solid" on hardened blanks, and easily threading parts of material difficult to thread by other methods are some of the advantages that thread grinding

makes possible in production requiring accurately threaded hardened parts. Threads on previously roughed work pieces can be matched to the grinding wheel by means of a built-in lead pick-up. The part may be ground in both directions of the work spindle rotation.

There are several advantages to thread grinding besides being able to cut from hardened material. Threads ground from the solid do not have hardening cracks, and the tearing always present to some extent in any other material removal method. Distortions due to heat treatment may be eliminated by grinding from the solid after hardening. Aircraft engine part threads which demand high accuracies and freedom from distortion and stress cracks are produced in this manner.

Whether grinding fine threads from the solid or coarse threads that have previously been roughed and heat treated, a tolerance on the pitch diameter of plus or minus .0002 can be held with manual operation, and plus or minus .0003 with automatic stop and dress control. Leads can be held to plus or minus .0002 in any inch or plus or minus .0003 in any 12 inches.

An external and internal thread grinder are shown in Figures 38 and 39.

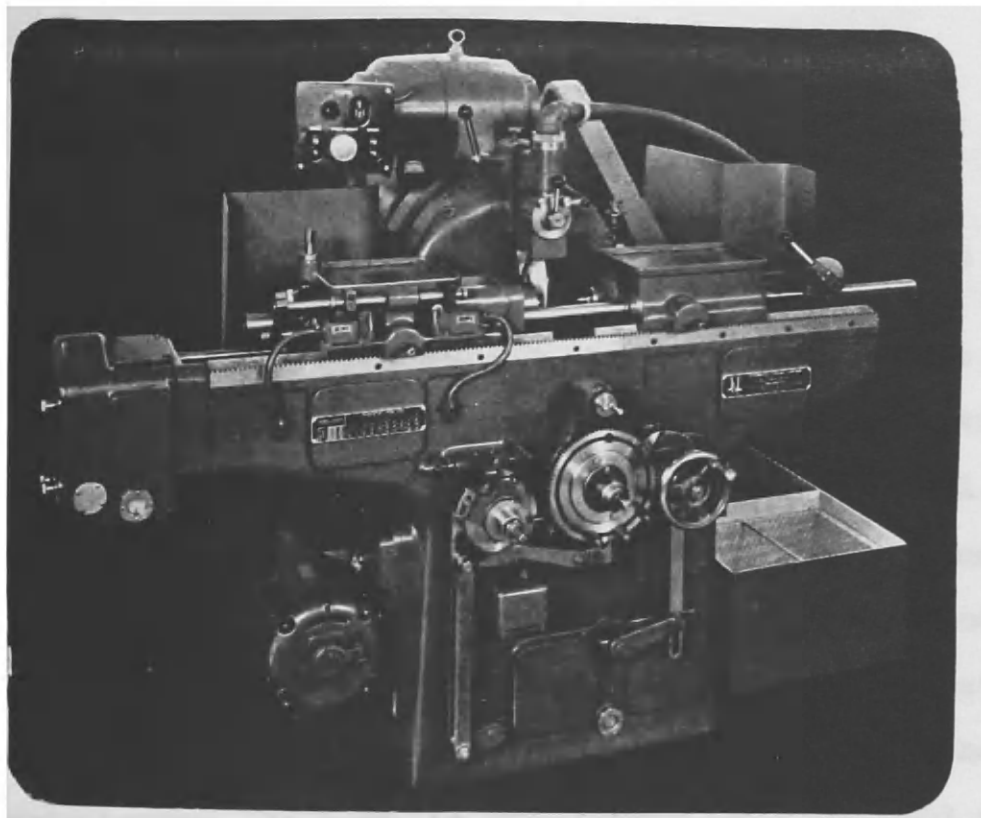


FIG. 38- EXTERNAL THREAD GRINDING MACHINE

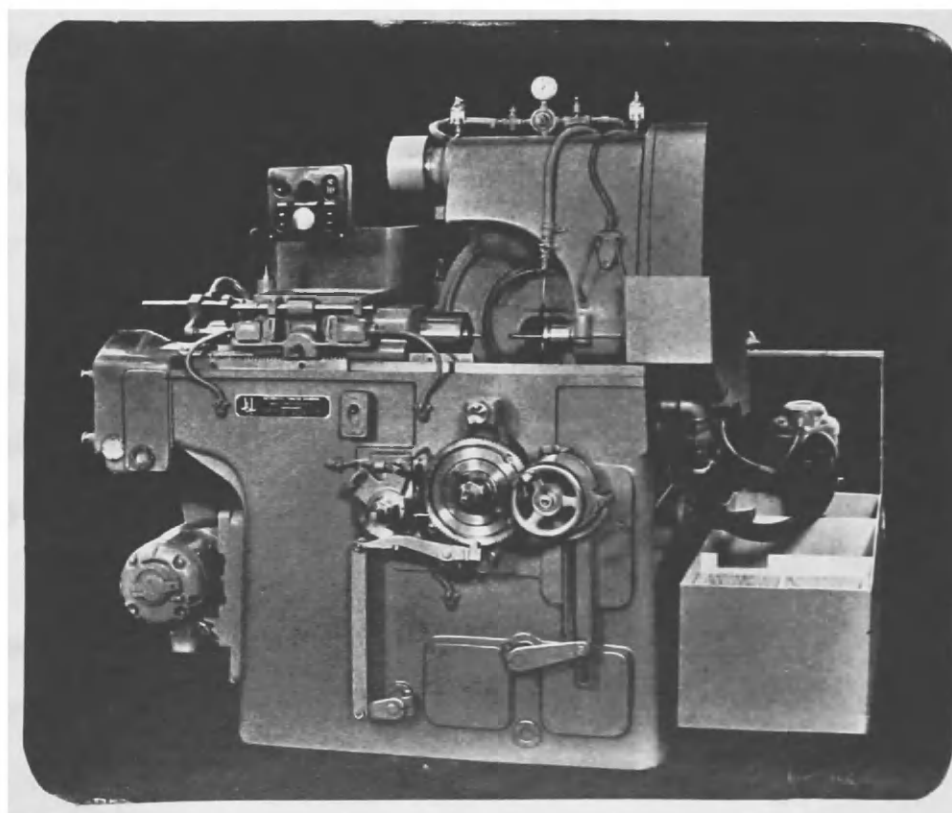


FIG. 39-INTERNAL THREAD GRINDING MACHINE

VI. PLANERS, SHAPERS AND SLOTTERS

There are three variations of machines that incorporate the straight back and forth motion of the tool with respect to the work or the work with respect to the tool. The planer, shaper and slotter all belong to the same class of machine because in each a flat surface is machined with a single point tool. In the planer, the tool is stationary and the work piece moves past it, but in both the shaper and the slotter the work is stationary and the tool moves past it. All three machines are used to machine a flat surface but the selection of the proper machine will depend on the size, quantity, and the nature of the work. For large work the planer is about the only machine that can be used. With rather small parts to be machined, the choice might depend on the quantity. If the quantity is rather small the shaper would be the machine to be used, but if the quantity is large, a great number can be set up on the table and machined at once on the planer. Also, if the number is large, the milling machine might be given consideration depending on the cutter and machines available. There is one factor that many times enters into the selection of the planer over the milling machine and that is the quality of castings to be machined. Often in a small run of castings the quality may

be a little below standard. They may tend to be rough, dirty, sandy and scaly. If this is the case, the planer would be selected because with a milling machine expensive cutters would be ruined.

The slotter may also be called a vertical shaper because the action is the same as the shaper but the ram carrying the tool moves vertically. In some tool room models this ram can be set at an angle. This machine is especially useful in work requiring machining of a flat surface at right angles to the main base. Such a work piece would be difficult to set up on either the planer or shaper. The slotter has been largely superseded by the vertical milling machine in most shops except in some of the railroad shops where their type of work lends itself well to this machine.

VII. BROACHING MACHINES

The broaching machine and broaches are a development and a result of high production manufacturing. The broaching machine does what could be done on one or a combination of the basic machine groups, driller, millers, lathe or shaper, but at a much greater rate.

In any discussion of broaching machines there must first be a basic knowledge of the broaching process. Broaches are metal-cutting tools with a series of teeth in which a gradual rise in tooth circumference or height allows each successive tooth to remove only a predetermined amount of stock as the broach is moved past or through the work piece. Each tooth cuts a specific amount of metal until the last teeth have produced a form of the exact shape and size required. Unlike other cutters, each tooth on a broach is in contact with each part only once and cuts only a small portion of the entire stock removed.

The advantages of broaching over other methods are: speed of stock removal, high finish, and close tolerance, which can be maintained consistently. Broaching is economical on high production operations and low production where quality of finish and close tolerance is required.

There are two classifications of broaching operations: internal and surface broaching. Internal broaches are used

to broach round holes, splined holes, irregular shaped holes such as hex, squares, rectangular or any contour. Surface broaches are generally of slab or sectional construction and are mounted on broach holders which are adapted to the machine ram. Surface broaches may be designed to broach half round, cams and various shaped contours.

There are several ways of forcing the broach through or by the metal. The two most common methods are pushing the broach or pulling it -- giving rise to the term "pull broaches" and "push broaches". In addition, certain types of surface broaching are often performed by drawing the work across the broach. There is no limitation to the form of a broach tooth and so there is no limitation in the shape of broached surface. The only type of surface that cannot be broached is one that has an obstruction that interferes with the passage of the broach.

There are four broad classes of broaching machines in use today. The horizontal machine is used mostly for internal work. The vertical pull up or pull down machine is also used primarily for internal work. The vertical machine is best adapted for surface broaching. The fourth type, the hydraulic press, is used for push broaching. Any broaching machine, however, may be used for a variety of different operations. For example, a horizontal machine can be adapted for surface broaching by the proper design and construction

of the broach and fixture. In much the same way a surface broaching machine can be set up to do internal work.

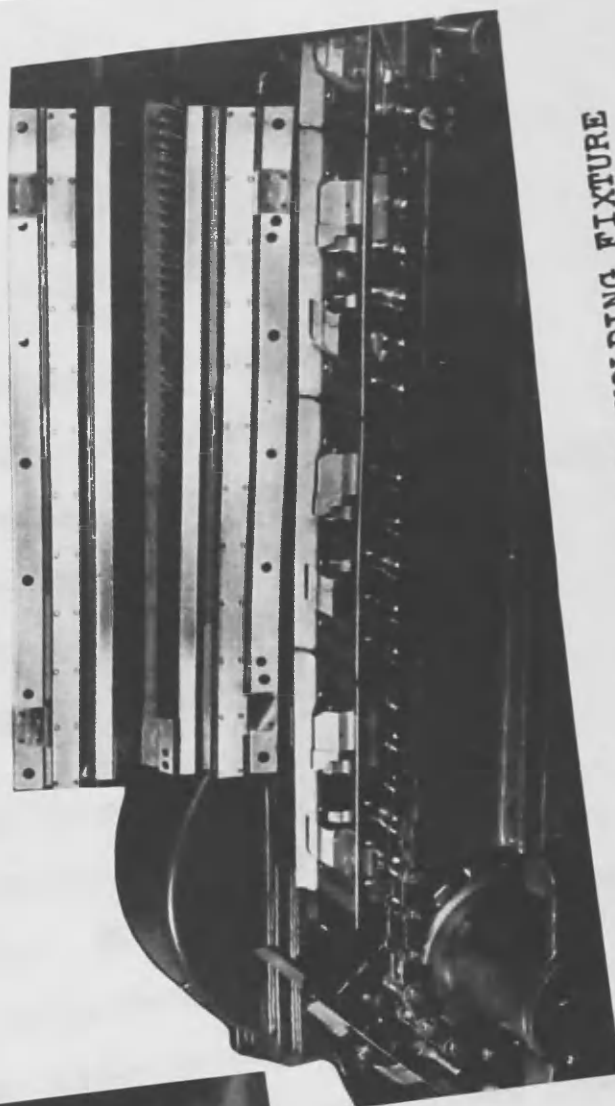
In addition to the previous mentioned broaching machines, there is one type that is somewhat special in nature and is seldom used except on high production. In this machine the work is pulled across the broach or broaches. In Figure 40 is shown this type of machine and in a close-up of the broach holder and fixture can be seen how this is done. In this particular machine the broaches are stationary in the head and the fixture mounted on a chain carries the work piece.



CONTINUOUS BROACHING MACHINE



WORK HOLDING FIXTURE



BROACH HOLDER

FIG. 40-CONTINUOUS BROACHING MACHINE, BROACH HOLDER AND WORK HOLDING FIXTURE

VIII. HONING, LAPPING AND SUPERFINISHING

There are three methods to obtain the ultimate in fine surface finishes on metal parts and for obtaining extremely close dimensional accuracy or optical flatness. These methods all use abrasives in one form or another, but not in the form of a grinding wheel. The three machines used for this purpose are the hone, lapper and the superfinisher.

Hones. The honing machine in many cases is much like the vertical drill press in appearance. The spindle motion, however, is very much different. The honing machine spindle rotates rapidly while being reciprocated up and down at the same time but at a much slower speed in feet per minute.

Honing is an abrading process used to shear stock from a cylindrical surface. It is used largely for removal of tool marks and as a final finish process for cylindrical bores and other bearing surfaces. The hone consists of a series of four or six abrasive sticks mounted in a circle in a steel holder. As the tool is expanded these sticks are forced out radially with equal pressure in all directions. With all the sticks in contact with the surface the tool is stabilized in the cylinder and thousands of grits abrade a large area simultaneously. The work is clamped in a stationary

position on the table usually by means of a fixture. The hone is allowed to float freely, and does not generate alignment as related to squareness, concentricity or parallelism of axis in adjacent parts. The hone tool will correct taper and out of roundness in the bore, and will generate a true cylindrical bore. Accuracy of roundness is generated by the rotary motion of the hone, and accuracy for diametric straightness is generated by the reciprocating motion always given the hone. The speed in the honing process ranges from 10 to 250 feet per minute. From .003 to .0045 of stock is removed when honing a cylindrical bore.

The hone is used to finish bores in engine cylinders, air and hydraulic cylinder sleeves. Any machineable material and many materials ordinarily considered unmachineable can be honed. These include all types of cast iron and steel, all non-ferrous metals, ceramics, glass and some plastics.

Lappers. Lapping is a name given several methods of producing fine finishes on ground parts. The process may be either machine or hand operation. There are two general types of lapping machines in use: the vertical and the centerless. The centerless is used exclusively for cylindrical work whereas the vertical can do either cylindrical or flat pieces.

The vertical lapping machine is arranged with two round cast iron laps or disc in a horizontal plane. The upper lap

is free to float in small machines to adjust itself to the work, but in large machines is power driven. The lower lap is rotated in all cylindrical lapping, for most flat lapping and for dressing. The work to be lapped is placed between these two laps, the top lap is lowered to apply a slight amount of pressure on the work, and the laps rotated. The proper grade and grit of lapping compound is applied to give the desired finish. Generally the abrasive is contained in oil.

The other common type of lapping machine is the centerless lapper. This machine is somewhat similar to the centerless grinding machine in that it has two driven wheels, or rolls that turn at different speeds. These machines may vary in size from small bench models to a machine as large as a centerless grinder. The work piece is placed between the rolls with a slight amount of pressure and the proper abrasive and allowed to rotate until the desired finish and size are obtained. Compared with grinding the speed is very slow and usually only a few millionths of an inch of material are removed.

Most fixed size gages as plug gages and gage blocks are lapped. Lapping is particularly efficient for production of size blocks, plug gages, sides of ball races and thrust washers. Valve plates, the component parts of metering pumps, hydraulic pump parts, refrigerators, compressors, and diesel

engine injectors are some of the many other parts also in this category.

Superfinishing. Superfinishing is a form of lapping that reduces surface irregularities left by grinding to a few millionths of an inch variation from the geometrically true cylindrical surface. One of the objects of superfinishing is to remove metal deformed by the previous operation, such as grinding.

In general purpose type of superfinisher, the work is supported between centers as in a lathe and rotated at moderate speeds. A power driven mechanism at the rear carries the stone holder and provides means of applying pressure on the stones and for reciprocating the holder back and forth with short rapid motions, also means for slowly traversing along the work. Bonded abrasive sticks similar to hone sticks are used but the motion is over an irregular path so that no one point on the stone crosses its own path again. In many cases this process is accomplished without a superfinishing, but instead is done on a regular lathe with a superfinishing attachment mounted on the cross slide.

This process is necessary in some cases depending on the function of the part in the assembly. In grinding, each abrasive particle of the grinding wheel acts as a very small cutting tool and shears off metal in small chips. This means

that the surface of the metal has been subjected to a compressive force sufficient to exceed the compressive limit of the metal. Thus, even on a finely ground surface there is a thin layer of stressed and deformed metal. Grinding and other common machining methods have been shown to be of value as dimension creating operations, but surfaces produced by such means definitely cannot be regarded as being sufficiently true to be wear resistant. Superfinishing will more completely produce the required type of surface than any other method. This type of finish is efficient in the surface refinement of cylindrical, spherical, conical, or taper shaped parts. Although it is not primarily a dimension creating process, it is necessary that some little stock be removed, averaging .0001 to .0002 on the diameter to remove the spurious layer of stock.

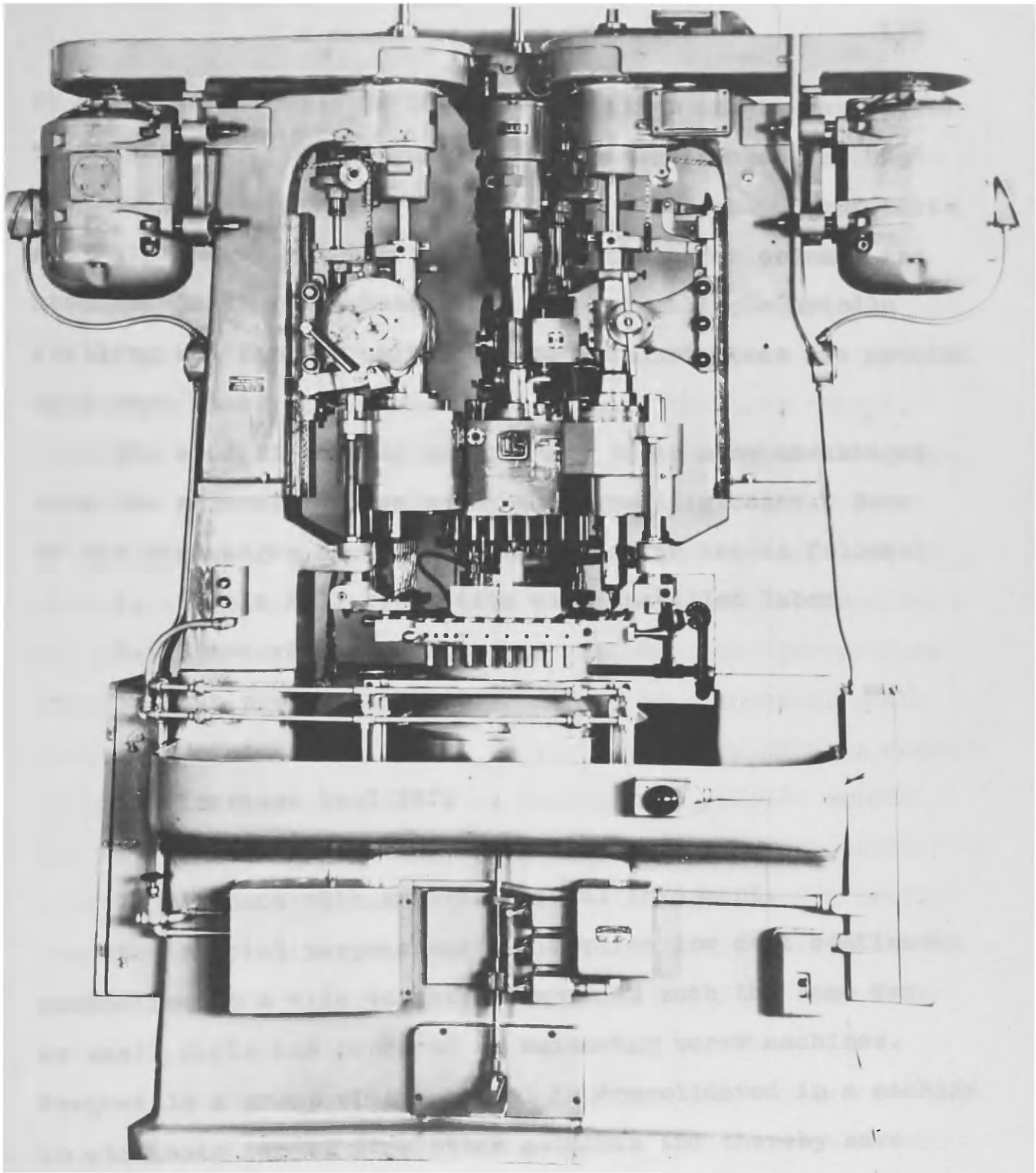
A positive pressure is not used; the abrasive is held in place on the work by a rather flexible force of 10 to 40 pounds per square inch. This process is not to be confused with grinding where surface speeds range around 6000 feet per minute. In superfinishing the speed seldom exceeds 80 feet per minute and is approximately 50 to 60 feet per minute. In all cases the work is flooded with coolant to carry off the heat generated.

Crankshafts, clutch plates, valve stems, piston pins, and rocker shafts are only a few of the representative automotive parts superfinished.

IX. SPECIAL PURPOSE MACHINES

One of the first factors essential to interchangeable manufacturing is the use of machinery in the place of hand work. Often it is advisable to use a machine other than the general purpose drilling, turning, milling, grinding, and shaper groups. Usually this machine and the work that it does is quite special in nature as contrasted to the general nature of the work performed by the standard machine. This type of machine is designed to do a specific operation or operations on a particular part of a given design. This type of machine is called special purpose because if the design of the work piece is altered radically, the machine must be almost completely rebuilt to be of further service in making the revised design.

The work piece might be almost any manufactured part. For example, the work piece might be an engine block and the machine might be built to bore, ream, and hone the cylinder bore and at the same time the stud holes could be drilled, countersunk and tapped. In nearly all cases several operations are being performed on the work piece at one time or several different operations are done in succession. In Figure 41 is shown a typical special purpose machine that was designed to tap, drill and countersink in the first station,



**FIG.41-SPECIAL DRILLING, COUNTERSINKING, AND TAPPING
MACHINE**

to drill an oil hole in the second station and to tap in the third station. The fixture in the center indexes and has one loading station and three working stations. Eight parts are machined at one time. Note that the upper columns are standard drill press heads with special multiple spindle drilling and tapping units. These standard heads are mounted on a cast base.

The special purpose machine may offer many advantages over the general purpose machine in specific cases. Some of the advantages such a machine may offer are as follows:

1. Obtain full production with unskilled labor
2. Conserve manpower
3. Cut production cost
4. Reduce floor space
5. Increase tool life
6. Maintain exacting accuracy
7. Produce with smaller capital investment.

The special purpose machine applies low cost continuous production to a wide variety of work in much the same way as small parts are produced on automatic screw machines. Frequently a group of operations is consolidated in a machine to eliminate two or more other machines and thereby save labor. These machines are made to complete any one or a combination of turning, milling, drilling, boring, reaming, tapping, and grinding operations automatically. As complicated as some of these machines may look, a man can

be trained to operate them in a few hours time, and relatively unskilled workers can operate them. Accuracy is built into the machine to eliminate the human error and thereby maintain precision tolerances even though the operator lacks skill and experience. As strange as it may seem, more skill is required to run a general purpose machine than a highly special one that need only be supplied with work. These machines are usually engineered with full automatic operating cycle to load, clamp, feed, unclamp and eject the work.

Machines designed for a particular purpose are compact, self-contained production units which occupy less space than the machines that they replace and at the same time produce more work. They simplify the problems of economical plant layout and reduce handling. Another advantage of this machine is that it conserves tool life because the spindle speeds and feeds are fixed so cutters always operate under conditions most favorable to economy, and interlocking controls prevent breakage. Furthermore, the initial cost of this type of machine with all its automatic features is often less than the combined cost of a group of standard machines.

These are all factors that must be given consideration in selecting a special purpose machine. Even with all these features this type of machine does have some disadvantages that must be considered. Such machines take highly skilled mechanics to build and special tools and fixtures are needed

with them. It also takes highly intelligent mechanics to maintain and repair them. Another factor that is all important in the machine decision is the length of the production run. On a special machine the total cost must be amortized over the length on the run of the one work piece, because at this time the machine will be of little or no future value for production without extensive rework. In the case of the standard machine, when production is completed on one part, the cutters and the fixtures can be taken off and replaced by new equipment for a new work piece. In this way the machine cost can be spread over a long period making the machine cost for any one production part very economical.

IV. SUMMARY

As used in the foregoing sections of this thesis the term "tool engineering" has become recognized as meaning the design and selection of the necessary tools and machinery for the economical production of a given quantity of parts or assemblies. In this general definition is included the two major objectives of concern to the tool engineering group: tool design and production machinery. The scope of this thesis is limited to the discussion of these two objectives. Special emphasis has been placed on the ultimate production of manufactured goods by the most economical means, and the necessary procedures by which that end is attained.

The essential purpose of tool design is to furnish designs and drawings of the necessary jigs, fixtures, and gages for the complete tooling of any desired part. General methods of tool design which enable the designer to develop ideas into practical specifications for modern manufacturing methods form the basis of this section. Many graphic illustrations are included to show the principles and problems involved in tool design. While every tool designer is confronted by different problems, there are certain fundamental principles which can be modified to meet existing

conditions and applied to most cases. In the discussion of the design of jigs and fixtures, the problems were approached by considering the various purposes for which these tools are used, such as guiding the tool, locating the work, clamping the work, secondary operation features, chip and coolant control. Under each of these purposes were considered some of the principles and problems involved. While the contents were aimed primarily at presenting general principles of design, many suggestions should help in the solving of technical problems.

Also presented in this text is the objective of good tool design from the standpoint of motion economy. This is very important for the most economical production of the work piece and an item over which a designer may have direct control. Motion economy in design deals with those factors which enable the operator to produce a work piece in less time. These items may include such things as to eliminate barriers, to provide sufficient chip clearance, and to provide quick and easy clamping and unclamping of the part.

To tool engineering an industrial gage is an instrument to determine the dimensional fitness of a given work piece for subsequent operations or to function in the assembly of which it is a part. Since tool engineering is responsible for the design or purchase of all the necessary gages for production, they must have a complete knowledge of gages and

gaging, including gaging principles, purpose, and classification of gages. In general, all industrial gages can be classified into three groups as manufacturing gages, inspection gages, and reference gages.

The personnel of the tool engineering division must also have a complete knowledge of all types of production machinery, both standard and special, for with them rests the responsibility of selecting or purchasing the necessary equipment for production. To do this efficiently the function, purpose, operation, advantages and disadvantages of each must be taken into consideration. The machine selected will depend on several factors, the principal ones being: the type of production, volume of production required, manufacturing equipment available, and the required quality of finish. Many photographs are included to supplement the descriptive material and to give the reader a better idea of the types of machines used in industrial production. Besides the description of the general types of production machinery, advantages and disadvantages of the special single purpose machine is also included.

The complete work and field of tool engineering has not been covered by any means by this thesis. However, an introduction to tool engineering has been given which will be interesting to both the technical student and the practicing engineer. In the text of this thesis has been presented

background of industrial information that will give a better understanding of modern industry. Also was discussed the purpose, function, and some of the "know-how" of the technical profession known as "tool engineering".

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