HOW TO SKETCH MECHANISMS

A Simple Rapid Method of Making Neat, Well-Proportioned Sketches of Machine Parts, Mechanisms, and Inventions, Using Pad and Pencil Only

By
FRANKLIN D. JONES

THE INDUSTRIAL PRESS
148 Lafayette Street, New York
Publishers of MACHINERY
and
HEATING AND VENTILATING

1948 PRINTING

PRINTED IN THE UNITED STATES OF AMERICA

WHY MEN IN THE MECHANICAL INDUSTRY SHOULD KNOW HOW TO SKETCH

If your work is along mechanical lines, it is quite likely that you either make sketches at times or would like to. A man cannot travel far along the mechanical road before discovering that sketches and drawings are a very important part of the language of the mechanical industry. When two engineers or experienced mechanics meet and start to "talk shop," it isn't long before one of them finds it necessary to use a pencil and paper for illustrating some scheme, mechanical device, or invention. A few lines often "put over" the idea better than all of the words in the dictionary. The designer, shop superintendent, foreman, or machinist, who cannot make even simple sketches, is greatly handicapped as a general rule. Sketching comes in handy for representing and developing new devices, and for drawing existing machines or parts either in connection with manufacturing or repair work.

A common characteristic of men in the mechanical field is that they are continually hatching out new ideas. These may relate to improvements on existing machines or tool equipment, or they may pertain to original inventions; but the best invention ever conceived is, of course, useless if it remains inside the inventor's head, and a sketch or drawing is the first step in changing a mere idea into something real. A sketch which has been dated, signed, and witnessed, may also prove valuable in establishing your claim to an invention.

Many engaged in mechanical work never are called upon to make finished drawings, but nearly everyone finds that there is a decided advantage in knowing how to make neat sketches.

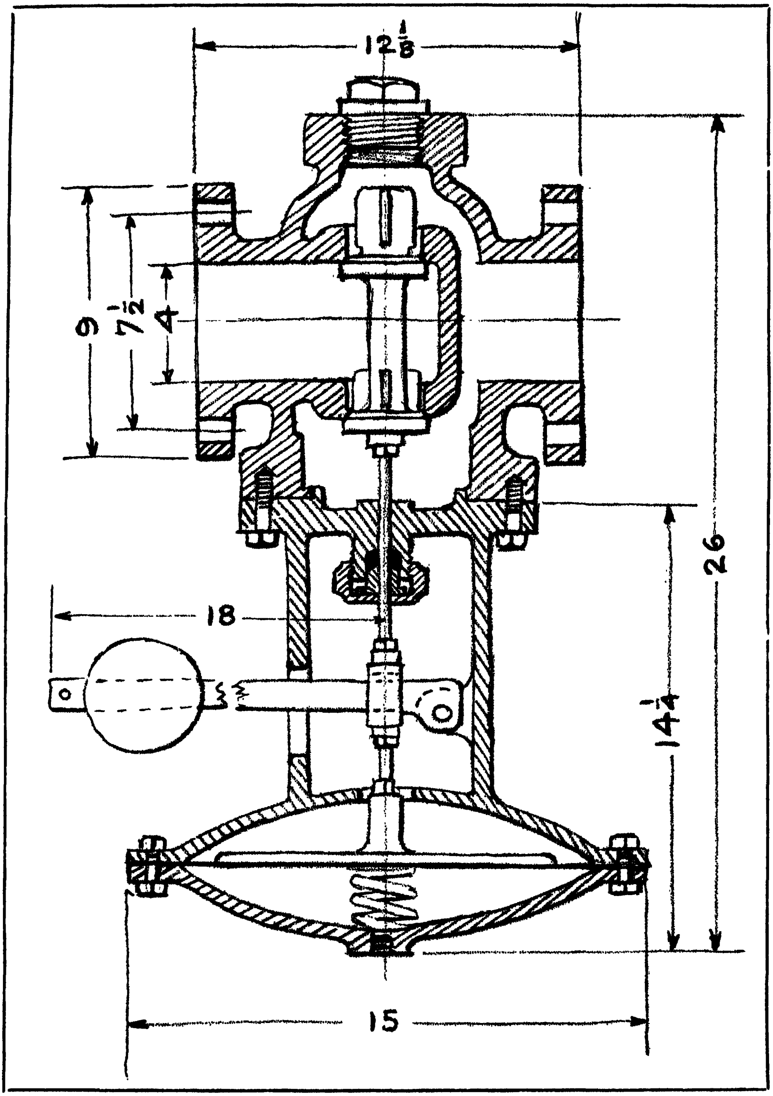


Fig. 1. By Applying the Simple Methods Described in this Treatise, Well-formed Sketches Like this One May be Made without Instruments and in Less Time Than Required by Haphazard Sketching

Simple Plan of Sketching Based Largely Upon Method of Procedure

The simple method of sketching to be described will enable almost anyone to make clear, well proportioned sketches in less time than is required ordinarily and with comparatively little practice. All of the sketches reproduced in this book are examples of work done by following this method.

Can you make a sketch like the reproduction Fig. 1, using a pencil and pad only? If you cannot, this treatise will tell you how it is done. According to this method of sketching, the way you "go at it" determines quite largely the neatness or quality of the sketch; in other words, it is the *method* that counts. You start with simple straightline exercises and soon learn how to make complete sketches by adding one detail to another in order to build up what may appear to be a complicated drawing, in much the same way that a building is constructed by assembling a lot of small elements or pieces. This all sounds very simple and it is not nearly so difficult as most people imagine. Although practice makes perfect in nearly everything, the average man in the mechanical field can make satisfactory sketches without much practice by following the general methods to be described.

This treatise deals only with the making of sketches; that is, with methods of drawing lines and of proportioning a sketch so that it resembles in form the object drawn. The sketches used in engineering work are similar to mechanical drawings, excepting that they are less accurate and frequently much simpler, due either to a reduction in the number of views or to other abbreviated methods commonly employed in sketching. Those who do not understand at least the fundamental principles of mechanical drawing should acquire a knowledge of these principles before taking up sketching. It is essential to understand the projection method of drawing, the use of sectional views, and the general procedure in drawing mechanical devices. There are many books on mechanical drawing which may be referred to.

Application of Sketches in the Mechanical Industry

The term "sketch" as used by engineers, designers, and mechanics in general, means a drawing made without the use of instruments. Ordinarily, a pencil and sketch pad constitute the materials, although when a dimensioned sketch of some machine part is to be made, some measuring tools will be required for determining whatever dimensions are necessary.

Sketches serve several important purposes in connection with mechanical work. They are used very largely for illustrating ideas of a mechanical nature. This use is not, of course, confined to the engineer and draftsman, since sketches are frequently made by shop executives as well as by machinists, toolmakers, and other skilled artisans. Inventors and designers use sketches in developing new appliances; in fact, sketches often assist greatly in originating some new device, or, they may reveal defects and show that an idea is impracticable. Many chief engineers and chief designers transfer their ideas to paper in the form of sketches which are then used as a guide by draftsmen in making finished drawings. Another important use of sketches is to show the size, form, and arrangement of existing devices, including machine parts, special tools, or complete mechanisms. Sketches are used, in fact, for so many different purposes that a more complete list need not be given since the practical application and value of sketching are generally appreciated by almost every man likely to see this treatise on the subject.

The Difference Between a Poor Sketch and a Good One

Before considering the method of procedure in sketching, it might be well to get clearly in mind the difference between poor sketches and those that are neatly executed. Generally speaking, a poor sketch, in so far as the drawing is concerned, is formed of lines that are not of the right length, that are not in the proper relation to one another, and possibly lines that are very crooked when they should be fairly straight. If the sketch includes curves or circles, there is an even greater chance of making a poor sketch, especially if all circles are simply drawn free-hand. A sketch may also be classed as poor because it is incomplete, either in regard to the arrangement and number of views shown, or because important dimensions and explanatory notes are lacking.

On the other hand, a good sketch clearly and completely represents a part or mechanism, and its proportions are such that it resembles the part drawn. Clean-cut straight lines and fairly accurate curves or circles are important primarily to secure a clear, well proportioned drawing rather than to obtain a work of art.

Horizontal and Vertical Lines Predominate in Most Drawings

Most mechanical drawings consist principally of straight, horizontal and vertical lines which vary as to length and as to their location relative to one another. From 75 to 85 per cent of the lines on many sketches are either horizontal or vertical, not counting small fillets and cross-section lines. By way of illustration, look at the sketch Fig. 1, the horizontal and vertical lines of which include 85% of the total number, excluding the section lines. There are, of course, many drawings which are exceptions to this rule, but it will be found that straight, horizontal and vertical lines predominate in a large percentage of drawings used in the mechanical industry. It is evident, then, that the first step in learning how to sketch without the aid of instruments consists in drawing at least fairly straight lines, and the next step is to so place these lines and govern their respective lengths as to obtain satisfactory proportions. There is nothing very difficult either in drawing the horizontal or vertical lines, or in judging their lengths and positions if the general methods of procedure to be described are employed.

Circles and arcs of circles are prominent features of many sketches or drawings and these can also be drawn accurate enough for sketching requirements without the use of instruments. Just how this is done will be explained later on. Information will also be given on a simple natural method of proportioning sketches. When you know how to draw straight lines at right angles to one another and locate all these lines approximately where they belong, you have gone a long way toward mastering the art of sketching.

Materials Used for Sketching

Before describing the different line-drawing exercises, it might be well to include some information on materials. This is not considered very important, however, because in many cases it is necessary to use whatever materials are at hand. In making sketches by the method to be described, use either a pad having a cardboard back to make it rigid, or mount a sheet of paper on a small drawing-board. A board suitable for this purpose is sold in some of the 5-and-10-cent stores.

Sketching pads may be obtained in various sizes; but for average work, the 8½- by 11-inch size is recommended. Pads sold by dealers in stationery and engineering supplies are of three different types: One has plain, unruled paper; another type has cross-section paper (the use of which will be referred to later); and a third type consists of sheets of transparent or tracing paper; the latter is used when blueprints of the sketches are desired. These tracing paper sketch pads are accompanied by one or two sheets of cross-section paper, this sheet being placed beneath the tracing paper to serve as a guide in making the sketch, as shown later.

Pencils for Sketching

The pencils used for sketching should be somewhat softer than those employed in ordinary drafting-room practice. The grade marks for pencils vary somewhat; but a system of marking, in general use, is as follows:

6B	Extra soft and very deep black	H	Hard
5B	Extra soft and very black	2H	Medium hard
4B	Very soft and very black	3H	Very hard
3B	Very soft and very black	4H	Extra hard
2B	Very soft and black	5H	Extra hard
B	Soft and black	6H	Extra extra hard
HB	Hard and black	7H	Extra extra hard
F	Firm	8H	Specially extra hard

Pencils of the 2B to HB grades will be found satisfactory for most sketching.

DRAWING STRAIGHT LINES AND CIRCLES WITHOUT INSTRUMENTS

In view of the fact that horizontal and vertical lines predominate in most drawings, it is essential to know how to make them without the use of instruments. Fig. 2 illustrates a simple, easy method. This particular view shows the use of a pad having a cardboard back to make it rigid. A small drawing-board to which a sheet of paper is attached by thumb-tacks might have been used instead.

As the pencil is drawn across the paper, it is guided by the end of one finger which glides along the edge of the pad. The little finger is used ordinarily, as shown by Fig. 3; but if a line is quite close to the edge of the pad, it may be more convenient to use the third finger in guiding the pencil (see Fig. 4). If the little finger is used, then, as it slides along the edge of the pad, the third finger also slides lightly over the top surface of the pad and supports the hand. This simple method will enable you to draw lines that are practically straight and parallel, with little or no practice.

Varying the Distance Between Lines

In drawing a line, the movement of the pencil can be quite rapid and, in fact, a fairly rapid stroke is preferable. Begin this exercise by drawing lines which are near the guiding edge of the pad, and then draw lines in the center of the pad by changing the position of the guiding finger and hand as illustrated in Fig. 5. By spreading the hand in this way, the distance between lines is varied. As the distance from the line to the guiding edge increases, the difficulty of drawing the line also increases somewhat, but this may be overcome with a little practice. It is unnecessary,

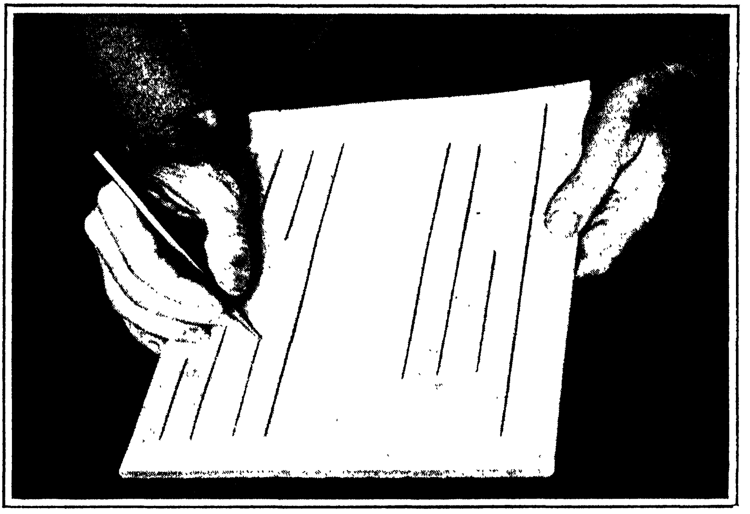


Fig. 2. Drawing Straight Parallel Lines by Guiding the Pencil from the Edge of the Pad

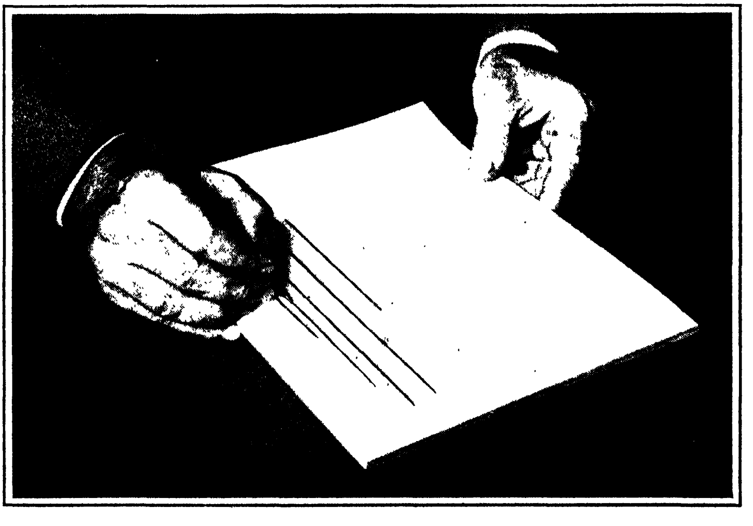


Fig. 3. The End of the Little Finger Slides Along the Edge of the Pad While Drawing a Straight Line

of course, to draw lines which are farther from the guiding edge than one-half the pad width. The edge of the pad nearest to the line to be drawn should be used for guiding, which permits the entire surface of the pad to be covered readily, provided it is not over 8 or 10 inches wide. Fig. 6 shows a pad on which thirteen parallel lines were drawn in one minute to show that the guiding method is not only rapid but accurate as well. This method will be found decidedly superior to the free-hand method. The latter, however, must be employed for certain lines as explained later. One writer on the subject of mechanical drawing and sketching says that "It is legitimate, in technical sketching, to draw long vertical or horizontal lines by using the little finger as a guide along the edge of the pad or clip board."

Of course, this is true; in fact, the use of a rule or straight edge for drawing straight lines and a compass for circles is also legitimate, assuming that they are at hand and promote the job of making the sketch. In other words, sketching without mechanical apparatus is not done as a "stunt," but because it is a convenient, practical method of procedure under conditions common to most sketching. Drawing instruments usually are not at hand; and, even if they were, an ordinary pad and pencil would be preferable for sketching under average conditions. The primary object of sketching is not, of course, to demonstrate one's skill in drawing, but to put on paper, by the simplest and most convenient means at hand, a clear representation of some idea or mechanical device.

Drawing Lines at Right Angles and in Different Positions

It is well to keep in mind that most drawings, as previously mentioned, consist quite largely of horizontal and vertical lines, or lines located perpendicular to one another; hence, when we know how to draw lines at right angles and in different positions, we have learned more about sketching

Fig. 4. If Lines are Very Close to the Pad Edge, the Pencil May be Guided by Using the End of the Third Finger

Fig. 5. In Drawing Lines Located Near the Center of the Pad, the Pencil is Moved Inward by Spreading the Hand

than might be supposed. Fig. 7 illustrates the next exercise which is simply that of drawing series of lines at right angles to one another, using the four edges of the pad. The pencil is guided by the little or third finger as before, and from whichever edge of the pad is nearest to the line or group of lines to be drawn. The drawing of horizontal and vertical lines by this method should be easy after very little practice. The drawing of parallel lines should be followed by drawing simple geometrical figures, such as squares and rectangles of different sizes, to obtain practice in locating lines and placing them somewhere near their proper position. Then, proceed a step further by drawing simple objects which are formed entirely or largely by straight, horizontal and vertical lines.

Applying Straight-line Exercises to a Simple Sketch

The building-up of a simple sketch by drawing horizontal and vertical lines is illustrated in Fig. 8. This sketch shows a method of attaching a fan-pulley spindle. The sketch consists of twenty-five lines (not counting the section lines) and eighteen of these lines are either horizontal or vertical.

The upper illustration represents the first stage. Begin by drawing the center-line and then two horizontal lines on each side and representing the spindle body or fitted part. Then draw vertical lines spaced to suit the width of the part shown in section. This width is about one and one-half times the spindle body diameter, and it is by noting such relative dimensions that all sketches are proportioned.

The spacing of these lines establishes the size of the sketch which may be approximately the same size as the part drawn or the size may be reduced as a matter of convenience. In some cases, the sketch is larger than the actual size of the part drawn, especially if the latter is small and an enlargement is needed to show the details more clearly. In all sketching it will be understood that the proportions

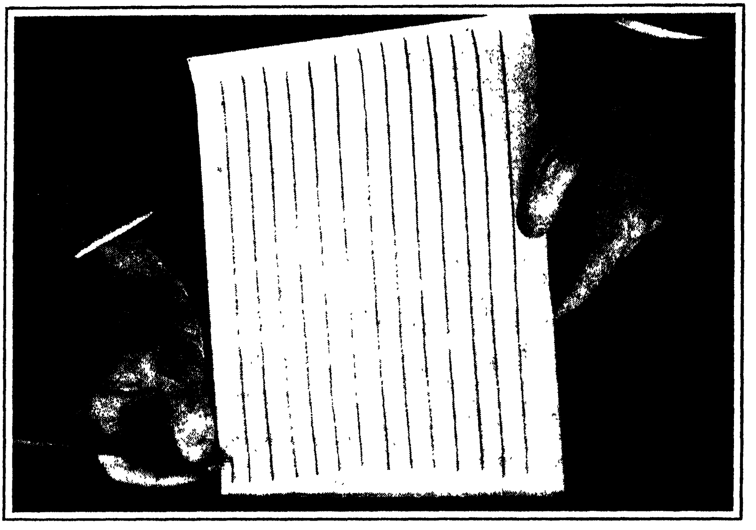


Fig. 6. The Thirteen Parallel Lines on this Pad Were Drawn in One Minute to Show that the Method is Rapid and Accurate

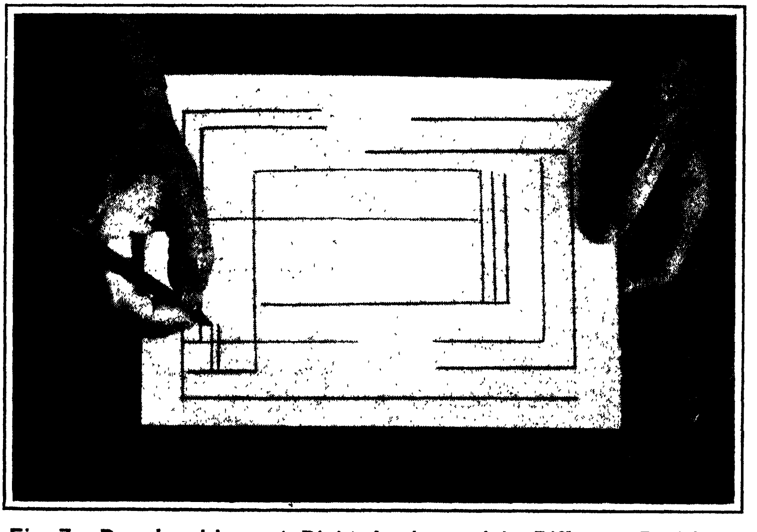


Fig. 7. Drawing Lines at Right Angles and in Different Positions by Guiding the Pencil from the Four Edges of the Pad

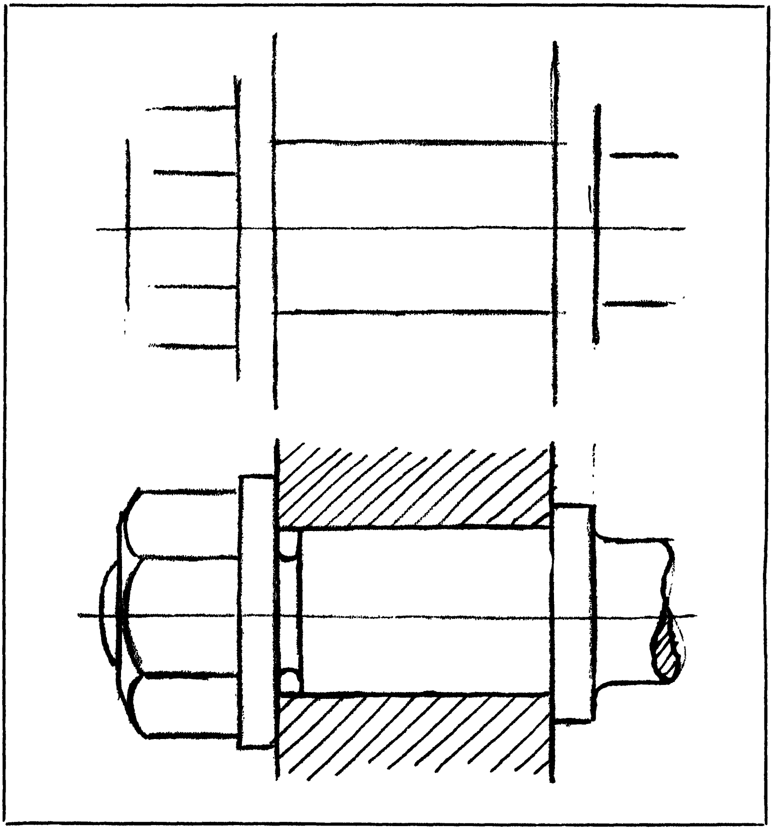


Fig. 8. Example Showing How the Straight-line Drawing Exercises are Applied in Making a Simple Sketch

of the sketch are estimated or judged by the eye, except, possibly, when a pencil is used as a measuring stick as described later on.

Continue by drawing a vertical line for the spindle flange and another for the nut flange, and a third vertical line for the top of the nut. Now draw horizontal lines representing the nut corners and also short lines at the right for the fan-pulley spindle which is only partly shown on this sketch.

These few lines (fourteen in all) nearly complete the sketch although this first stage has a very unfinished appearance; however, after drawing these fourteen lines, you will find that it is comparatively easy to fill in the remaining details and complete the sketch as shown at the lower part of the illustration.

In all sketching, remember this: First draw the most important lines. These are the ones which establish the main proportions of the sketch and enable this proportioning to be done in a most simple and direct manner. The practical application of this fundamental principle in sketching will be illustrated by the different examples of sketching to follow. These examples have been selected to illustrate different points and show methods of procedure in making sketches representing different types.

Lines Which Must Be Drawn Free-Hand

Straight lines are drawn by guiding the pencil from the edge of the pad (as described previously in connection with Figs. 2 to 5) only when this method is convenient or practicable. Incidentally, the object of guiding the pencil is partly to obtain straight lines and partly to assist in drawing such lines more rapidly than by the free-hand method which requires more hesitation and usually additional time in erasing those lines which have been drawn poorly.

As a general rule, the pencil is guided from the edge of the pad in drawing the main or "foundation lines," such as the center-lines and the longer lines establishing the general proportions of the sketch. There are certain lines, however, and often many of them, which should be drawn free-hand, such, for example, as section lines and short connecting lines forming the small details. It is easy, of course, to draw the short lines free-hand. A little practice in sketching will show when and when not to guide the pencil from the edge of the pad.

Fig. 9 shows an ink sketch of a poppet valve and seat which illustrates the point just referred to. In making this

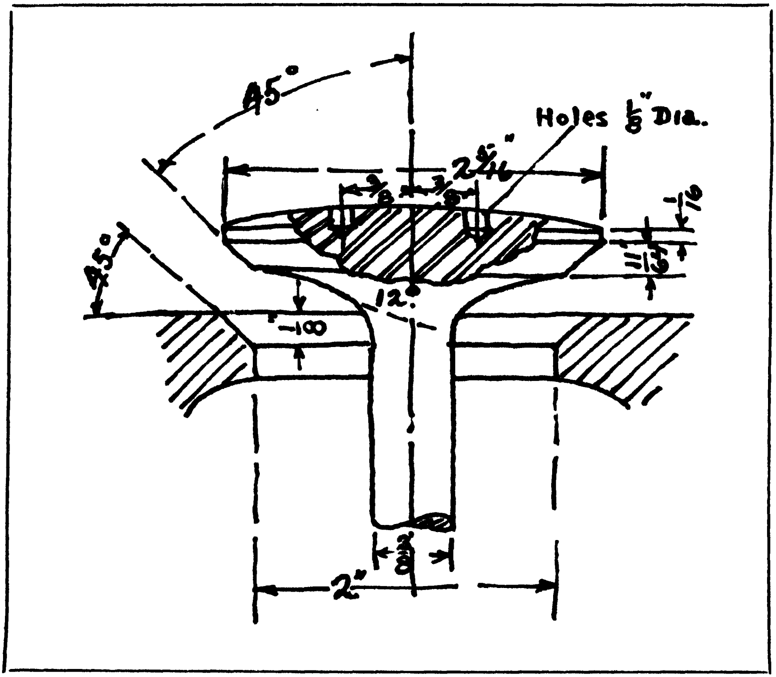


Fig. 9. Sketch of a Poppet Valve Drawn in Ink with a Fountain Pen

sketch, the pencil might be guided in drawing the vertical center-line, the vertical lines for the valve-stem, the three horizontal lines for the valve-seat, the three horizontal lines on the head of the valve, and the horizontal and vertical dimension lines. The remaining lines would be drawn free-hand.

This sketch was drawn with a fountain pen, whereas the one shown in Fig. 8 was drawn with a pencil upon paper having a rough surface or stipple finish. This explains the difference in the appearance of the two reproductions. In practicing sketching, it may be advisable to use a fountain pen at times, especially if the tendency is to do too much erasing when using a pencil. Several ink-drawn sketches are reproduced in this treatise.

How to Draw Long Lines Free-Hand

When long lines are not parallel to either side of the sketching pad, there are two general methods of drawing them free-hand. First turn the pad so that the line can be drawn by a left-to-right movement. In other words, even though the line may be vertical on the sketch, the pad is turned so as to draw it the same as a horizontal line.

One method is to draw the line by making a continuous stroke. Do not look at the pencil point but at that point on the paper where the line is to end. Place the pencil at the starting point and then move it along with a bold, even stroke toward the end point while looking at the latter.

A second method of drawing long lines free-hand, which is preferred by some, consists in forming a line by a series of short pencil strokes with each stroke lapping back somewhat over the preceding one; thus the line is gradually formed by a succession of intermittent strokes. Lines drawn this way are likely to be rough and some of this roughness may be avoided by using a series of strokes with little or no back overlap. Practice each method referred to and use the one which gives you the best results.

Sketch Consisting Chiefly of Angular Lines

Some sketches consist almost entirely of lines which are not parallel to either edge of the pad or drawing-board. An example is shown in Fig. 10, which illustrates a side view of a swivel-vise converted into a jig for drilling holes in blocks beveled at one end to an angle of 30 degrees, the holes being perpendicular to this beveled surface. The illustration shows the vise in its angular position as applied to this particular job.

In making this sketch, the horizontal and vertical lines forming the swiveling part of the vise were drawn by using the sides of the pad as a guide. Thus the sketch, in this instance, was not in its natural position on the pad. If such a position were required, then the pencil in this instance

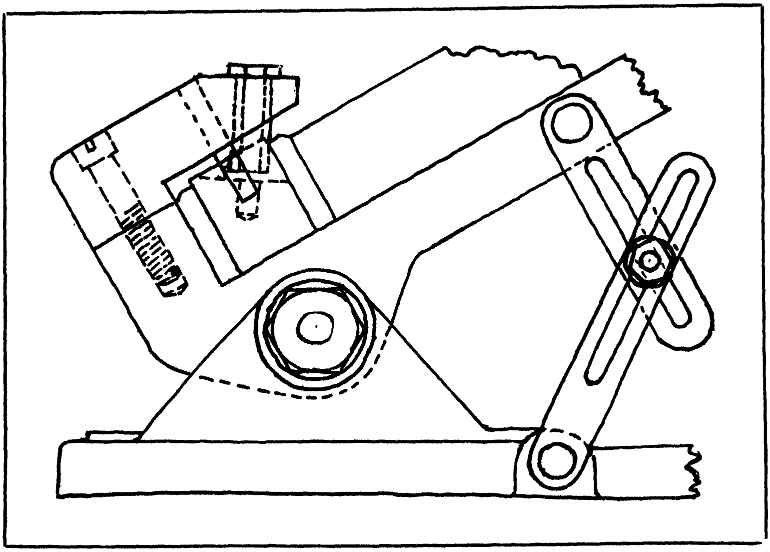


Fig. 10. Ink Sketch Consisting Chiefly of Lines which are Neither Horizontal Nor Vertical, Thus Requiring a Special Method of Drawing

could be guided only for drawing the two long lines of the base. Since there is a larger number of lines on the swiveling vise which are at right angles to one another, the edges of the pad were used in drawing these lines, thus, in effect, placing the vise in a horizontal position relative to the pad. The point is that sketching can sometimes be simplified by the way the sketch is located with reference to the guiding edges. This is another example of ink sketching.

Drawing Circles Without Using Instruments

Circles or arcs of circles form an important part of many sketches. In fact, one or more circles in some cases are the main or foundation lines of the sketch. How are circles to be drawn with any degree of accuracy without instruments?

You have heard how Columbus made the egg stand on end merely by smashing one end in slightly. Before he gave this simple demonstration, everyone present doubtless expected either a brilliant trick or some mysterious performance; but the Columbus method proved to be unimpressive because it was so simple.

Fig. 11 shows a circle being drawn upon a pad, using only a pencil held in the hand. When you are told how this is done, you may be disappointed because of the simplicity of the method.

There are two general ways of drawing circles without using instruments. One way is illustrated in Fig. 12. The pad is supported upon one knee, and the little finger of the hand holding the pencil forms, with the knee, a pivot about which the pad is rotated. In other words, the pencil is held stationary in one hand at the required radius, and the pad is turned beneath it, using the other hand. It is desirable to use a pad having a rather stiff back and a fair amount of pressure should be exerted by the little finger to prevent shifting of the pivot point. If the diameter of the circle is comparatively large, say 5 or 6 inches, it may be more convenient to use the last joint instead of the end of the little finger as a pivot (see Fig. 13.)

Do not be disappointed if the first few attempts at circle drawing by the method described are not altogether satisfactory. A little practice may be required.

Drawing a Circle Upon a Separate Sheet of Paper

A second method, which may be found easier than the first one mentioned, is for drawing circles upon a separate sheet of paper before it is mounted upon a drawing-board. The sheet is placed upon some supporting surface (see Fig. 14) and, with the left hand, is turned slowly about the point where the little finger, acting as a pivot, holds the paper in contact with the supporting surface. If a sketch requires two or more concentric circles, this latter method usually gives the better results.

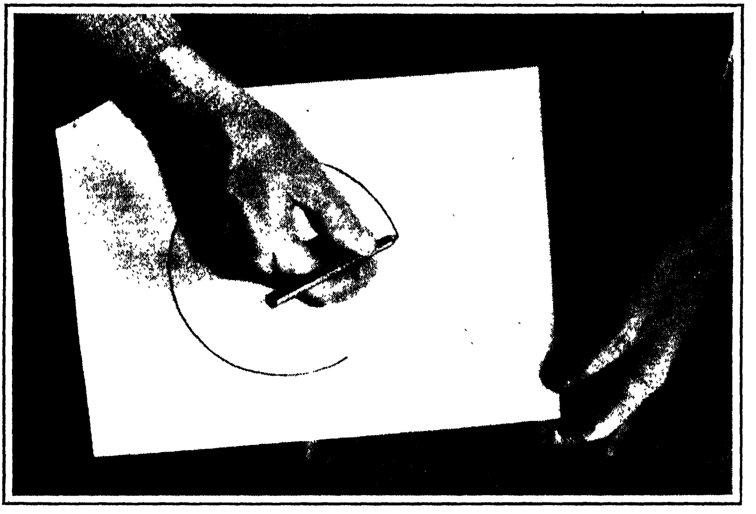


Fig. 11. Drawing a Circle Upon a Pad Using a Pencil Only. This Plan View Shows the Accuracy Obtained

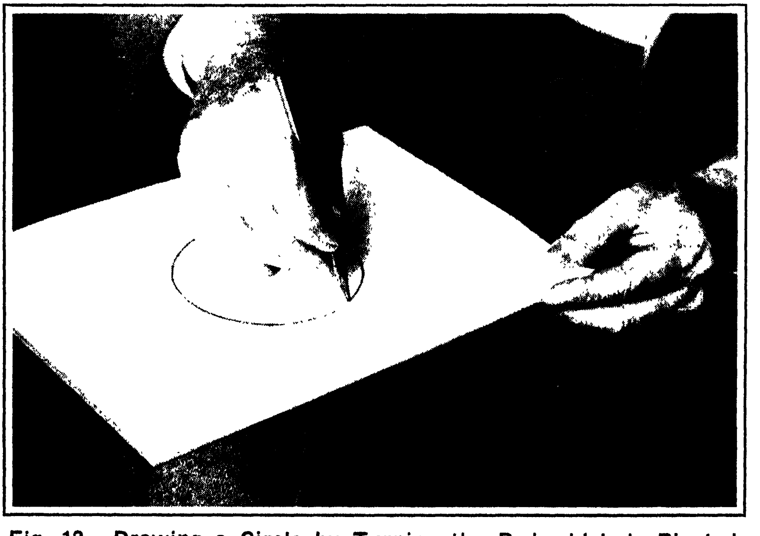


Fig. 12. Drawing a Circle by Turning the Pad which is Pivoted Between the Knee and End of the Little Finger; the Pencil is Held Stationary at the Required Radius

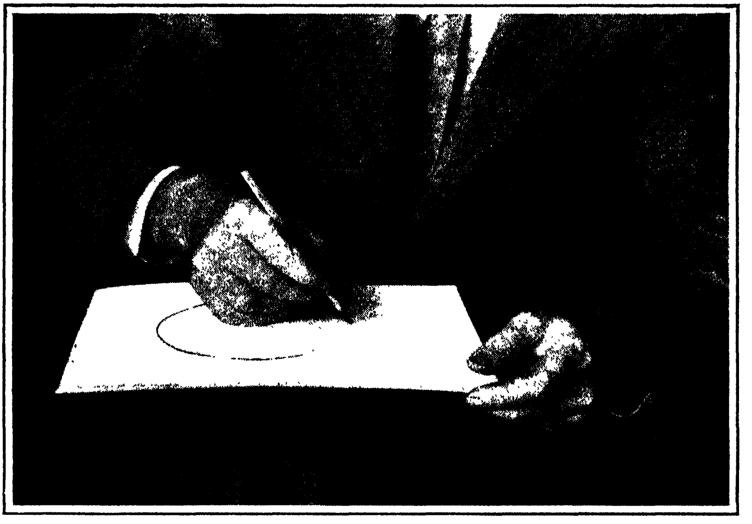


Fig. 13. If a Circle is Comparatively Large, It May be More Convenient to Use the Joint of the Little Finger as a Pivot

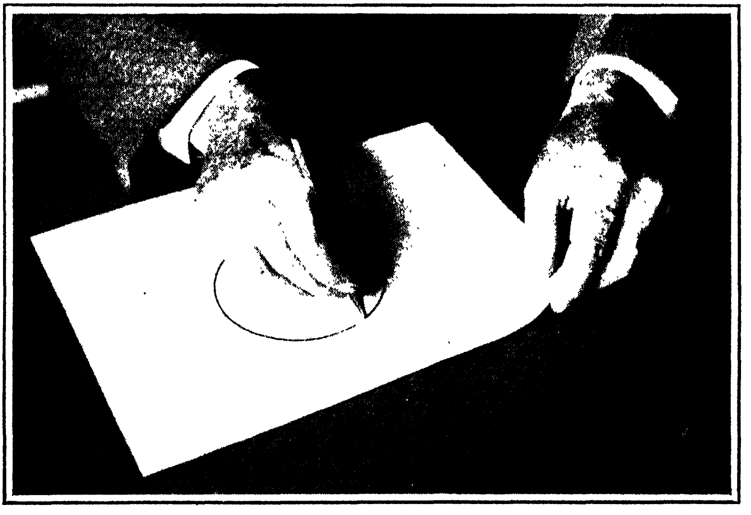


Fig. 14. Drawing a Circle Upon a Single Sheet of Paper which is Turned About a Pivot Formed by the End of the Little Finger and Some Supporting Surface such as a Board or Table

The methods just referred to are intended only for the larger and more important circles, and especially when the latter may be classed as foundation lines. For example, if the circles range in size from 2 or 3 to, say, 6 or 7 inches in diameter, it is possible to draw them by the methods described and sometimes they are nearly as accurate as those drawn with a compass. Small circles representing bolt holes, etc., are drawn free-hand. In drawing circles free-hand, the general tendency, after starting from a given point, is to make the curve too abrupt, or, in other words, to flatten the circle. Horizontal and vertical center-lines assist in drawing circles free-hand because then the circle may be formed by drawing four arcs.

NUMBER OF VIEWS REQUIRED IN SKETCHING

In making sketches it is the general practice to reduce the number of views as far as possible, although the completeness of a sketch or the amount of detail may depend upon its purpose. For example, if a sketch is practically a drawn memorandum for the one making it, or an approximate representation of some plan or scheme, a skeleton type of drawing, accompanied perhaps by several explanatory notes, may meet practical requirements. On the other hand, if the sketch is to be used as a guide by someone else, or possibly as a working drawing, then it may be necessary in some cases to make it just as complete as a regular mechanical drawing so far as the number of views and dimensions are concerned. No fixed rules can be given except this one: Make each sketch self-explanatory, especially if it is to be used by others and is to serve as a more or less permanent record.

Sketches Should be Simplified as Far as Possible

Whenever possible, only one view is shown on a sketch, even though two views might be considered necessary on a mechanical drawing. Many machine parts, for example, are understood to be round or of circular cross-section, by designers and experienced mechanics, so that an end view is unnecessary. Even when an end view might properly be added, this is sometimes avoided by the use of an explanatory note or possibly by inserting a small detail of the particular section or part which is the important feature.

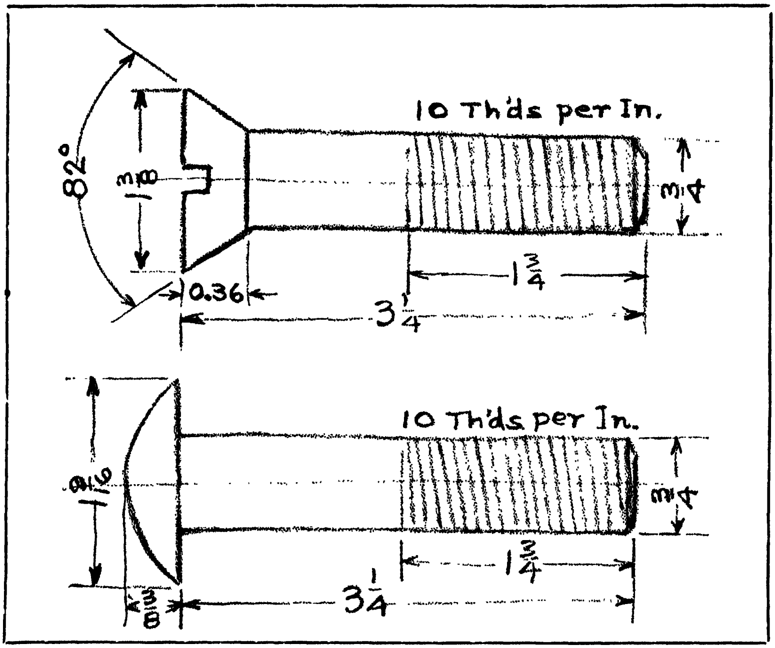


Fig. 15. Examples of Sketches Requiring One View Only

When parts of a mechanism are of especial importance or complicated in design, detail views of such parts, drawn possibly on an enlarged scale, may be used to make the sketch clearer and to avoid too many small details on the main sketch. The typical examples to follow illustrate when one, two or three views meet practical requirements. A knowledge of the principles of mechanical drawing is essential in technical sketching and there are excellent books on mechanical drawing for those who need instruction in this subject.

Sketches Requiring One View Only

The upper sketch, Fig. 15, shows an American Standard flat-head cap-screw and the lower sketch an American Standard button-head machine bolt. One view of such simple parts is sufficient. An end view to show that the head is round is unnecessary.

Fig. 16 shows sketches of two forms of standard grinding wheels. The upper sketch shows a dish wheel and the lower one an offset wheel. Everyone knows, of course, that a grinding wheel is round; hence, one view only is needed. For the same reason, it is common practice in sketching to show only one view of such parts as pulleys, gears, etc. The number of views in any case cannot be determined by fixed rules because the conditions vary, especially in regard to sketching practice, and judgment or common sense must be relied upon as a guide. While sectional views of the grinding wheels, Fig. 16, are not absolutely necessary, they show the shapes clearer than the use of full and dotted lines.

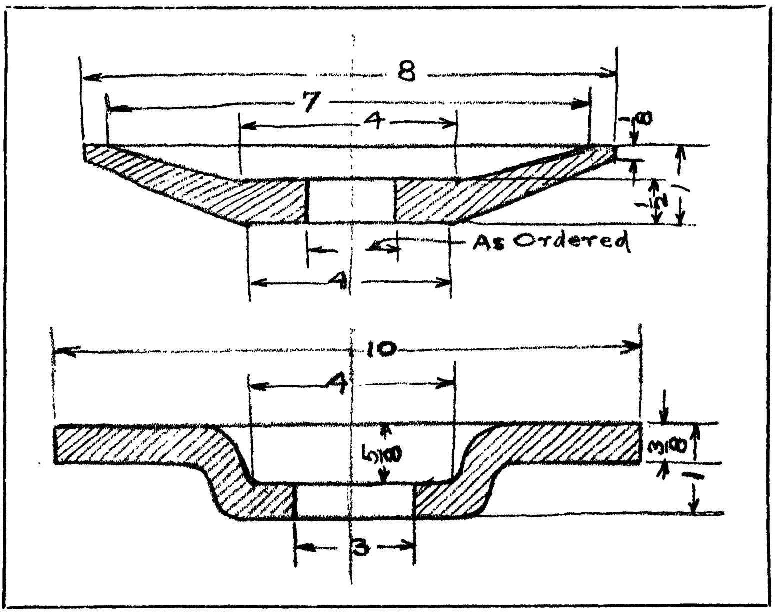


Fig. 16. Sketches Showing the Shapes and Sizes of Two Standard Grinding Wheels

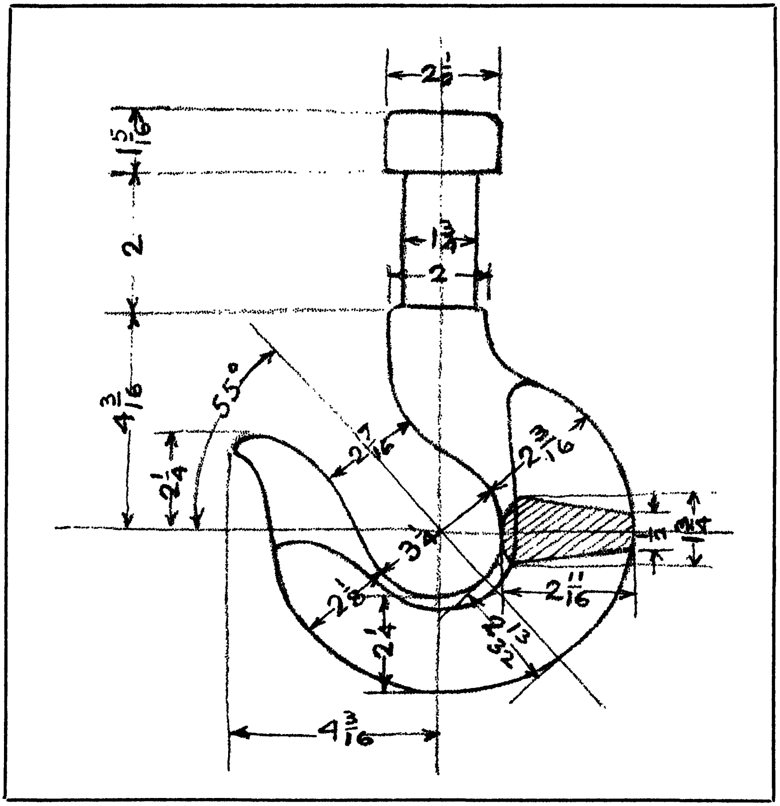


Fig. 17. Sketch of a Crane Hook. Note How Cross-section is Used to Show Shape of Hook on Horizontal Center-line

A crane hook of four tons capacity is shown by the sketch Fig. 17. In this case, a single view is supplemented by a sectional view which indicates the shape of the hook on the horizontal center-line. In other words, if the hook were sawed apart along this line, the shape and proportions would be as shown by this detailed sectional view. This plan of placing sections directly on the drawing of a part is often resorted to both in connection with sketching and in mechanical drawing practice.

In sketching this crane hook, first draw a half-circle for the outer part of the hook and then the vertical and horizontal center-lines with reference to this half-circle. Continue by drawing the inner curve of the hook, free-hand, and then complete the curved lines and add the upper part of the hook.

When Two or More Views Are Necessary

The sketch Fig. 18 shows an S.A.E. standard shackle for aeronautical work. If the left-hand view had not been supplemented by the side view at the right, it would be impos-

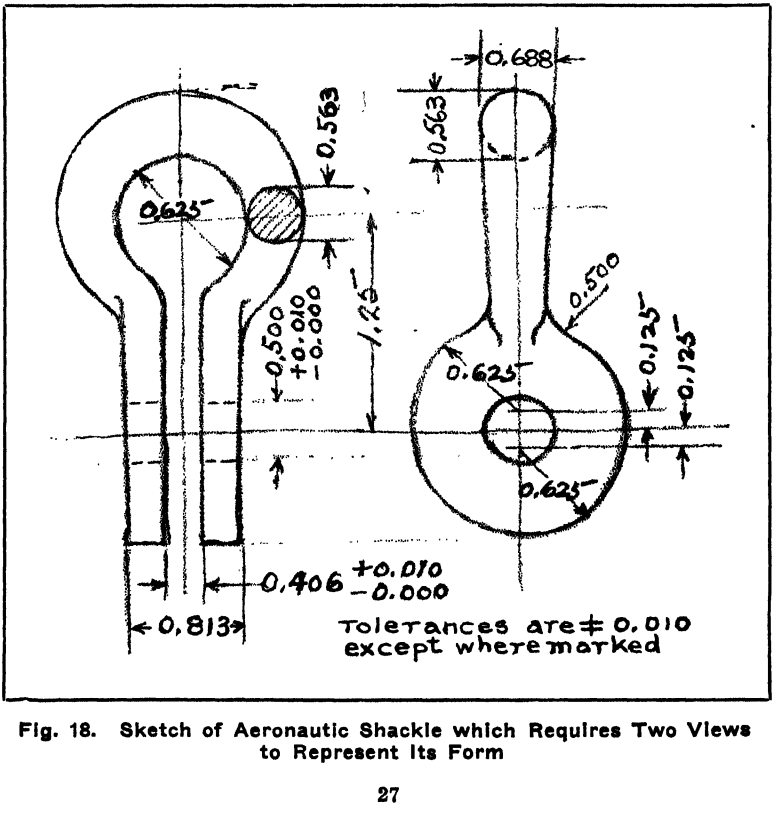


Fig. 18. Sketch of Aeronautic Shackle which Requires Two Views to Represent Its Form

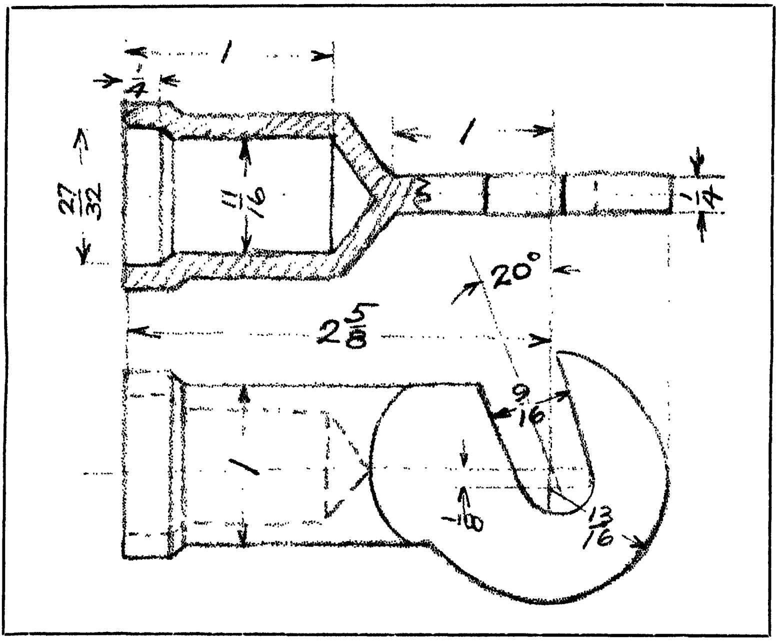


Fig. 19. Sketch of Battery-tray Terminal Lug which Also Requires Two Views

sible to determine definitely the shape of the lower part, which, as will be noted, is not round, but oblong. Note, also, that the upper half or ring-shaped part is made of round stock that tapers from the top toward the flat part of the shackle as indicated by the diameter of the small section as compared with the diameter at the top. A note shows that the tolerances are either plus or minus 0.010 inch, excepting where other tolerances are given.

Another sketch requiring two views (see Fig. 19) represents an S.A.E. standard battery-tray terminal lug. The lower view shows the hook-shaped end and the upper view the width of this end. An end view might have been added in this case, but the mere fact that it is not included indicates that the left-hand half of the terminal lug is round.

Sketches Requiring Three Views

The bracket shown by the sketch Fig. 20 requires three views to represent its shape. The plan view shows the circular form of the pad or raised part on the top of the bracket, and the end view at the right shows the shape of the lower part and the width of the central stiffening rib as well as the location of the bolt holes. If any one of the three views is removed, it will be evident that the sketch is incomplete.

The sketch, Fig. 21, shows a propeller blade clamp-ring designed and proportioned according to S.A.E. recommended practice. This is another example of a part requiring three views. The upper or plan view, however, is broken off to show only the shape of the bolt lugs at the left. While this plan view might have been made complete, all necessary

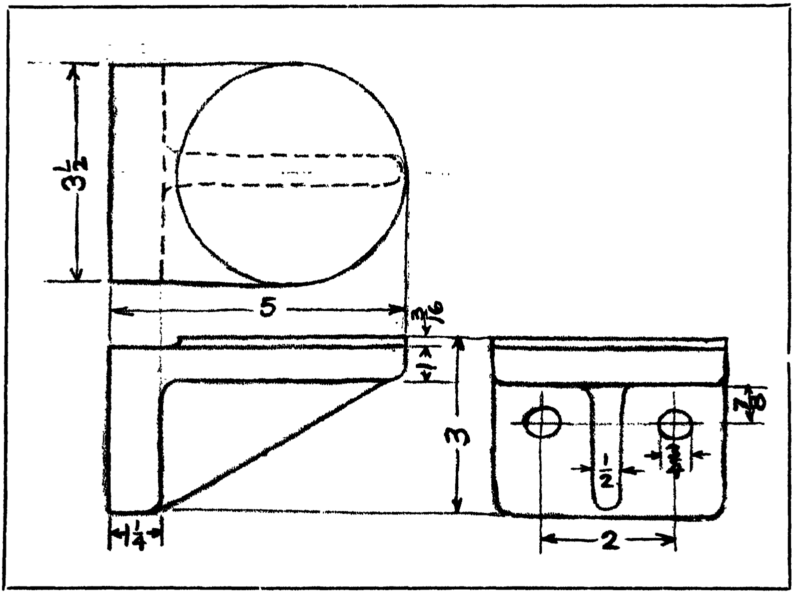


Fig. 20. Sketch of a Bracket Requiring Three Views to Show Its Form

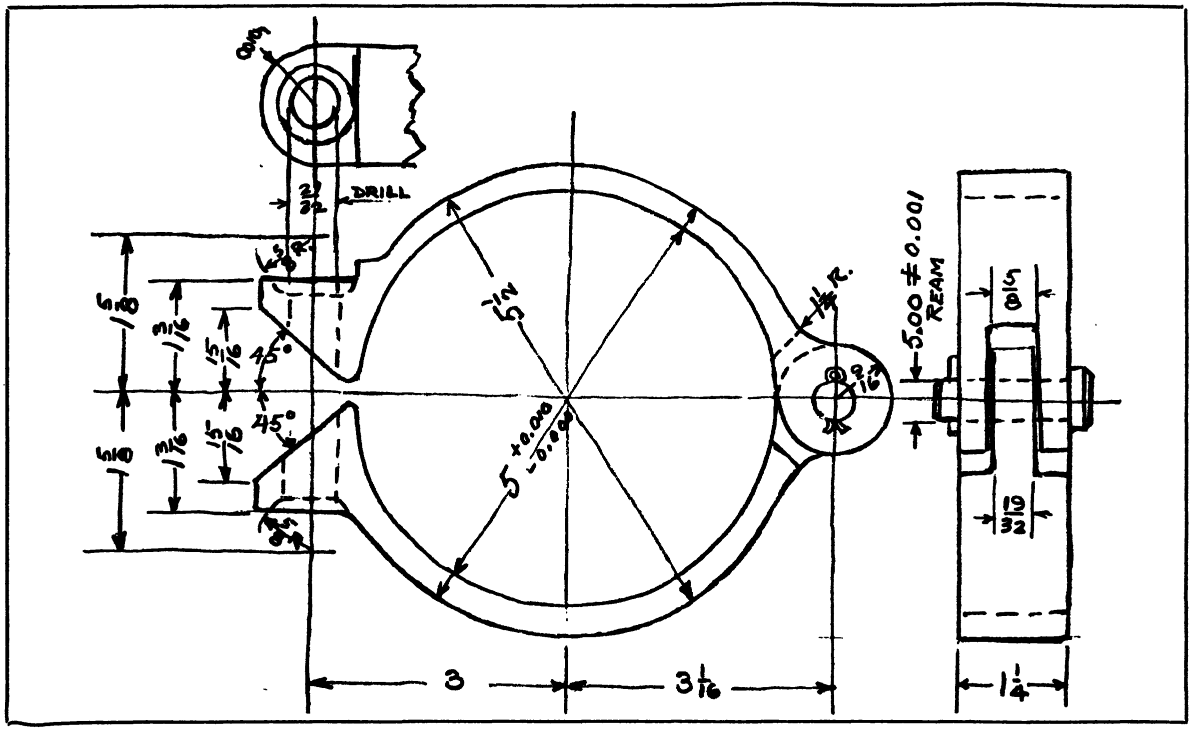


Fig. 21. A Propeller Blade Clamp-ring. This is a Pencil Sketch Drawn Upon Smooth Paper which is the Reason Why the Lines of this Reproduction are Darker than Those of Sketches Like Figs. 20 and 22

information about the shape and proportions of the hinge at the right is given on the side and end views. This particular sketch was made on smooth paper, which explains why the lines are darker than those of sketches like Figs. 18, 19 and 20, which were made on paper having a rough stipple surface.

The Use of Sectional Views to Show Interior Shapes

You doubtless have seen airplane and automobile motors, which, for demonstration purposes, have had sections cut away to show interior passages and the relative movements of important parts, such as pistons and valves. This scheme of showing sections is applied extensively, both in making sketches and in mechanical drawing practice.

Sectional views are especially useful for showing interior shapes. If a plain cylindrical part has a hole through it, this hole can be represented clearly by dotted lines and without drawing a sectional view; but when there are various interior parts and passages, the use of numerous dotted lines would be confusing and a sectional view is much clearer. Fig. 1 is an example illustrating this point. The valve and its stem are not shown in section because this is unnecessary. Moreover, this unsectioned part provides a contrast which makes the drawing clearer than one completely sectioned. The arms of pulleys and gears are not shown in section, although the cutting plane is supposed to pass through them. This practice is also followed ordinarily for parts such as bolts, shafts, and other details which do not require sectioning.

Sections usually coincide with the long axis of the object (as in Fig. 1) or they are at right angles to this axis. The first are known as longitudinal sections; the second class, as right or cross-sections. Oblique sections, which neither coincide with the longitudinal axis nor are perpendicular to it, are sometimes required. In fact, the cutting plane for the section may lie at any angle necessary to show clearly the interior shapes or details. Some sectional views, also, represent an object as though it were cut through partly on one plane and the remainder of the distance on another plane taken either at a higher or lower level as may be required. Such a section should be supplemented by a guide line on a plan or other view, indicating just where the different cutting planes lie; and, in such cases, there should be a note

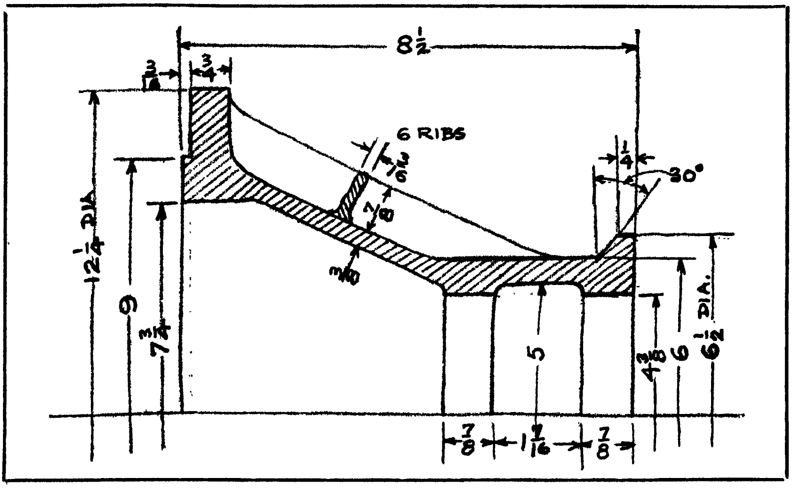


Fig. 22. If a Part is Symmetrical or Has the Same Shape Each Side of the Center-line, Half-sections Like this One Often Save Time and Serve Practical Purposes

below the sectional view, such as, "section on lines AB, BC, and CD."

Sketches Simplified by Drawing Half-views or Sections

The art of sketching lies partly in knowing where to stop in order to avoid wasting time and making sketches unnecessarily complicated. For example, if the shape of a part is symmetrical or the same on each side of a center-line, a half-section or drawing often will meet the requirements.

The sketch, Fig. 22, is an example. The outside diameter at each end is followed by the abbreviation "Dia." to indicate clearly that the part is circular in cross-section. A note shows that there are six stiffening ribs; and the sectional view on the one rib included in the sketch shows the width and the shape.

This sketch would have a more finished appearance if the lower half had been added, but such an addition would not contribute any information about the shape or proportions; consequently, half-sections like this are often used both on sketches and on regular mechanical drawings. It is possible, however, to abbreviate sketches so much that the saving of time is more than offset by lack of clearness.

Establishing the Size of a Sketch

Clearness is the essential point in determining the size of a sketch. In other words, it should be drawn large enough to clearly show all details. If the object is so large that only a very small sketch, or one greatly reduced in scale, could be drawn upon a sketch pad, a series of sketches representing different sections on a larger scale might be necessary. In sketching mechanisms having considerable detail and requiring two or more views, and possibly a series of sections or other details, it is better to use a separate sheet for each view than to crowd two or more on one sheet. An unusually small part of a mechanism may be enlarged to show the details clearly and provide room for dimensions and notes where required.

It is a good plan for engineers and designers who make sketches frequently to adhere to one or two standard sizes to facilitate filing sketches for future reference. The 8½- by 11-inch size is large enough for average work and standard loose-leaf binders may be obtained for this size, assuming that binders are to be used for filing.

PROPORTIONING THE DIFFERENT PARTS OF A SKETCH

Drawing straight and circular lines is one thing, and placing them where they belong is another. It is evident that the appearance and accuracy of a sketch depend upon the relative lengths and positions of the different lines composing it. Proportioning the different parts should not be a matter of judgment entirely; in fact, many sketches may be proportioned chiefly by the method of procedure. Some of the examples to follow will demonstrate this point and show that employing the right method often simplifies greatly the placing of lines at least within gunshot of where they belong.

A sketch may be lop-sided, top-heavy, and distorted generally, but "get by" so far as strictly practical requirements are concerned; and yet nearly everyone prefers to see a reasonably neat well proportioned sketch, especially if such improvements do not require more time than is needed for poor sketching. The point is that well executed sketches may be made by such direct reasonable methods that time is not wasted in erasing every other line and in fiddling around generally. The "sloppy" sketch often is the result of drawing in an aimless haphazard way rather than lack of skill.

Draw the Main or "Foundation Lines" First

In all sketching, an important point to remember is that the foundation lines should be drawn first. This point may be emphasized repeatedly because of its importance. The first few lines that you draw determine, as a rule, not only the general proportions of the sketch, but its appearance as

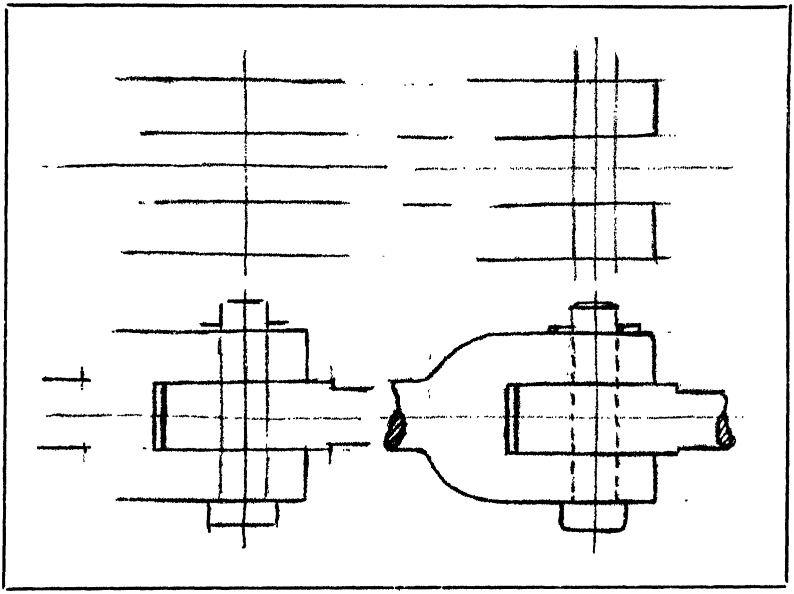


Fig. 23. Sketch of a Knuckle Joint. This Sketch has been Divided Into Different Stages to Show Method of Procedure

well. Just what is meant by drawing the foundation lines is illustrated by the very simple example shown in Fig. 23. This sketch of a knuckle joint is accompanied by three preliminary steps or stages which illustrate how easily a sketch of the right size and proportions can be made when the first half-dozen lines are placed where they belong.

In making this particular sketch, first draw the horizontal center-line and then four horizontal parallel lines spaced so that the inner part of the joint is somewhat wider than the outer sections of the forked member. Next, draw a vertical center-line for the pin. The sketch is now as represented in the upper left-hand corner of the illustration.

In connection with the second stage, draw lines spaced to suit the pin diameter. Since these lines, excepting at the top, represent a part of the pin that is concealed, they may be drawn in lightly, using the edge of the pad as a guide,

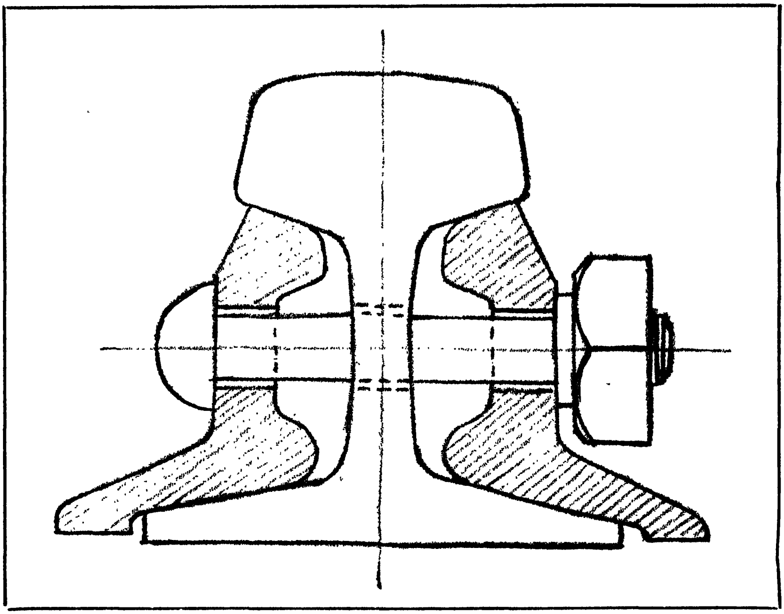


Fig. 24. Example Illustrating How the Part Being Sketched Often Can be Used as a Measuring Stick in Obtaining Relative Proportions

and then be dotted in afterward free-hand. Draw vertical lines locating the end of the fork, thus completing the second stage.

The procedure in connection with the third and fourth stages should be apparent from the illustration. Note how easy it is to change Stage 1 of the sketch into Stage 2, Stage 2 into Stage 3, and the latter into the completed sketch. In all sketching, the more you rely upon method, the less skill will be required.

Using a Part Being Sketched as a Measuring Stick

Relative dimensions or proportions of the part being sketched often provide the best, and, in fact, the only safeguard against making certain lines or sections much larger or smaller than they should be. This point is illustrated by the sketch, Fig. 24, which shows one of the standard shapes for railroad rail splice-bars. This is not, of course, intended as a complete sketch as the latter would require a side view. Dimensions would also be needed, but these have been omitted on many of the sketches here used since the primary object of these particular sketches is to illustrate sketching principles and methods of procedure.

Referring to Fig. 24, first draw the vertical and horizontal center-lines, and then the horizontal line for the bottom of the rail flange. Note that the width of this flange is about the same as the total height of the rail, and in this way establish the flange width and the total height of the sketch. Note that the average thickness of the rail-head is about one-fourth of the total height of the rail. (In sketching a curved part such as this head, it is helpful to first draw lightly a rectangle and use these lines as a guide in drawing the sloping sides and curved part.) In laying out the width of the head, note that the width at the top is about equal to the height of the web. Note that the thickest part of the web is about the same as the thickest part of the flange.

After the rail has been well proportioned by noting relative sizes as described, the splice-bar sections can be drawn in readily. In actual sketching practice, the proportioning may not be thought out in quite as much detail as here described, but the main object in referring to these details is to get over the important principles involved.

Procedure in Making the Sketch, Fig. 25

The sketch, Fig. 25, is another example typical of the kind which might be used as a practice exercise in proportioning. This represents an end view of a four-wheel carrier which moves along the rail shown in section and serves to support any load-carrying device. Here is another example where

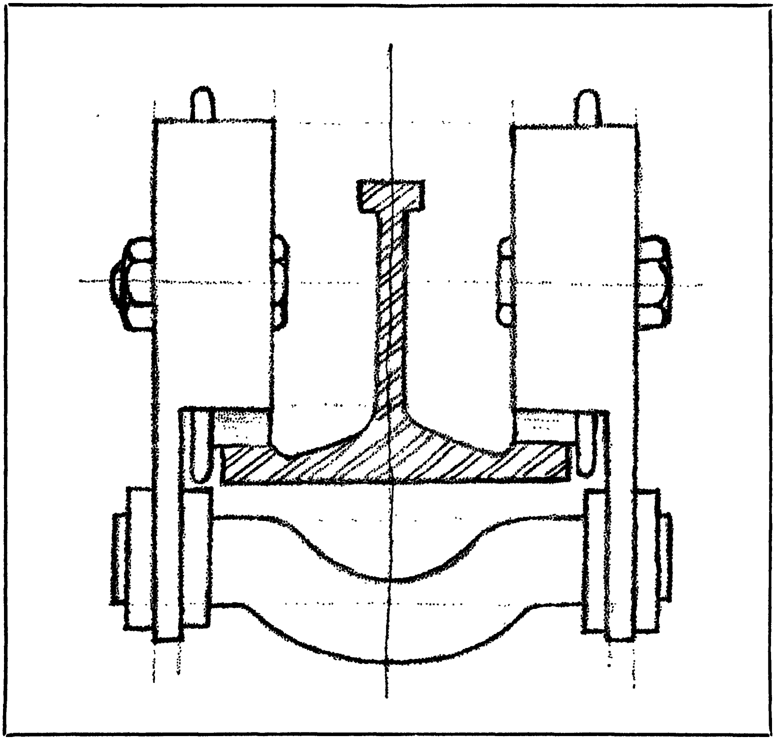


Fig. 25. This is Another Examp.e of a Sketch Proportioned by Noting Relative Sizes of Different Parts

a side view would be required in connection with a complete sketch.

In drawing this end view, note that the upper half of the end view is divided into four approximately equal sections represented by the right and left ends of the carrier and the spaces between the rail web and these ends; hence, begin by drawing five equally spaced vertical lines (including the vertical center-line), the spacing being in accordance with the size of sketch desired. Continue by drawing vertical lines for the web of the rail and then horizontal lines for the bottom of the rail flange. Notice that this flange

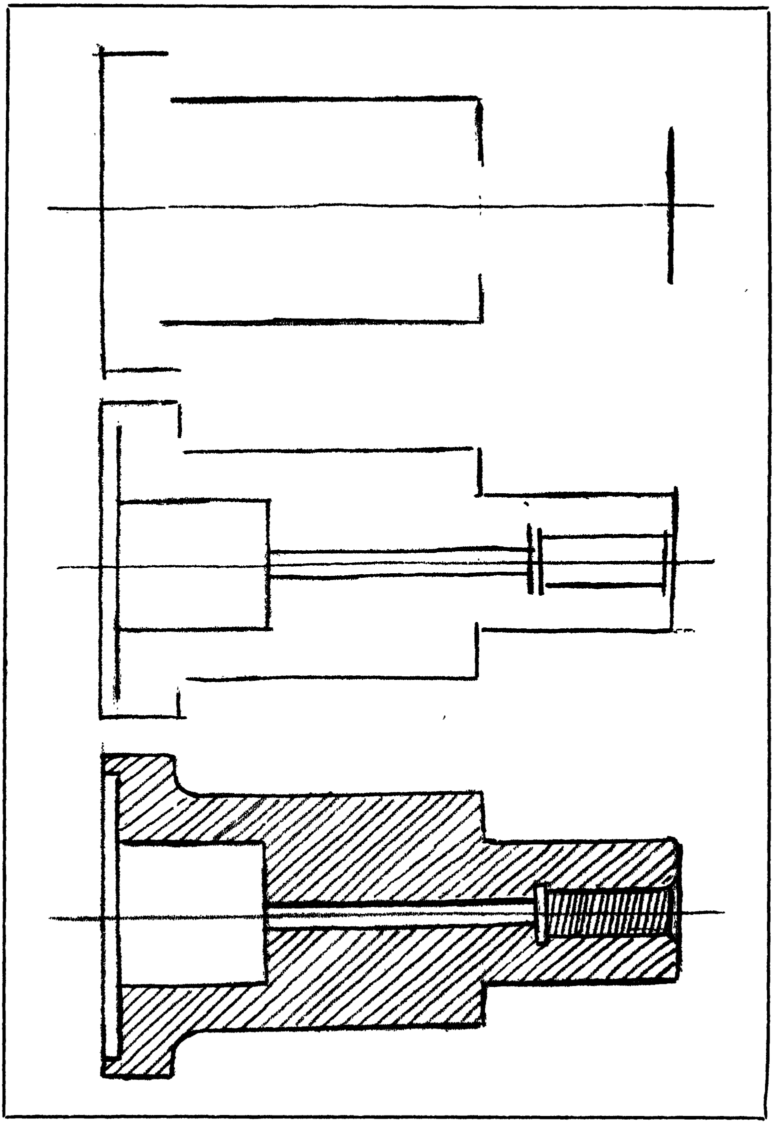


Fig. 26. Example Showing How a Sketch is Proportioned and Built Up by First Drawing the Foundation Lines

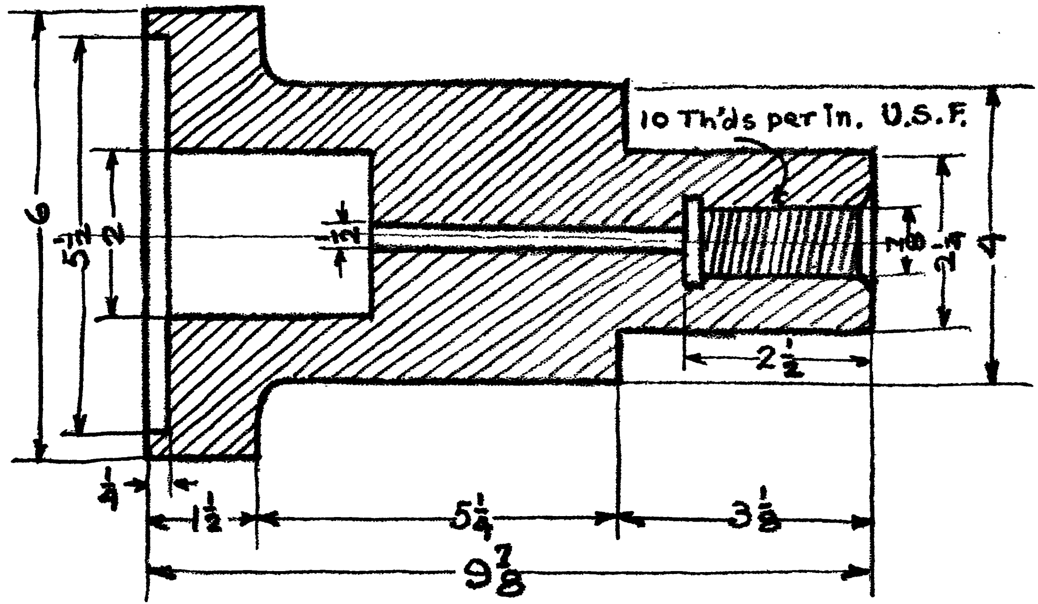


Fig. 27. Sketch Made as Illustrated in Fig. 26 with Dimension Lines Added

extends to the center of each end of the carrier. When the sketch has reached this stage, there should be no difficulty in adding the details.

Example Illustrating Importance of Foundation Lines

Fig. 26 shows the two preliminary stages in making the sketch shown in section. The first stage does not make much of a showing, and yet it is very important because the few lines shown establish the main proportions of the sketch and its size.

In making this sketch, first draw the center-line and parallel horizontal lines on each side of the center-line, representing the diameter of the main body. Next draw a vertical line approximately equal in length to the flange diameter. Next draw horizontal lines for the flange size, noting the relation between this flange diameter and the body diameter. The end of the body is then laid off by vertical lines, and finally the vertical line at the extreme right is spaced from the end of the body a distance, in this case, equal to about one-third of the total length of the piece.

The work done during the second stage is clearly indicated by the illustration. The exact order in which these lines are drawn might be varied more or less, but it is well to follow whatever order makes the next step easier.

An additional sketch of this part is shown in Fig. 27 with the dimensions added. Check this sketch and see if you can find anything wrong with it. In making such a check, assume that you are to make a part like this. Does the sketch give complete information?

"Practice Makes Perfect" in Estimating Dimensions

Men who have had considerable experience in mechanical work, in designing departments or shops, can, as a rule, estimate or judge small dimensions with considerable accuracy. This is due to the fact that the daily use of measuring scales and other instruments so trains them that any small dimension, such as 1 inch, 3 inches, or 6 inches, is carried in the mind's eye. This training not only enables such men to guess, often with surprising accuracy, the dimensions of a given part, but also to lay off any given distance provided it is within the range of comparatively small dimensions common in mechanical work.

This ability of judging dimensions and proportions is, of course, very helpful in sketching. The latter, however, requires estimating the dimensions of one part relative to another rather than the actual dimensions. If a dimensioned sketch of some part is required, these dimensions are, of course, obtained by the use of scales, calipers, micrometers, etc., the practice being to first make the sketch and then transfer to it each measurement as it is taken. Such measurements have nothing to do with the practice exercises referred to in the next paragraph, since these are merely to improve one's judgment of relative sizes and of given dimensions, so that one unaccustomed to such work will be more proficient in the proportioning of sketches.

How Accurately Can You Guess Dimensions?

If you are handicapped in establishing proportions and dimensions, a little practice will very quickly result in decided improvement. Begin by marking on a piece of paper the width and thickness of any object, such as a book, for example; then compare the distance between these marks with the object. At first, attempt to mark down the actual sizes. Then continue these exercises by laying off widths, thicknesses, or lengths which are reduced to half-size and then to three-quarter size.

Another series of exercises which will train one's judgment consists in attempts to lay off actual dimensions. Upon a piece of paper make two marks 7½ inches apart as nearly as you can estimate this dimension. Make these marks near the top of the sheet and then fold over this upper strip so as to conceal the marks. Then try again to lay off 7½ inches. After making a third trial, continue with a series of three trials at 3½ inches, and finally a series of three trials at one inch.

A number of men of wide experience in mechanical work were given this simple test and it was found, as a rule, that the tendency is to make short dimensions long and long dimensions short. For example, in attempting to lay off a dimension of one inch, 76 per cent of the distances were over one inch. The 3½-inch tests showed that the marks were over 3½ inches in 75 per cent of the trials. On the contrary, when these same men attempted to lay off 7½ inches, 80 per cent of the distances were too short. It was found, however, that the individual usually is consistent in that he generally is either short or long on all three trials for a given length. These errors in judgment, however, are very quickly corrected. For example, if your guess as to one inch turns out to be 1⅛ inch, it is quite likely that a second or third trial will largely correct this error; hence, the value of a little practice conducted along the lines referred to.

Determining Relative Dimensions By Sighting with a Pencil

In sketching an object of any kind, the scheme of using a pencil as a measuring stick is an old one that is often helpful. This method has long been employed by artists as well as by draftsmen. The pencil is held at arm's length (see Fig. 28) and parallel to the measurement required. The thumb is then moved along until the distance from the thumb to the end of the pencil apparently coincides with the part being measured as nearly as can be determined by sighting over the pencil. In other words, the length or width of the object is projected onto the pencil, and to a scale that is reduced as the distance between the object and the pencil is increased. An actual dimension of one foot, for example, is equivalent to about two inches of pencil length when held by the writer at arm's length and at a distance of ten feet between the pencil and the object. If your arm is longer than mine, you would, of course, get a slightly different result in so far as the reduction in scale is concerned. This

Fig. 28. Sighting Along Pencil to Obtain Proportions of Part Being Sketched by Projecting Its Length Upon the Pencil

scheme is merely to determine approximately relative proportions.

Suppose that the total length of a part when projected onto the pencil is equivalent to a very small part of the pencil length. Then it would be necessary to move closer to the object in order to enlarge the scale and avoid too great a reduction in the size of the sketch. This method of sighting with a pencil, if used at all, is employed more especially for a few of the main proportions.

Practice Exercises to Train the Hand and Eye

Begin by sketching simple parts like the ones shown in Figs. 15 to 20. Do not be too anxious to sketch rapidly, but remember the old adage and "make haste slowly." A little deliberation, especially when drawing the main or foundation lines, usually pays in the end. Take a good look at these main lines and study the relative positions and lengths before beginning to sketch.

Start these practice exercises by copying small drawings of simple machine parts; then gradually work up to the more complicated designs. "Everybody makes mistakes," they say, and that is why they put rubbers on lead pencils —but try to sketch without a lot of erasing. Rubbing out lines continually not only wastes time, but too often denotes careless work. If the rubbing-out habit is growing on you, discard the pencil and use a fountain pen temporarily. The pen makes it necessary to avoid erasing and tends to develop the plan of thinking while you draw.

When you can copy simple drawings without difficulty, make sketches of machine parts, castings, and finally of complete mechanisms, beginning with the simpler designs. In checking a sketch of a machine part, imagine that you must reproduce the part from a sketch. If the sketch is complete, it indicates clearly the shape of the part and gives all of the important dimensions.

When Measurements of Parts are Required

Sometimes it is necessary to make sketches of broken or worn parts of machines which may be located at some distant point. It is possible that lack of information on such sketches might cause considerable trouble and expense. In making such a sketch, the measurements are obtained from the old piece and measuring tools would be required. These may include a graduated rule or scale, ordinary calipers, micrometer, height gage, depth gage, square, straight-edge, thread gage for determining pitches, and possibly other types of measuring and gaging equipment.

It is impracticable to specify the equipment or to explain how the measurements should be taken because each job presents a new problem and frequently offers an opportunity to exercise considerable ingenuity. It is important to remember that the measurements should be taken after the sketch is completed and all dimension lines have been added to it. When the sketch is finished, take each measurement and fill in that dimension before measuring any other part.

HOW TO BUILD UP SKETCHES UPON THEIR FOUNDATION LINES

Everyone who has had experience in construction work knows how important it is to start right. Even a dog house requires a little planning if it is to be worthy of a good dog as well as an ornament to the back yard.

In making any sketch, do a little thinking or planning before drawing even a single line. The reason why this is important will be illustrated by several sketches which are shown in different stages of completion to demonstrate how the sketches have been built up upon the foundation lines or framework.

A Sketch Divided Into Four Stages to Show Procedure

Figs. 29 and 30 show what might be called the evolution of the sketch of a self-lubricating wheel for a pan conveyor. Before starting any sketch, consider carefully which lines will serve best as the foundation and then draw these first. In this case, inspection will show that the width of this wheel is about equal to its radius; hence, draw the horizontal center-line and then horizontal lines above and below for the tread of the wheel as shown at the left in Fig. 29. Now draw vertical lines spaced a distance apart equal to the wheel radius. These few lines of the first stage establish the size of the sketch. It will be understood that distances are not actually measured, but are laid off entirely by judging relative proportions.

Compare the few lines of this first stage with the finished sketch and note how they have fixed the general proportions

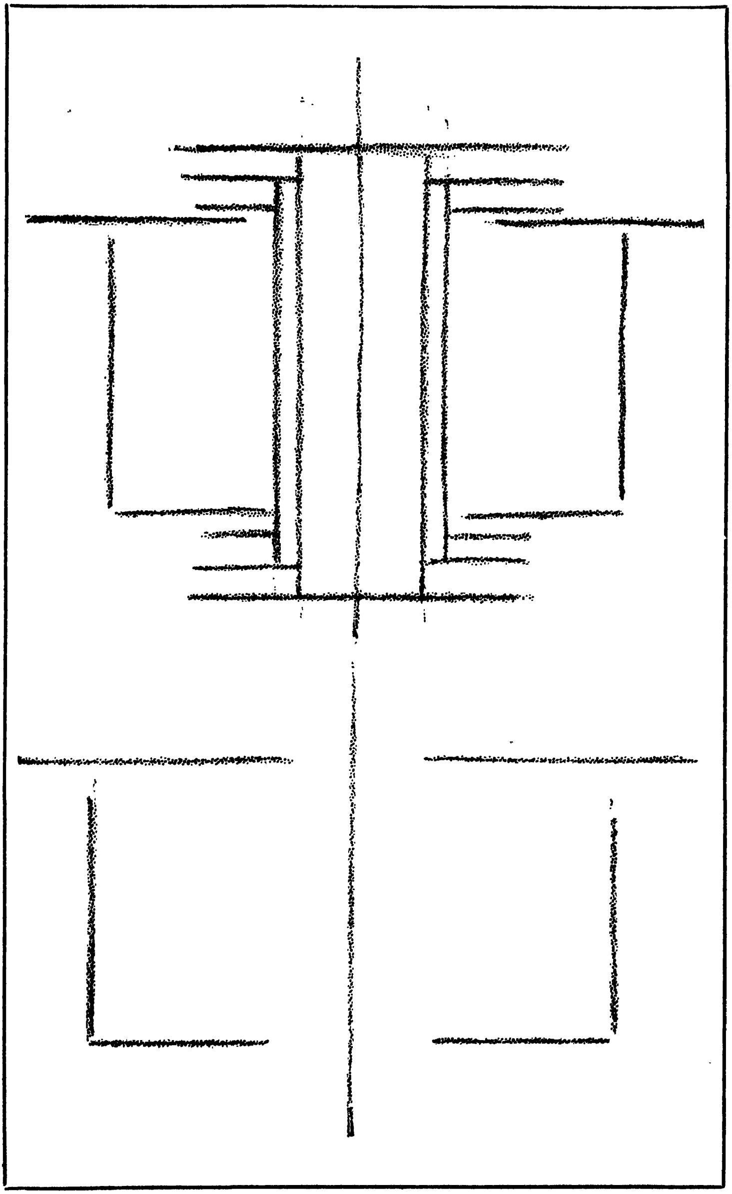


Fig. 29. The First and Second Stages in Making the Sketch Shown in Fig. 30

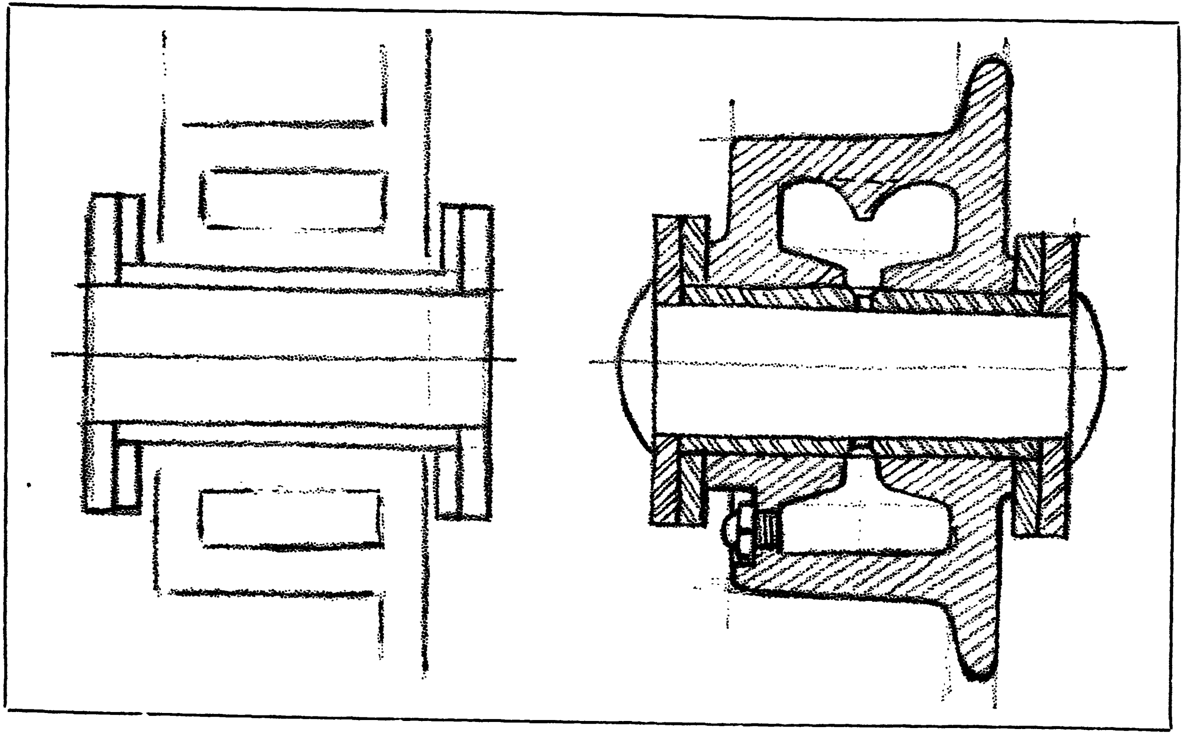
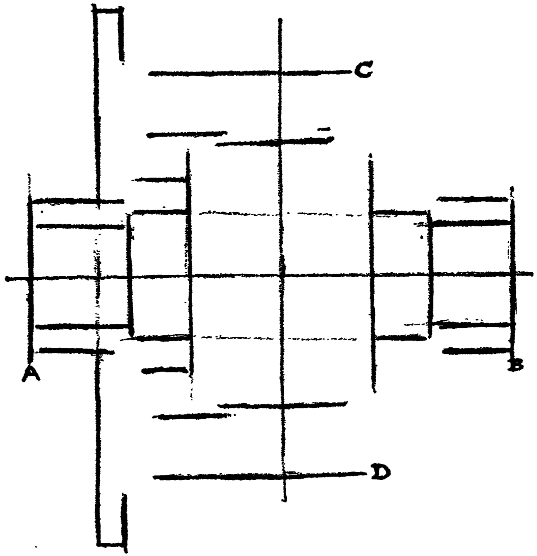


Fig. 30. The Third and Final Stages in Sketching a Self-lubricating Conveyor Wheel



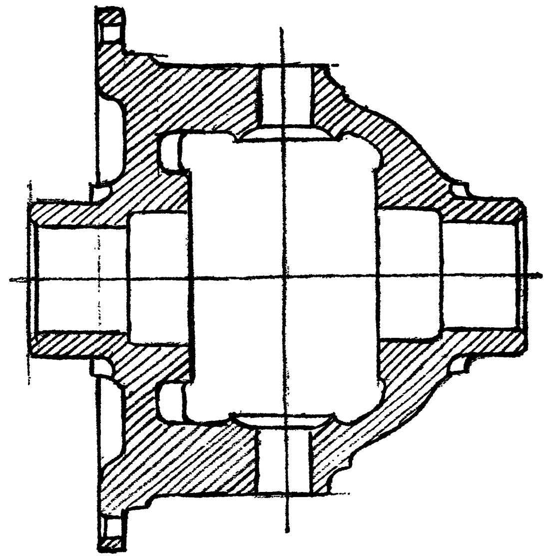


Fig. 31. The Foundation Lines for the Sketch, Fig. 32, of a One-piece Differential Housing

Fig. 32. Finished Sketch Made by Adding the Smaller Details to the Skeleton Drawing, Fig. 31

so that the work of adding other lines and details is greatly simplified. Very little time, however, is required for this first stage—just a little thinking and the building-up of a sketch according to a definite plan instead of working aimlessly.

Continuing with the second stage (shown at the right in Fig. 29), draw horizontal lines for the bearing pin; parallel lines for the bushing; and vertical lines representing the side links of the conveyor chain. The sketch at this second stage has a very unfinished appearance; and yet, changing the second into the third stage, and the third into the completed stage, involves much less work than might be supposed. Moreover, if one were to use the second stage as the starting point, it would be difficult to avoid making a well proportioned sketch. The third stage (at the left, Fig. 30) consists in blocking-out the inside cavity of the wheel, drawing light guide lines for the wheel flange, and completing the side links.

In making this sketch or others illustrated in this treatise, the exact procedure here described need not be followed necessarily. There are no fixed rules governing work of this kind, and the only object in illustrating and describing these different stages is to demonstrate what are considered the fundamental principles of good sketching practice.

The Horizontal and Vertical Lines of this Sketch Comprise 84 Per Cent of the Total Number

The sketch of a differential housing, shown in Fig. 32, might easily be distorted greatly if not drawn with reference to the foundation lines. In this sectional view 84 per cent of the lines are either horizontal or vertical, not counting the small fillets and the cross-section lines; consequently the actual drawing of the lines is not difficult. The appearance of the sketch depends very largely upon locating properly the few lines shown in the first stage.

Making the Skeleton Drawing, Fig. 31

First draw the horizontal and vertical center-lines. Then draw the vertical lines *A* and *B* equidistant from the vertical center-line, thus establishing the size of the sketch in a horizontal direction. Also draw the two vertical lines representing the width of the central space. It should be noted that these two lines divide the distance from *A* to *B* into three approximately equal spaces.

Next draw the vertical line for the flange face and then short horizontal lines representing the flange diameter. This diameter exceeds the horizontal length *AB* somewhat, although to determine this would require accurate judging of the relative dimensions. The point is that if the flange diameter is fixed by noting this relationship, the sketch will be fairly accurately proportioned unless the one making it is a poor judge of relative dimensions.

Continue by drawing horizontal lines *C* and *D* equidistant from the horizontal center-line. Draw horizontal lines for the bore, counterbore, and for the outside diameters of the right and left ends. Continue by drawing horizontal lines, fixing the height of the inner cavity, and also vertical lines for the depth of the right and left counterbores.

Whenever lines are duplicated on each side of the sketch, draw these corresponding lines on both sides before changing the position of the pencil for other lines. For example, after drawing the line for the bore on the left-hand side, continue by drawing a similar line on the right-hand side and proceed in the same way in drawing the right- and left-hand counterbores. This method not only saves time but insures accurate proportioning of duplicate parts.

Converting the Skeleton Drawing Into a Finished Sketch

If the few foundation lines, Fig. 31, are located somewhere near their correct positions, a well proportioned sketch is assured. This will be evident by noting the relationship between this skeleton drawing of the first stage and the finished sketch, Fig. 32. It is often advisable to draw these preliminary lines lightly to begin with and then make them heavier when the respective positions and lengths have been more definitely determined. This applies particularly to rather complicated sketches, the drawing of which may be greatly simplified by exercising a little care in locating the foundation lines.

The sketch as represented in Fig. 31 is much nearer completion than many would suppose, because filling in the smaller details is easy when the important lines have been located properly. The procedure in changing the second stage into the completed sketch should be apparent from an inspection of the two illustrations. It consists chiefly in adding small lines and details to a well proportioned framework.

Another Example of Sketching by Building Upon the Foundation Lines

The sketch, Fig. 33, represents a boiler manhole with frame, yoke and cover of pressed steel. Begin by establishing the foundation lines as in previous examples. Referring to the first stage (upper left-hand corner of illustration), draw the vertical center-line; then draw the horizontal line at the bottom, making its length equal to the diameter of the manhole cover, reduced, of course, to whatever scale is wanted for the sketch. In this particular design the cover diameter over the flange is about equal to the over-all length of the bolt, or in other words, to the total height of the sketch. Draw short horizontal lines for the upper end of the bolt and the top of the yoke. Note that the horizontal line, coinciding with the outer surface of the boiler shell, is about midway between the bottom of the cover and the top of the yoke; therefore, draw this horizontal line in that

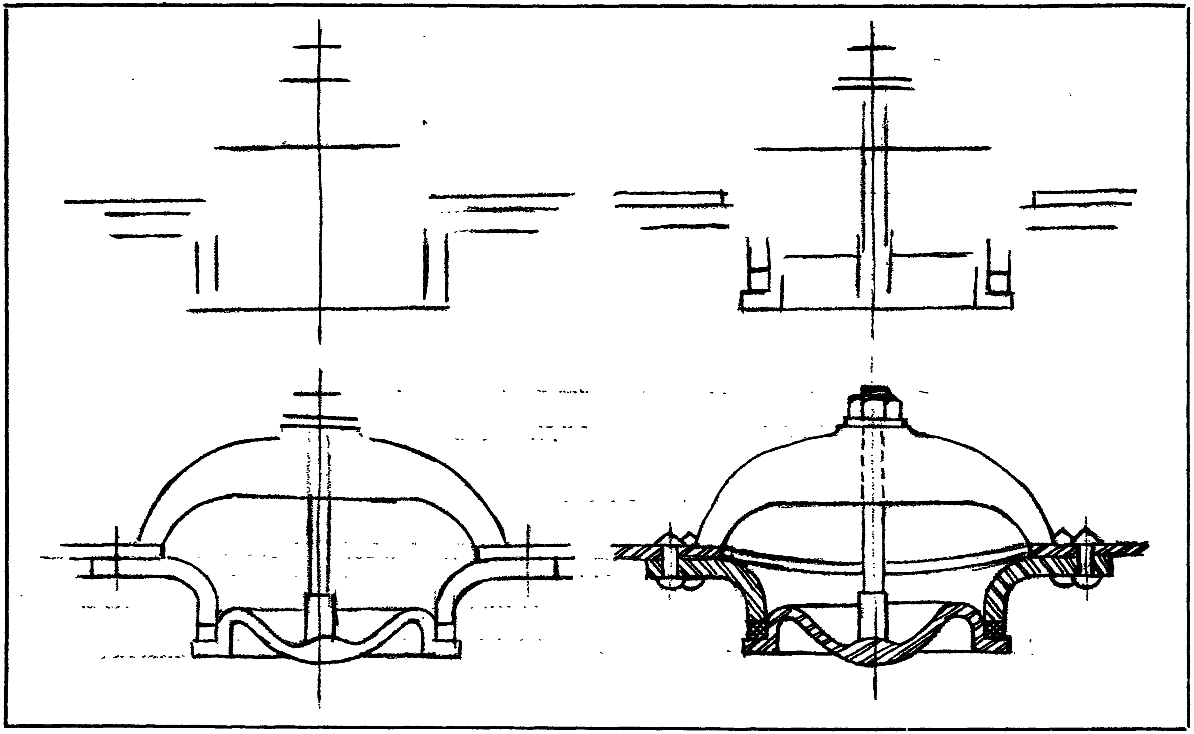


Fig. 33. Sketch of a Boiler Manhole, Including Preliminary Stages to Show Method of Procedure

position. Then draw parallel lines spaced to suit the thickness of the boiler shell and additional lines for that part of the flange which is riveted to the shell. The addition of vertical lines representing the manhole opening completes this first stage.

The second and third stages show how the other lines are added, the principle being to draw all lines in the order of their importance, which in turn depends upon their length and the extent to which they assist in proportioning the sketch as a whole.

Making a Sketch of a Globe Valve

The sectional view of a globe valve, Fig. 35, is a good example of a sketch that would be difficult to proportion properly without building it up from a few carefully drawn foundation lines. If you consider this sketch a very difficult one to make, look at the preliminary stage, Fig. 34. Can you draw these few lines and place them somewhere near their correct positions? If so, then you can also add to this skeleton sketch the smaller details which are needed to change Fig. 34 into the complete sketch, Fig. 35. If there is any doubt on this point, try your hand at it and you will be surprised to discover that there is much less difference between the first and final stages than is indicated by mere appearance.

The Skeleton Drawing for First Stage of the Globe-valve Sketch

The first stage of the globe-valve sketch, Fig. 34, is marked with similar letters wherever the proportions are approximately equal, as nearly as can be judged by the eye. In other words, the object itself is used as a measuring stick as shown by preceding examples.

To begin with, note that the length *a* of the valve body is about equal to height *a* from the horizontal center-line to

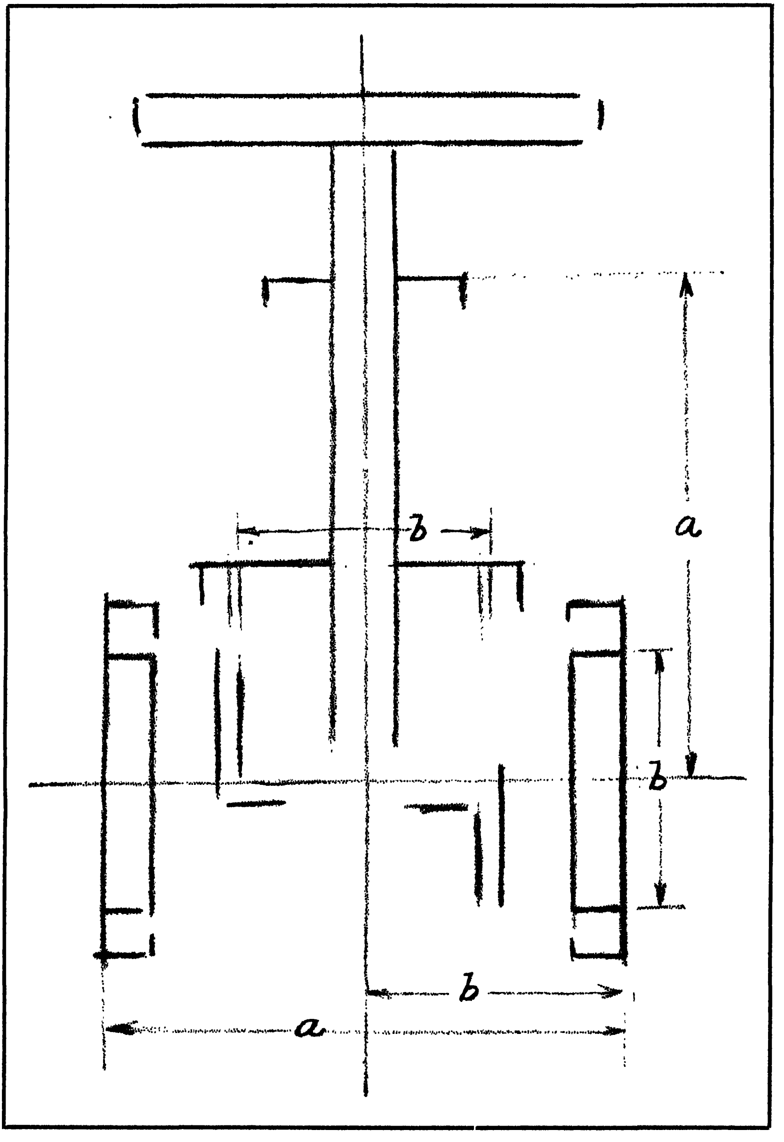


Fig. 34. The Foundation Lines or Skeleton Drawing for the Globe-valve Sketch Shown in Fig. 35. These Few Lines are Very Important

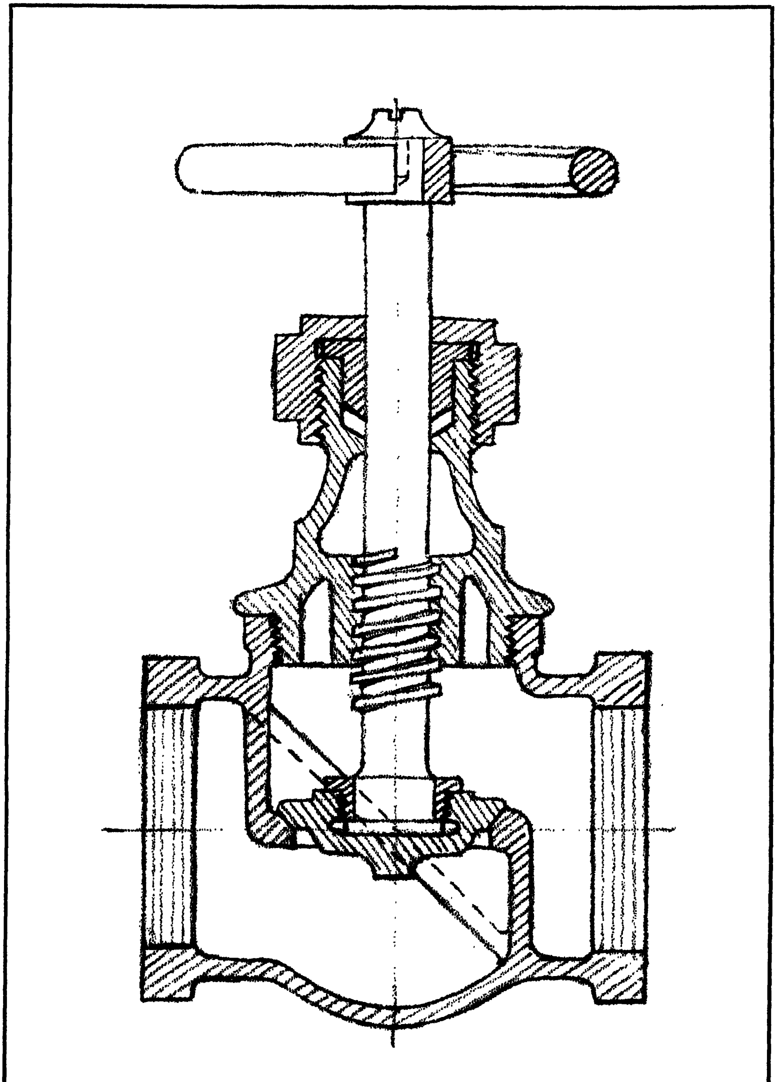


Fig. 35. Sketch which Would be Difficult to Proportion, Excepting by Building It Up from Carefully Drawn Foundation Lines

the top of the packing-box nut. Now note that one-half the length *b* of the body is about equal to the diameter of the tapped holes in the body ends, and also that the bonnet thread in the top of the body is equal to *b* as nearly as can be judged. When length *a*, height *a*, and diameters *b* have been laid off to whatever scale is desired for the sketch, a very important part of the work has been done because fairly accurate proportions for the main parts have been established.

Lines for the vertical sections of the wall inside of the valve body are drawn to line up with the bonnet thread at the top of the body. The vertical lines for the valve-stem are spaced in relation to the general proportions of the valve, and horizontal lines are drawn for the handwheel which is placed above the packing nut at whatever distance appears to be approximately correct.

Finishing the Globe-valve Sketch

In completing the sketch, all of the smaller details are proportioned directly from the main lengths and diameters. For example, the valve proper intersects the horizontal and vertical center-lines, and its diameter is fixed by the vertical interior walls, the lines for which have been drawn during the first stage of the work. The handwheel diameter is a little less than the body length *a* and all other parts are proportioned by noting their relationship, especially to the main locating lines.

From this point on, the work consists in adding small details which make quite a showing because they change the skeleton drawing into a finished sketch; however, there is no great difficulty involved in adding these details because this part of the work is something like adding weather-boards and shingles to a well constructed framework of a building. If you can draw the few lines represented by the first stage, there is no reason why you cannot finish this sketch. In actual sketching practice, sketches usually are not as neat and precise as the one shown in Fig. 35, although it is well to remember that the accuracy of form and line is largely the result of the method of procedure.

The exact procedure as described in connection with this and other examples is not governed by cast-iron rules and might be varied more or less without affecting the final result. In other words, the order in which different lines are drawn might not be precisely as here suggested. The exact method as represented by the different stages has been explained somewhat in detail, partly to illustrate the working principle and also because the procedure as described appears to be logical and conducive to the building up of a well proportioned sketch by following a natural, practicable method.

Procedure When Circles Form an Important Part of the Sketch

If a large circle forms a prominent feature of a sketch, it should always be drawn first (using one of the methods illustrated in Figs. 12, 13 and 14). The sketch of an engine crank disk and pin, Fig. 36, is a case in point. The large circle representing the circumference of the crank disk was drawn first, and then the horizontal and vertical center-lines were drawn. In drawing circles by the methods previously described, it may not be possible to locate the center exactly where it is wanted, as, for example, at the intersection of two center-lines previously drawn; consequently, the circle is drawn first and then it is comparatively simple to locate the center-lines approximately in the central position.

In making sketches like Fig. 36 requiring two views, light projection lines (which may be seen faintly in the illustration) are drawn from one view to the other so that the proportions will be the same on each view. In this case, for example, projection lines were used to extend the diameter of the circle over to the sectional view, and the same method was followed in drawing the hub and crankpin.

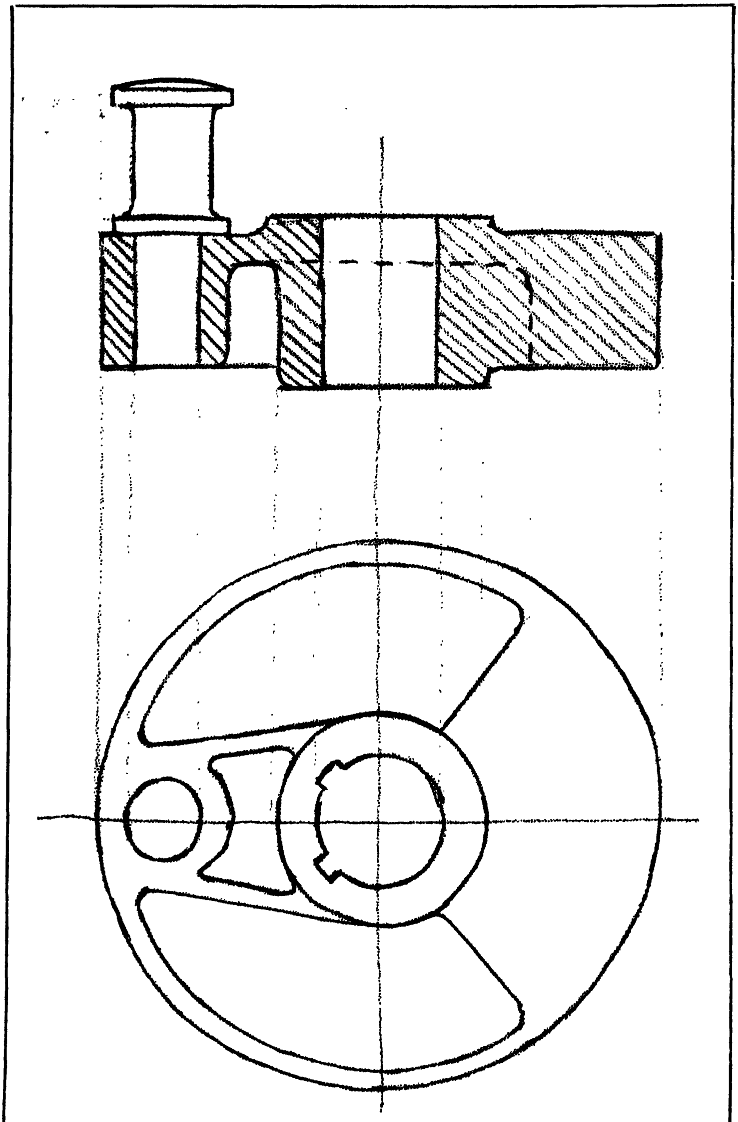


Fig. 36. Example Illustrating Procedure when a Circle Forms an Important Part of a Sketch

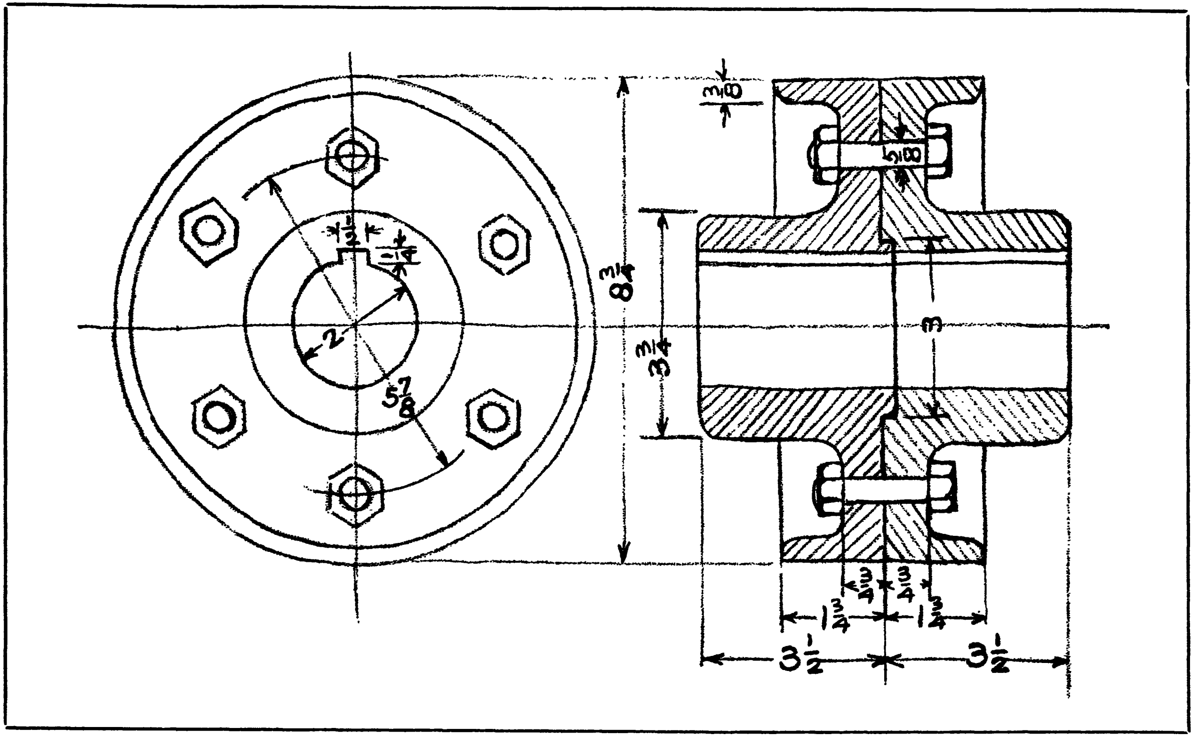


Fig. 37. End and Sectional Views of a Shaft Coupling

Sketch of a Shaft Coupling

The sketch, Fig. 37, shows sectional and end views of a shaft coupling. After drawing the outer circle, the inner one representing the inside of the coupling flange might be drawn free-hand by merely following the outer circle. Usually it is more convenient to draw a concentric circle in this way, especially if it is close to another circle which can be used as a guide.

Sketches should be simplified as far as possible and an end view of this coupling might be avoided. In fact, as a general rule, an end view of such a part would not be considered necessary. Everyone likely to use such a sketch knows that a shaft coupling is circular and the diameters of the bore and of the bolt circle might have been added to the sectional view. The number of bolts could be indicated by some note, such as "6 equally spaced bolts." A small detail view could be used to show the keyseat dimensions. Another common method is to use a note such as the following: "Keyseat 1/2 by 1/4 inch." It is understood that the 1/2-inch dimension is for the keyseat width, and the 1/4-inch, the depth as measured at the side.

Examples of Sketches Containing Circles or Large Arcs

Examples of sketching, Figs. 38 to 40, further illustrate some of the points referred to in connection with circles, and also show something of the general procedure in building up sketches of different kinds.

The ink sketch, Fig. 38, illustrates a special form of slotted cross-head or Scotch yoke. The Scotch yoke is a well-known type of mechanism for eliminating the irregularity of motion common to all ordinary crank drives and it transmits what is known as a harmonic motion. The particular design shown has, in addition to the usual vertical slot, a horizontal

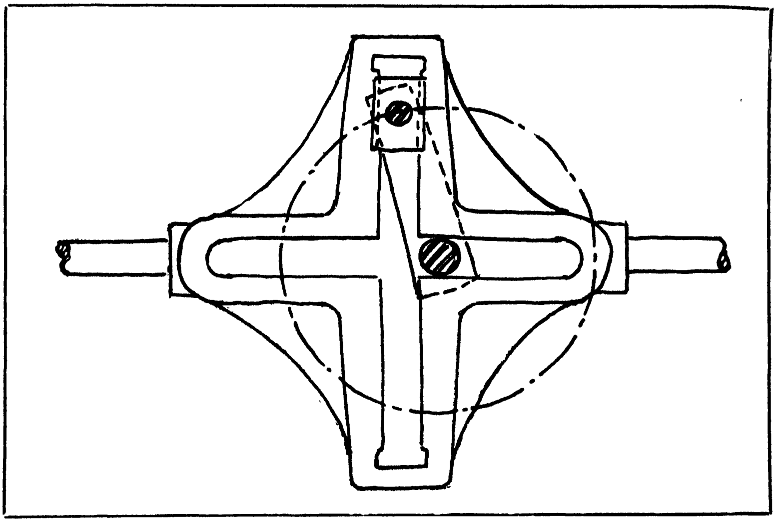


Fig. 38. Ink Sketch of a Special Form of Slotted Cross-head or Scotch Yoke

one forming a clearance space for the shaft so that the latter can be continuous and be supported on each side of the yoke.

In making this sketch, the circle representing the path of the crankpin should be drawn first. Next draw the horizontal center-line and then lines for the yoke shaft ends, slots, and other details. Light preliminary lines often are used to advantage, especially in establishing the main proportions of a sketch.

Sketch of a Special Ratchet Mechanism

The sketch, Fig. 39, shows a friction ratchet mechanism equipped with a pawl of the worm type. When the pawl lever is moved in the direction indicated by the arrow, the thrust is against the plain thrust bearing at the right and the resulting frictional resistance prevents the worm from revolving so that it acts as a ratchet and turns the wormwheel. When the pawl lever is moved in the opposite di-

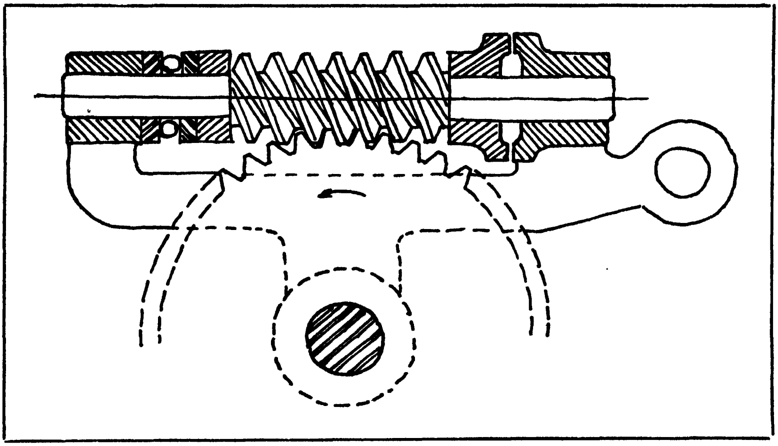


Fig. 39. Ink Sketch of a Friction Ratchet Mechanism of the Worm-gearing Type

rection, the thrust is against the ball-thrust bearing at the left which offers very slight frictional resistance, so that the worm revolves and the worm-wheel remains stationary during the backward movement of the worm.

In making this sketch, which was also drawn in ink, the worm-wheel arcs were drawn first in pencil. Next, horizontal pencil lines were drawn coinciding with the outside diameter and root diameter of the worm, the worm being proportioned with relation to the size of the worm-wheel. A center-line is then drawn for the worm and bearings, in ink, after which it is easy to establish the other lines and details. As a general rule, center-lines are drawn first; but it was easier to proportion this sketch by proceeding in the manner described.

Use of Large Circle as Basis in Proportioning Sketch

The mechanism shown by the ink sketch, Fig. 40, is a ratchet-and-pawl mechanism designed especially for moving

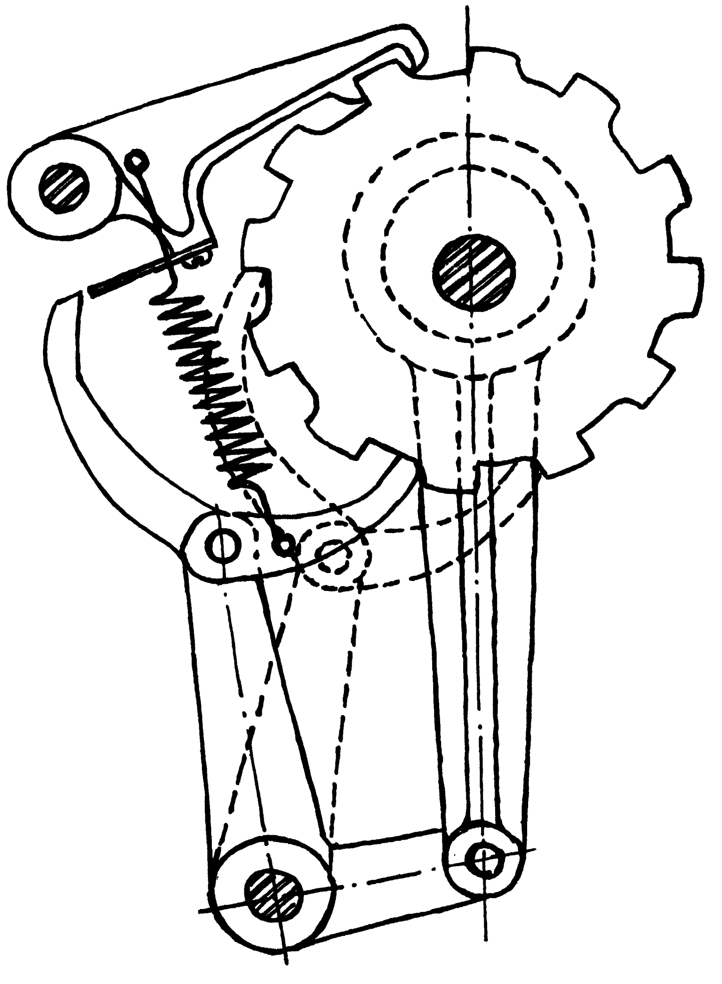


Fig. 40. Ink Sketch of a Ratchet-and-pawl Mechanism Designed Especially for Moving Heavy Loads Intermittently and Accurately

heavy loads intermittently and accurately. The ratchet wheel is locked positively during the idle period, and a positive stop prevents over-travel and insures uniform intermittent movements.

This is another example where the circular part is drawn first and to a size which establishes the proportions of the other parts of the sketch. In sketching this mechanism, draw first a circle for the circumference of the ratchet wheel, using a light pencil line to serve as a guide line in drawing the tops of the teeth. (In this case a pencil should be used for the guide circle, in preference to a pen, to permit drawing a continuous line.) The next step would be to draw a vertical center-line through the center of the ratchet wheel and on this mark off the length of the vertical link which connects the eccentric of the ratchet wheel with the bell-crank at the lower part of the mechanism. The size of the circle and the length of this link establish the main proportions of the sketch and provide a basis for proportioning the other details.

After a few of the long and more important lines have been drawn in proper relation to the ratchet wheel circle, a well proportioned sketch is assured. On the other hand, if a sketch like this is started in the wrong way, a badly mixed-up mess is likely to be the result.

Dividing Circles Into a Given Number of Spaces

In making sketches like the one shown in Fig. 40, it is necessary to divide, with a fair degree of accuracy, a circle into a given number of spaces. While sketches are not supposed to be very accurate, a reasonable degree of accuracy is desirable because excessive distortion makes sketches difficult to understand. Furthermore, accuracy obtained by following the right methods usually saves time in the end.

In dividing circles for locating on sketches ratchet-wheel teeth, etc., first divide the circle into four divisions by drawing horizontal and vertical center-lines. Then, each quarter section may be divided into the number of spaces required, and this can be done quite accurately without dividers, especially when each quarter section contains a whole number of divisions.

Details, such as ratchet teeth for example, might be eliminated on many sketches; requirements of this kind depend upon the purpose of the sketch and the ideas of the sketcher

Fig. 41. Drawing a Curved Line or Arc of Large Radius by Swinging the Pencil from the Elbow which Serves as a Pivot

as to neatness and finished appearance. One should remember, however, that the orderly and logical way of sketching not only is conducive to neater and more accurate work, but usually requires less time than sketching by haphazard methods. In other words, if you *think* while you draw, there is much less fiddling around, erasing, and changing.

Drawing Arcs of Large Radius

Certain sketches require curved lines or arcs which do not deviate much from a straight line since the radius is comparatively large. Curves of this kind can be drawn easily by using the elbow as a pivot provided a table, desk, or large drawing-board is at hand. The elbow rests upon the supporting surface as shown in Fig. 41 and by swinging the arm, the pencil is made to draw an arc, the radius of which is somewhat greater than the length of the forearm. This method is recommended when conditions are such that it is convenient.

GENERAL RULES FOR DIMENSIONING SKETCHES

Some of the sketches in this book have been reproduced without dimensions in order to reduce the number of lines and illustrate more clearly the procedure in building up the sketch itself. In other words, the chief object of this book is to teach the making of sketches. Most of the sketches used in the mechanical industry, however, are accompanied by dimensions. In some cases, only main or over-all dimensions are given, as shown, for example, by Fig. 1; but when sketches are used as working drawings, complete dimensioning is, of course, required.

The method of dimensioning any drawing is very important. When dimensions are being placed on a sketch or other drawing, it is well to keep in mind the different machining operations that will be required in producing the part. The dimensions and other data, such as angles, notes, etc., should be complete enough to enable a workman to machine the part without asking questions. This relationship between the dimensioning of a drawing and the machining of a part represented by it, is one reason why draftsmen and designers in general should have at least a general knowledge of shop practice. Another very important reason is to enable the designer to produce parts on paper so as to promote, as far as possible, efficient manufacturing practice.

General information on dimensioning will be found in books on mechanical drawing so that no attempt will be made in this treatise to cover the subject completely. There are, however, certain principles and rules which should be applied, and these will be outlined briefly.

Where to Place Dimensions

Dimensions should be placed on whichever view (assuming that there is more than one) shows most clearly the part of the drawing to which the dimension applies.

If a part has several different diameters throughout its length, as, for example, a shaft with shoulders of different sizes, place these diameters on the side view and not on the end view so they will show more clearly the section to which each dimension applies. This general rule also applies to parts having concentric holes or openings of different sizes.

Most dimensions and dimension lines are placed outside of the drawing itself to avoid a confusion of lines. In many instances, however, it is preferable to place dimensions within the outline of the drawing, especially when there are clear spaces and the dimension can be placed closer to the part or detail that it applies to.

A center line should never be used as a dimension line, but it is also bad practice to use any line of the drawing itself as a dimension line.

The diameter of a hole, unless quite large, should not be placed inside the hole, but projection lines should be used as illustrated in Figs. 18 and 20. In dimensioning circles, give the diameter and only use the radius in dimensioning arcs of circles.

Give Dimensions which Assist the Machinist or Toolmaker

Give dimensions which are related to surfaces from which a workman can and should measure directly, since this insures greater accuracy and avoids wasting time.

On sketches or drawings of jigs or other parts in which several holes are to be bored in a jig-boring machine, it is good practice to give all dimensions from common base lines located at right angles to each other. This method of dimensioning would also apply to work done on a milling machine, a horizontal boring machine, or any machine arranged to locate the work for boring different holes by adjusting it in two directions at right angles to each other.

Dimensions of a given part should not be repeated on different views because if changes have to be made on the drawing some of the duplicate dimensions may be overlooked; and, furthermore, the number of lines on a drawing should be reduced as far as possible to make the drawing clear or easier to read.

Expressing Large Dimensions in Feet and Inches

Dimensions are usually expressed in inches if less than 36 inches; in some plants, 48 inches is the limit. There are, however, certain exceptions to the use of feet and inches for long dimensions; for example, the stroke of a steam engine, or the length of the wheel-base of an automobile or locomotive, is given in inches regardless of the length.

When all the figures on a drawing represent inches and not feet and inches, it is common practice to omit the signs (″) which indicate inches.

Practice When Tolerances Are Not Given

It is the general practice to use decimal fractions in dimensioning parts requiring accuracy and ordinary fractions when accuracy is not especially important. In some plants it is customary to assume an allowable error of plus or minus 0.005 inch when ordinary fractions are used. The object in establishing a fixed tolerance for all dimensions expressed with ordinary fractions is to avoid leaving the question of accuracy entirely to the workmen.

Many finished surfaces do not require an accuracy of plus or minus 0.005 inch, and one prominent manufacturer has effected a substantial saving by establishing a fixed rule that all finished surfaces must be to size within plus or minus

1/64th inch, unless otherwise specified. When decimal fractions are used in dimensioning, the allowable errors or tolerances should always be given.

When Dimensions Are Accompanied by Tolerances

A "tolerance" is equal to the difference between the maximum and minimum limits for any given part. In other words, tolerance is the amount that a part is allowed to vary in size in order to secure whatever accuracy meets practical requirements but without unnecessary precision such as would tend to reduce production without improving the practical quality of the product. The "basic size" is a theoretical or nominal standard size from which variations are made.

The minimum hole should be the basic size whenever the use of standard tools represents the greatest economy. On the contrary, the maximum shaft should be the basic size whenever the use of standard purchased material without further machining represents the greatest economy.

The relation of the tolerance to the basic size should be in whichever direction will cause the least trouble. If a variation either way is equally dangerous, then a bilateral or divided tolerance should be used. For example, tolerances for center-to-center distances between holes usually should be bilateral. On the other hand, the tolerance for the center-to-center distance between gear-shafts should be unilateral or in one direction only and be plus, as otherwise the gears might mesh too tightly. These examples illustrate the general principle of applying tolerances.

Methods of Expressing Tolerances

If a tolerance is unilateral, it may be written as follows, assuming that the basic size is 2.250, the tolerance 0.006

and minus. $2.250 \begin{smallmatrix} + 0.000 \\ - 0.006 \end{smallmatrix}$. If the tolerance is bilateral, it may be written $2.250 \begin{smallmatrix} + 0.003 \\ - 0.003 \end{smallmatrix}$. Another common method is to give the maximum and minimum or the limiting dimensions. For example, $\begin{smallmatrix} 2.250 \\ 2.244 \end{smallmatrix}$ if the tolerance is 0.006 and unilateral, or $\begin{smallmatrix} 2.253 \\ 2.247 \end{smallmatrix}$ if the tolerance is 0.006 and bilateral.

It is incorrect to locate any point or surface with tolerances from more than one point in the same straight line. It is good practice to establish common locating points in each plane and to give, as far as possible, dimensions from these points. The dimensions of companion or mating parts should be given from the same relative locations as far as possible to assist in detecting interferences and other improper conditions.

Example Illustrating Why Unimportant Dimensions Should be Omitted

Three views of a disk-shaped part are shown in Fig. 42. If the widths *A* and *B* are the important ones, the over-all width should be omitted as shown by the left-hand sketch. If the width *A* of the flange and the over-all width *C* are the most important, dimension *B* should be omitted, as shown by the middle sketch. If dimension *A* is the least important, it should be omitted, as shown by the right-hand sketch.

Suppose that *A* equals $2.250 \begin{smallmatrix} + 0.000 \\ - 0.005 \end{smallmatrix}$; *B* equals $2.860 \begin{smallmatrix} + 0.000 \\ - 0.005 \end{smallmatrix}$; and *C* equals $5.110 \begin{smallmatrix} + 0.000 \\ - 0.010 \end{smallmatrix}$. Also, assume that all three dimensions are given and that *A* and *B* are the important dimensions.

Now if the machinist first finishes the over-all dimension *C* to the minimum length, or to $5.110 - 0.010 = 5.100$ inches, and then finishes width *A* to the maximum length

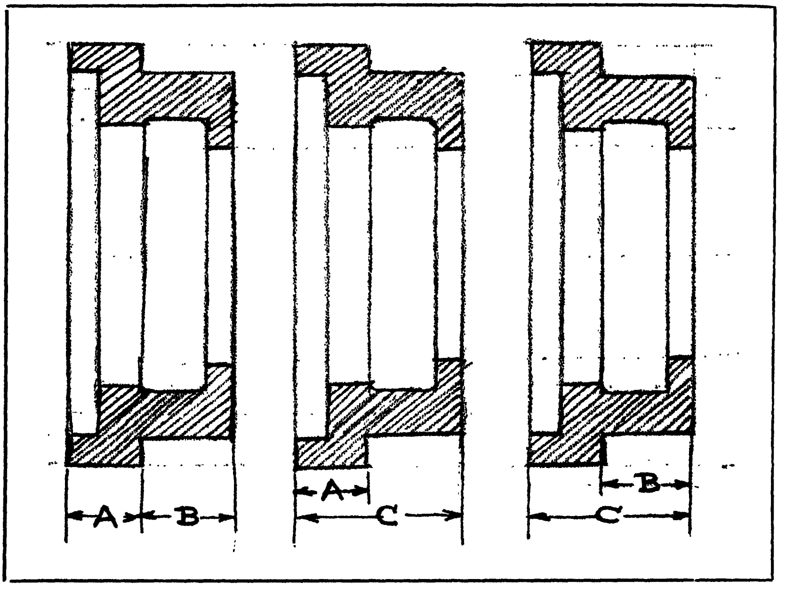


Fig. 42. If You Were Dimensioning this Part, Would You Give Dimensions A and B, A and C, or B and C?

of 2.250 inches, width *B* will equal 5.100 — 2.250 = 2.850 inches, which is 0.005 inch under the minimum length of *B*. This mistake could not be made if only the important dimensions *A* and *B* were given. This simple example illustrates a very important principle in dimensioning a drawing.

Accuracy of Measurements for Sketches

When sketches are to be used as working drawings or as a means of reproducing some mechanism or part, very accurate measurements may or may not be required. If you are making a working sketch of a broken machine part, it is evident that the measurements of that part must be sufficiently accurate to permit making a new one. In some instances, very precise measurements with a micrometer may be required.

On the other hand, suppose sketches are to be made of a complete mechanism or machine in order to reproduce the same general type, but not necessarily the exact proportions throughout. In a case of this kind, it might be sufficient to obtain fairly accurate measurements of the more important parts, and either approximate or no measurements of various small details, especially if it was considered desirable to do more or less redesigning of these smaller parts.

In taking measurements which are to be placed upon a sketch, always finish the sketch first and then insert each measurement as soon as it is taken. If you attempt to save time by placing two or more measurements on a sketch at one time, errors may result. In all mechanical work the safe way is the best way.

EXPLANATORY NOTES, ABBREVIATIONS AND CROSS-SECTION LINES

Brief notes often can be used to advantage on sketches to indicate the number or size of a drill, the size and pitch of a tap, the size and type of a screw thread, and different kinds of materials.

The use of abbreviations should be restricted to the most common ones which are generally recognized as standard. For example, such abbreviations as R.P.M. (revolutions per minute); H.P. (horsepower); U.S.S. (United States Standard); U.S.F. (United States Form—used only when the shape of the thread is standard but not the pitch); D.P. (diametral pitch); and a few other abbreviations may be considered standard due to long usage. There are other abbreviations, however, which may not be generally understood, even though some of them have been used generally in certain plants or localities. Unless an abbreviation is definitely known to be in general use, it is preferable to write out the term in full, especially in making sketches or drawings which are likely to be used by different men or in various shops.

Finish Marks on Drawings

So-called "finish marks" are commonly placed on working drawings to show what surfaces of a casting, for example, need to be finished. The letter *f* is very generally used. This letter is placed on the line representing the surface to be finished and with the cross-bar intersecting this line. In some plants, a capital letter *F* is used, the foot of the letter being placed on the line indicating the surface to be finished.

Another plan adopted by at least one large manufacturer is to use small solid triangles which are placed with the apex touching the surface to be finished. One triangle indicates a rough finish; two triangles, a medium finish; and three triangles, a fine finish. In order to avoid any misunderstanding as to these different grades of finish, actual samples are supplied both to the drawing-room and to machine operators throughout the shop. Moreover, these samples have been made up for different methods of machining, such as planing, turning, grinding, side-milling, and face-milling.

Still another method of indicating finishes is by the use of numbers or by adding numbers to the "finish marks" *f*. With a system of this kind, the meaning of each number or symbol must be indicated to the workmen by standard lists. This means that such special symbols would be meaningless to designers or machinists in other plants. Generally speaking, it is preferable to indicate by a note the kind of finish desired, especially if an exceptional quality of finish is necessary.

Representing Different Metals or Other Materials By Cross-section Lines

All sectional views require, of course, section lines to show what parts have been cut through by the intersecting plane. In making sketches, these section lines are drawn free-hand, preferably by resting the elbow and forearm upon a board or table, and drawing a series of parallel strokes at an angle of about 45 degrees and inclining in opposite directions for adjoining parts as illustrated by Fig. 1. In drawing section lines, do not hesitate but make bold, fairly rapid strokes, with lines spaced to make the sections stand out clearly.

Section lines on sketches usually are all alike. In other words, different kinds of section lines are not used to indicate the kind of metal or other material, as is done to some extent in regular mechanical drawing practice; however, there is no reason why the section lines should not be varied on sketches the same as on mechanical drawings, provided this practice will make the sketches more readable and easier to understand. The trouble with this method of indicating materials is that the different methods of sectioning, with a few exceptions, have not been universally standardized; besides, there are so many different grades of steels, cast irons and non-ferrous alloys now being used that the kind of material cannot be indicated precisely enough by any system of sectioning.

The standardization work done by such organizations as the American Society for Testing Materials and the Society of Automotive Engineers makes it possible to indicate, very definitely, different materials in common use by giving the standard symbols or numbers.

Section Lines Indicate General Class of Material Only

To illustrate the limitations of mere section lines, suppose that the drawing of a bearing is sectioned with crossed lines such as are commonly used for lead or babbitt metal. Anyone at all familiar with bearings would know that lead alone would not be used, and it would be evident that this method of sectioning indicates babbitt metal. But still this information is far from being complete, because there are many different white bearing metals all known as babbitt metal. The S.A.E. standard babbitt metals include five different compositions. One is very fluid and may be used for bronze-backed bearings, and particularly for thin linings such as are used in aircraft engines. This babbitt metal, No. 10, is also suitable for die-casting. Babbitt metal No. 11 is rather hard and may be used for lining connecting-rod and shaft bearings which are subjected to heavy pressures. It is also suitable for die-casting. Babbitt metal No. 12 is intended for bearings subjected to moderate pressures and also for diecasting. This is a relatively cheap composition because it has much less tin than the other two mentioned and a great deal more lead. The S.A.E. babbitt No. 13 is another cheap composition for use in large bearings and for light service; and this applies also to Specification No. 14.

Now on a sketch of a bearing lined with babbitt metal, the cross-section lines do give some information and are helpful in reading the drawing; but if supplemented by a note, such, for example, as S.A.E. babbitt No. 11, the information is as definite as it can be without including the exact composition of No. 11 babbitt. What has been said about white metal compositions applies also to brass and bronze alloys, as well as to steels, cast irons, and all common metals used in the production of mechanical products.

Shade Lines on Sketches

Mechanical drawings do not have shade lines ordinarily, but shading is sometimes useful on sketches to show the form of a part more clearly. The sketch, Fig. 1, is an example of shading. This method of shading consists in using light and heavy lines to represent the outline of a part. The light is supposed to come from the upper left-hand corner at an angle of 45 degrees so that all of the edges or surfaces on the opposite half are indicated by heavier lines. In order to secure a more pronounced shading effect, closely spaced parallel lines are sometimes used to make a shaft or hole appear cylindrical or a ball-shaped part appear spherical. Patent-office drawings are shaded, and shading is sometimes applied to assembly drawings of machines, particularly when they are merely intended for purposes of illustration. In ordinary sketching practice, the importance of shade lines depends upon the shape of the part.

SKETCHES OF GEARING

In making sketches of gearing, the completeness of the sketch and the number of dimensions required may vary considerably, depending upon the purpose of the sketch. Fig. 43 shows a sketch of a spur gear which gives the general dimensions of the gear blank as well as the dimensions and data needed in machining the blank and cutting the teeth. Incidentally, the half-circles, representing the outside and root diameters, have been dotted over lightly drawn full lines, although full lines on a sketch would serve the purpose. This half side-view is practically the same as a full view and it is easier to draw. Even the half side-view could be omitted if the sketch included only the dimensions required in machining the blank and cutting the teeth.

Sketch of Bevel Gearing

The sketch of bevel gearing, Fig. 44, is intended to give only those dimensions and angles required in machining the gear and pinion blanks, and in cutting the teeth on a regular bevel-gear cutter of the generating type. Sketches of gearing often are made either in connection with repairs or when work requiring a more finished drawing is not warranted. If the sketch is of a gear which is to be replaced, the pitch must, of course, be determined. In the case of spur and bevel gears, the pitch usually is based upon the diametral system but circular pitch is sometimes used, especially if the gearing is very large. A practical method of determining the pitch from measurements of a broken or sample gear will now be described.

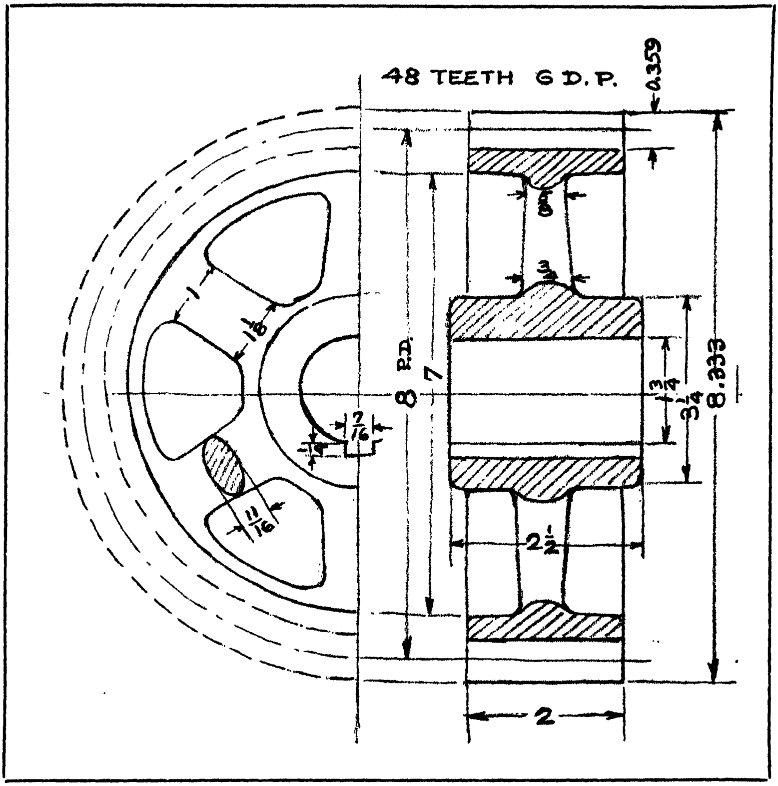


Fig. 43. Sectional and Half-end Views of a Spur Gear

Determining Pitch of Gear from Sample

Nearly all of the figures placed on sketches or other drawings represent dimensions or angles. The pitch of gearing, however, is an exception provided the diametral system is used.

Suppose a gear must be replaced, but not until the new one is at hand and a sketch is required giving all important dimensions and the pitch of the teeth. How is the pitch to be determined and how is one to know whether the pitch is

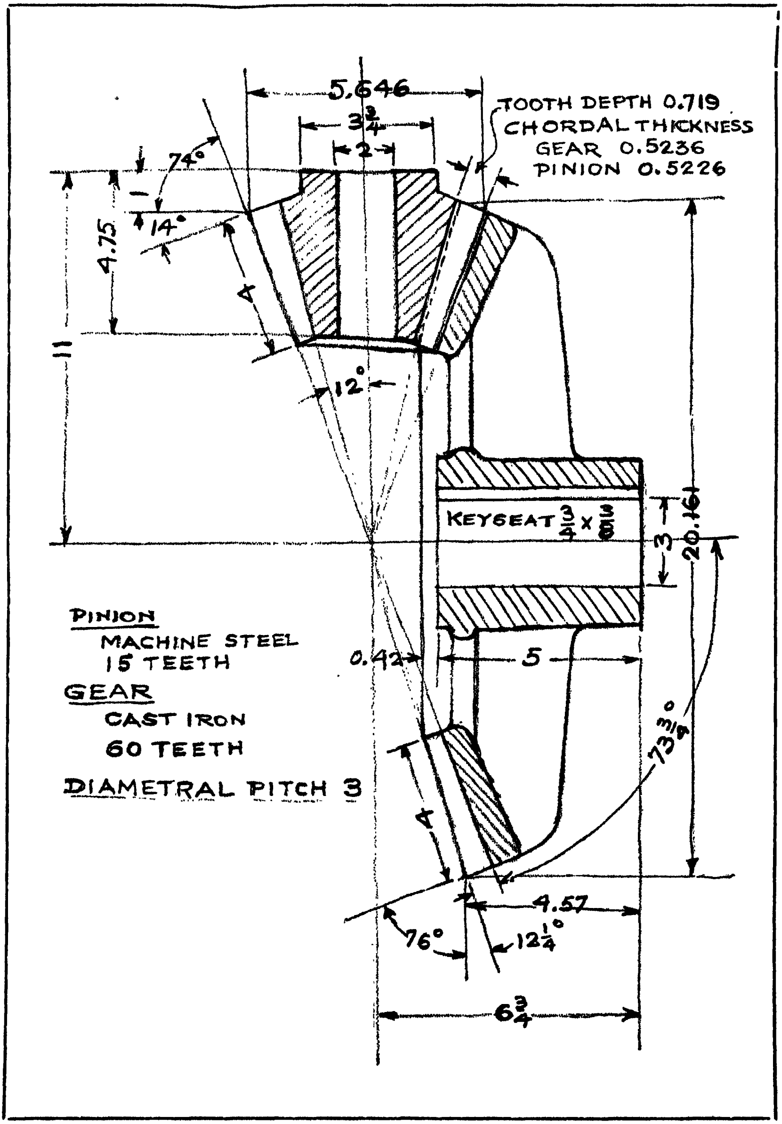


Fig. 44. Sketch of Bevel Gear and Pinion with Dimensions Required in Machining the Gear Blanks and Cutting the Teeth

diametral or circular? This is a practical problem likely to be encountered by any machinist or draftsman.

In MACHINERY'S Handbook, page 654, there is a rule and formula for determining the outside diameter of a gear when the number of teeth and diametral pitch are known. If O = outside diameter, N = number of teeth, P = diametral pitch, then

$$O = \frac{N + 2}{P}$$

If this formula is transposed to find the diametral pitch, then we have

$$P = \frac{N + 2}{O}$$

If this simple formula is expressed as a rule, then the diametral pitch equals the number of teeth plus 2, divided by the outside diameter. Suppose, for example, that a spur gear has 22 teeth and the outside diameter, or the diameter measured over the tops of the teeth, is 6 inches.
Then,

$$\text{Diametral pitch} = \frac{22 + 2}{6} = 4$$

How to Determine If Pitch Is Diametral or Circular

The circular pitch of a gear may be found by multiplying the outside diameter by 3.1416 and dividing the product by the number of teeth plus 2. Expressed as a formula,

$$\text{Circular pitch} = \frac{O \times 3.1416}{N + 2}$$

Suppose, for example, that the outside diameter of a gear is 11 inches, the number of teeth is 44, and the pitch is to be determined. Since practically all cut spur gears have teeth proportioned according to the diametral system, the rule or formula for diametral pitch would be applied first. In this case, we have

$$\text{Diametral pitch} = \frac{44 + 2}{11} = 4\frac{2}{11}$$

The fraction $\frac{2}{11}$ indicates that the pitch is not diametral but circular, because standard diametral pitches are 5, 4, 3½, 3, 2¾, etc., the fractions of all fractional pitches being either ¼, ½, or ¾. Applying the formula for a circular pitch, we have, in this case,

$$\text{Circular pitch} = \frac{11 \times 3.1416}{46} = 0.751 \text{ inch}$$

Checking Diametral Pitch by Using Center Distance

The center-to-center distance between the shafts of two mating gears may be used as a check in determining the pitch. If the total number of teeth in both gears is divided by twice the diametral pitch, the quotient equals the center-to-center distance; consequently, the diametral pitch equals the total number of teeth divided by twice the center distance; or, expressed as a formula,

$$\text{Diametral pitch} = \frac{N + n}{2C}$$

In this formula, N equals number of teeth in gear; n, number of teeth in pinion; and C, center distance in inches. This formula will be applied to the gear and pinion illustrated by the sketch, Fig. 45. The center-to-center distance is 6½ inches, the gear has 60 teeth, and the pinion, 18 teeth; hence,

$$\text{Diametral pitch} = \frac{60 + 18}{2 \times 6\frac{1}{2}} = 6$$

As a general rule, it is easier to determine the pitch by measuring the outside diameter, and sometimes this is the only dimension obtainable. Suppose, in this case, that the outside diameter had been measured using an ordinary caliper and a machinist's scale. The dimension thus obtained

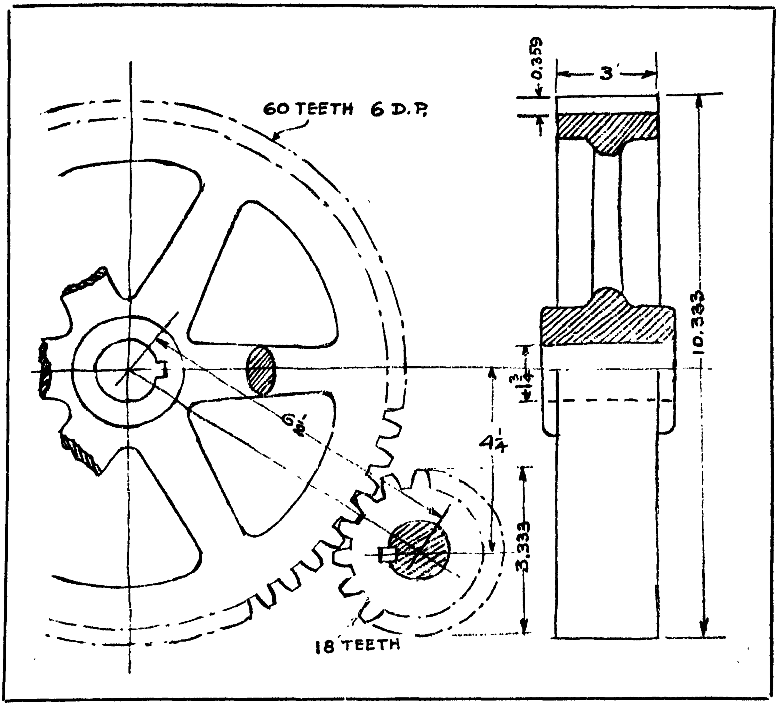


Fig. 45. Sketch of Spur Gear and Pinion Illustrating How Center-to-center Distance May be Used as a Check in Determining Pitch of Teeth

would appear to be either $10\frac{21}{64}$ or $10\frac{11}{32}$ as nearly as could be determined by the scale-and-caliper method. Assume that $10\frac{11}{32}$ is considered near enough for determining the diametral pitch. Then, using the formula previously given (see page 83), we have

$$\text{Diametral pitch} = \frac{60 + 2}{10\frac{11}{32}} = 6 \text{ very nearly.}$$

Since this final result is 6 almost exactly, it is evident that

6 diametral pitch is correct. Now the outside diameter of the gear can be determined accurately by calculation.

$$\text{Outside diameter} = \frac{60 + 2}{6} = 10.333 \text{ inches.}$$

A decimal equivalent table will show that this dimension lies between $10\frac{21}{64}$ and $10\frac{11}{32}$.

Using Center Distance as a Check on Circular Pitch

To find the center distance when circular pitch is given, multiply the total number of teeth in both gears by the circular pitch, and divide the product by 6.2832. It follows then that the circular pitch for a given center distance equals 6.2832 times the center distance, divided by the total number of teeth in both gears. Suppose, for example, that a gear has 44 teeth, the pinion 22 teeth, and a center distance of $7\frac{7}{8}$ inches. Then,

$$\text{Circular pitch} = \frac{6.2832 \times 7\frac{7}{8}}{44 + 22} = 0.75 \text{ inch}$$

USE OF CROSS-SECTION PAPER AND DIAGRAMS

A sketch drawn free-hand may be made quite accurate in its proportions and to a definite scale by using cross-section paper. In developing new designs or in originating some device, an accurate sketch often is helpful. A sketch which has been proportioned by the eye may be so distorted as to be misleading, even though proportioned by employing systematic methods such as have been described. Every designer knows that mechanisms or other mechanical devices, sometimes appear to meet requirements when roughly drawn but are shown to be impracticable after they have been drawn to scale.

Making a Sketch to a Reduced Scale on Cross-section Paper

The cross-section paper and pads obtainable from dealers in drawing materials are ruled with faint lines usually spaced either 1/10 inch or 1/8 inch apart, although there are other divisions. When a sketch is made on cross-section paper, it may be made full size, over size, or be reduced to any convenient scale; and, by using the cross-section lines as a guide, all proportions may be nearly as accurate as when drawing by the use of instruments.

To illustrate how a drawing is made to a given scale, suppose, for example, that the cross-section paper is divided into 1/8-inch sections or squares, and the sketch is to be one-fourth of the actual size of the part; then, 3 inches on the sketch equals 1 foot of actual measurement and every 1/8 inch division on the cross-section paper equals 1/2 inch.

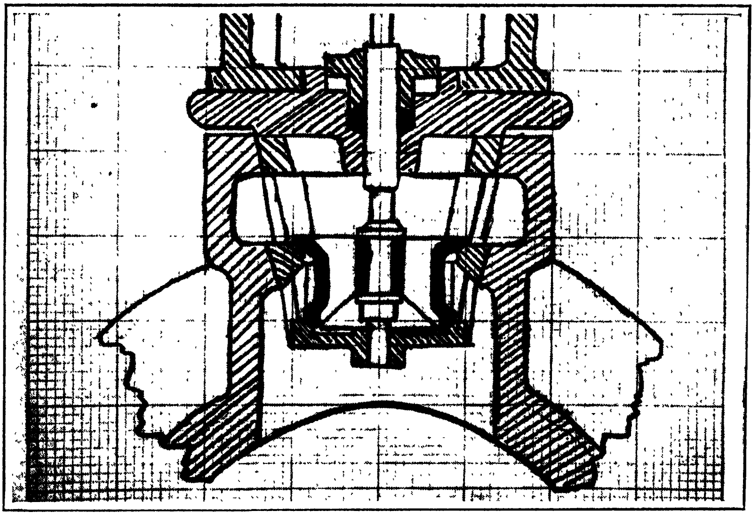


Fig. 46. Sketch of a Double-seat Poppet Valve Drawn Upon Cross-section Paper

For example, if the diameter of a shaft is 1 inch, it would be 1/4 inch on the sketch.

Many machine parts can be drawn either full size, half size, or quarter size. Assume, however, that cross-section paper is to be used in drawing the floor plan for a building; then a much larger reduction might be necessary. Thus, if 1/4 inch on the sketch equals 1 foot, the plan of a fairly large building could be drawn upon a sheet or pad of ordinary size, and all proportions be kept accurate enough for planning or lay-out purposes.

Coordinate or cross-section paper may be obtained in loose-leaf form and also in the form of pads. Fig. 46 shows a cross-section sketch pad divided into one-tenth inch divisions. The sketch on this pad has been drawn to scale and is nearly as accurate as a mechanical drawing. It represents a poppet valve which has two seats and is balanced or relieved of the steam pressure sufficiently to permit lifting the valve from its seat easily.

Transparent Sketch Pad Provided with Master Sheet of Cross-section Paper

The transparent sketch pad, Fig. 47, consists of fifty sheets of tracing paper and two master sheets of cross-section paper. One of these master sheets has 1/10-inch divisions, and the lines on the other are spaced two millimeters

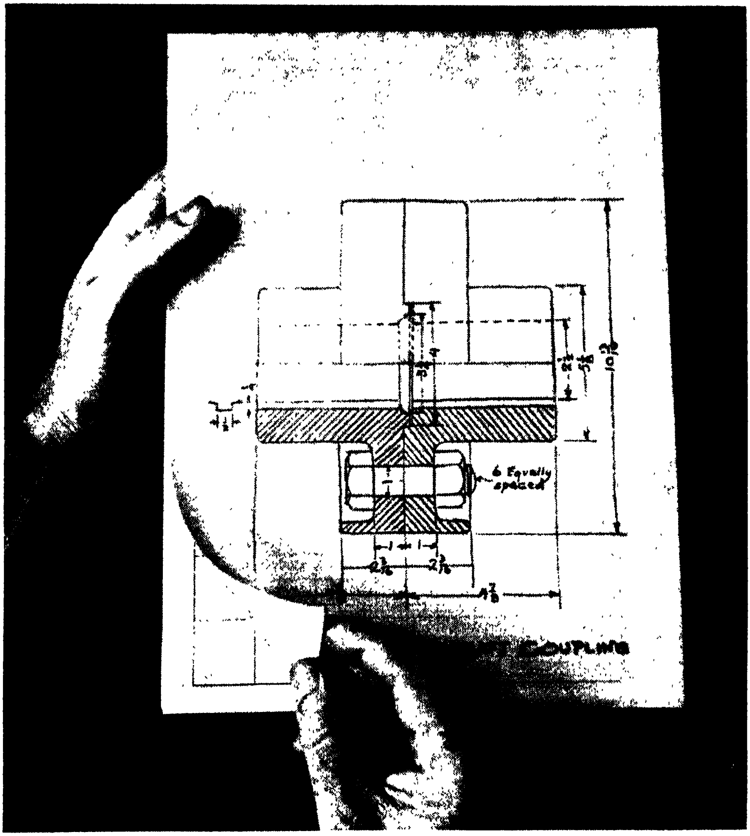


Fig. 47. Shaft Coupling Sketched Upon a Pad of Tracing Paper. A Master Sheet of Cross-section Paper is Placed Beneath the Tracing Paper to Assist in Proportioning the Sketch

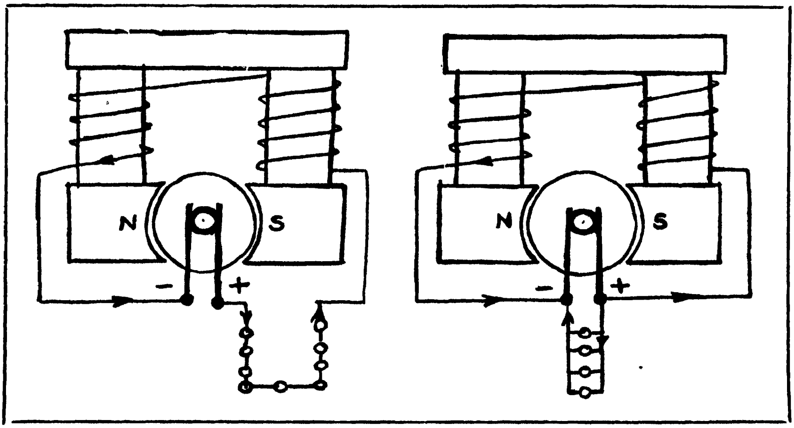


Fig. 48. Diagrams Like These Often Can be Used to Advantage in Illustrating Fundamental Principles of Mechanical and Electrical Apparatus

apart. The master sheet to be used is placed beneath the upper sheet of tracing paper which is sufficiently transparent to show clearly the cross-section lines beneath. One corner of the tracing paper has been turned upward to show more clearly the cross-section master sheet. Sketches made on tracing paper may readily be converted into permanent records by making blueprint reproductions. The illustration shows a sketch of a shaft coupling drawn to one-half actual size.

For some classes of work engineers prefer field books containing cross-section paper in a permanent binding so that sketches and calculations may readily be referred to.

Use of Diagrams to Illustrate Operating Principles

Often it is very simple to illustrate, on paper, ideas or mechanical principles which could not be described clearly, if at all, by the use of mere words. In this connection, diagrams or outline drawings are very useful for quick representation. They are also preferable to more complete drawings, especially when the only object is to picture a principle or general arrangement rather than actual construction.

The sketch, Fig. 48, shows two types of direct-current generator windings. The diagram at the left represents a series-wound generator. This type of generator has its field winding connected in series with its armature winding and the external circuit. The whole current delivered by the machine flows through the field winding and the voltage varies with the load, increasing as the load increases and *vice versa.* The right-hand diagram represents a shunt-wound generator. The field winding is connected to the brushes and is "in parallel" with the armature winding. The voltage of such a generator is maximum at no load, and, unless regulated, decreases as the load increases. In a book or article describing the fundamental principles of these two generators, it is evident that simple diagrams like the ones shown are very helpful because they are restricted to the fundamental features.

Sketch of a Straight-line Mechanism

An ink sketch of a straight-line mechanism is shown in Fig. 49. This mechanism consists of seven links which swing about two fixed centers or bearings, *A* and *B*. The links are so proportioned and arranged that this circular movement about points *A* and *B* causes end *C* to follow a straight line *D–D*. The dotted lines show how the relative positions of the different links change as end *C* moves upward along a straight line. This sketch is intended merely to illustrate the general arrangement of the mechanism and its action, and it is another example of the application of diagrams.

Sketches or drawings often are partly diagrammatic. This method of drawing might be used, for example, in representing the valve-operating mechanism of a locomotive. The locomotive cylinder, the valve, and driving wheels might be shown in their true relative positions, and the various links

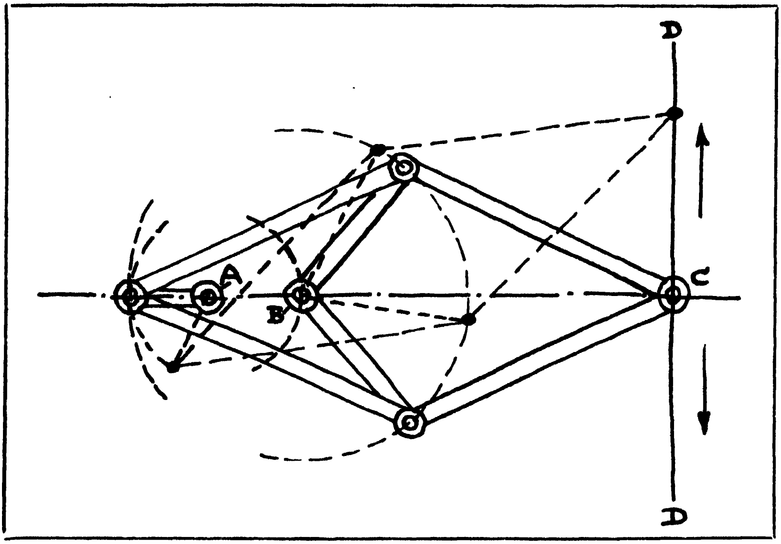


Fig. 49. Ink Sketch of a Link Mechanism Designed to Move End C Along a Straight Line

and rods of the valve mechanism be indicated by single lines, some of which could be dotted, thus showing the arrangement of these different parts and their action.

Sketch Illustrating the Action or Operation of a Mechanism

In sketching mechanical devices, considerable ingenuity may be exercised in determining what kind of a sketch or drawing will be the simplest and clearest. The ink sketch, Fig. 50, which was drawn with a fountain pen, represents a scooping mechanism for a truck designed principally for handling ore. The full lines show the position of the bucket at the beginning of the scooping movement, and the dotted lines an intermediate and the final scooping position.

In making a sketch of this kind, which consists largely of angular lines, there may be considerable distortion unless

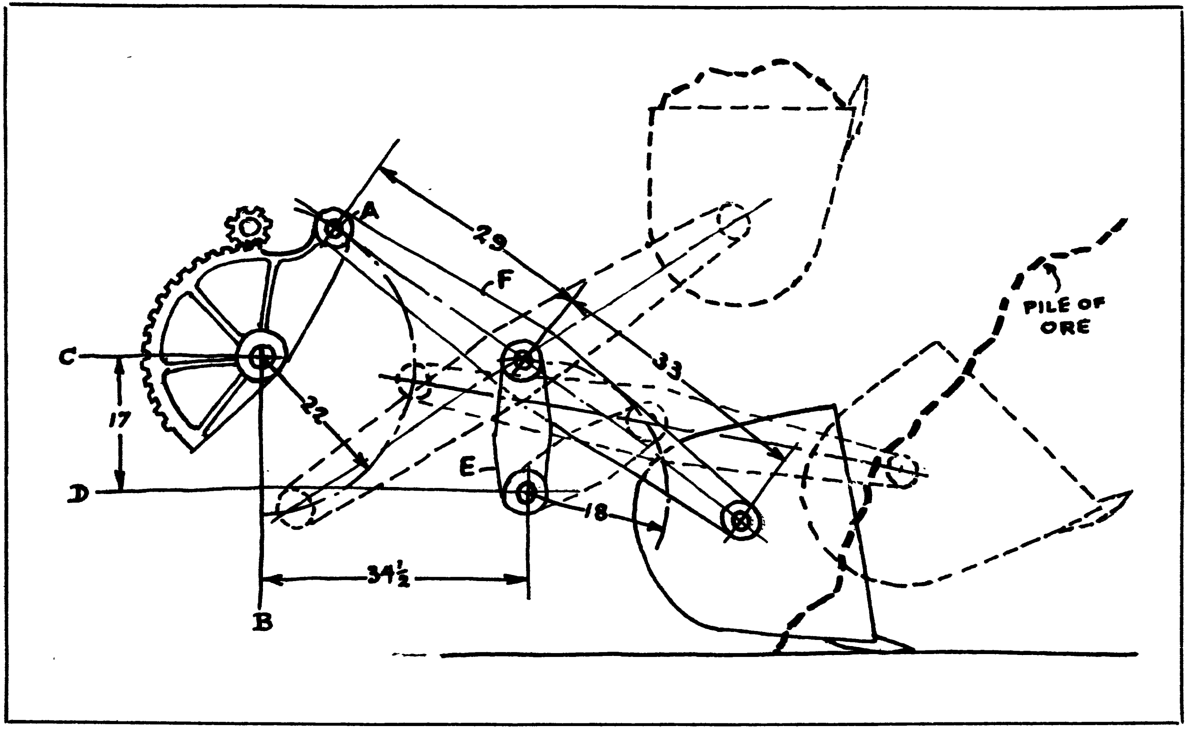


Fig. 50. Ink Sketch of a Scooping Mechanism with Full and Dotted Lines Illustrating the Action

the first half-dozen lines are properly drawn. First draw an arc for the segment gear and then an arc representing the path followed by pin *A*. Draw center-lines *B, C,* and *D,* and note that the distance between the horizontal center-lines *C* and *D* is about equal to the segment gear radius. Locate the pivot for link *E* and draw the arc representing its movement. Next draw center-lines for the three positions of arm *F*. After these foundation lines have been drawn, it will be comparatively easy to continue and without excessive distortion.

The First Sketch of an Invention May be Worth Keeping

The idea for a useful invention is likely to be hatched out almost anywhere—in a street car, at a movie, or in some place where least expected. This is why the first sketch of an invention often is very crude, and it may be drawn on the back of an old envelope or on the corner of a newspaper. Such crude drawings often are discarded, especially after better sketches or drawings have been made. It is well to remember, however, that the crudest sketch may prove valuable in establishing claim to an invention, provided it has been dated, signed by the inventor and by at least one witness. An approved form to use is as follows:

This idea conceived by..............................
(Signature of inventor)

Signature of witness..............................

Date........................

The first person to file an application for a patent might not be given priority over an opponent who could prove that he first conceived *and demonstrated* a similar device.