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Precision Tool Making for the Manufacture of Telephone Apparatus

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THERE is probably no field of human endeavor in which hand labor has been more completely replaced by labor-saving devices than in the field of manufacturing. The design and employment of special tools together with semi- and full automatic machinery for operating them have reached a high stage of development and are probably more responsible than any other factors for the present age being generally referred to as the industrial age. The notable economies of present day manufacture result no more from the rapid production of parts thus made possible than from the interchangeability of these parts because of the accuracy with which they have been produced.

At the foundation of precision manufacture by machine lies the art of tool making. As a result of the impetus given it by the economic justification underlying the transition from hand labor to mechanical devices, it has grown steadily in importance and in refinement. In large measure, it is the art of tool making which insures the interchangeability of product.

There are probably few industries in which the refinements of the tool making art have been carried further than in the manufacture of telephone apparatus and equipment, especially when handled on a large production basis as by the Western Electric Company. The purpose of this article is to outline some of the refinements of the tool making art as practiced by this Company and to do this, illustrative material will be drawn from among the large number of punches and dies used for punch press methods of manufacture. The methods employed and precision necessary in building the tools discussed below can be considered as representative of the high class of workmanship required throughout the Company's tool rooms.

Punches and Dies

Tool Making for Telephone Apparatus Manufacture. Briefly, a punch and die comprises a pair of individual tools so constructed with respect to each other that, when properly guided and forced into engagement with sufficient pressure, they will produce a uniform permanent change on the material placed between them. Punches and dies are made to perform a variety of operations, such as cutting or shearing parts from strip stock, commonly termed blanking, perforating or piercing holes, drawing, forming or bending, stamping, embossing, etc. In many instances two or more operations are combined in one tool, as, for example, a perforating and blanking punch and die, which cuts the part to its required shape and also perforates the required holes. Multiple operation tools may be constructed in many different ways, depending on the particular requirements of the part to be made. Typical illustrations of punches and

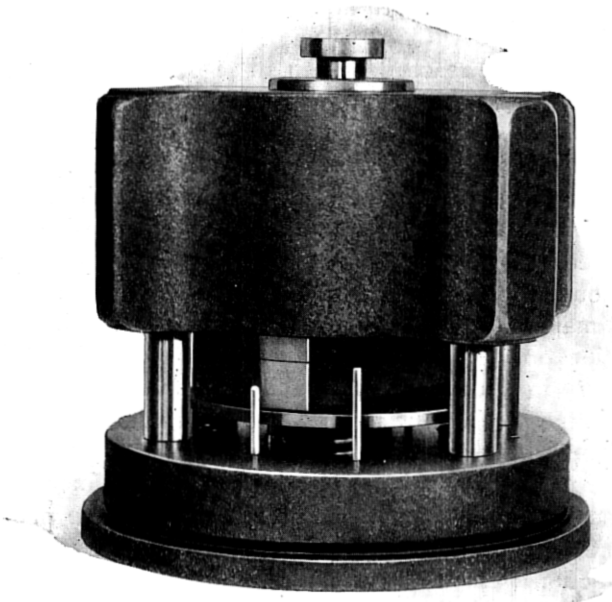

Fig. 1—Compound punch and die of the liner pin type assembled.

dies for accurate work are shown in Figs. 1 and 2. The former shows a compound punch and die of the liner or guide pin type assembled, and the latter shows a partially disassembled tool of the sub-press design, in which the moving member is completely enclosed and guided by the housing.

The compound type of construction mentioned in the preceding paragraph, which perforates and blanks the part complete in one die position and one stroke of the press, gets its name from this feature of performing a compound operation in one die position, and is generally used where very accurate parts, practically free from distortion and with clean-cut edges, are to be produced, and particularly where thin stock is used. It is also preferable to other types of tool construction when the part is irregular in shape or is to be produced in large quantities, because of the uniformity of product, high speed at which it can be operated and because of its long life. Where small holes are to be perforated, the compound type is often advisable due to the fact that the perforators can be supported more substantially, with reduced breakage.

Fig. 3 is a cross-sectional view of one of the standard designs of sub-press compound tools illustrating this type of construction. As its name implies, the sub-press type is a practically self-contained press which is placed, assembled, in the power press. As will be noted from this figure, the compound type of tool has the perforating punches

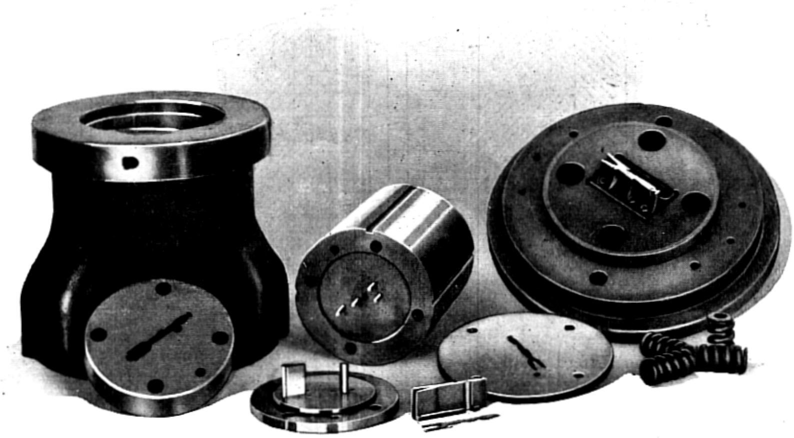

Fig. 2—Sub-press compound punch and die partially disassembled to show construction.

L located inside the blanking die *N*, and supported by the shedder *M*, and the die openings for the perforators inside punch *P*, which is fastened to the base *H* of the tool. In operation, the base *H* is mounted on the bed of the press and the cap adapter *A*, which is attached to the plunger *D*, is fastened to the slide or ram of the press. The stock is fed over the stripper *O* and the die *N* descends, thus depressing the stripper *O* and causing the shedder *M* to recede into the die *N*. As the shedder is backed up by a heavy spring *C*, the metal being blanked is held under pressure between the shedder and the punch *P* so that this type of construction fabricates thin sheet metal under conditions which insure the best results. As the downward movement progresses, the blank is cut from the stock and the holes perforated. The slugs forced out by perforators *L* drop through the punch P, and as the die ascends on the up stroke of the press the blank is forced back into the stock by the action of the stripper and

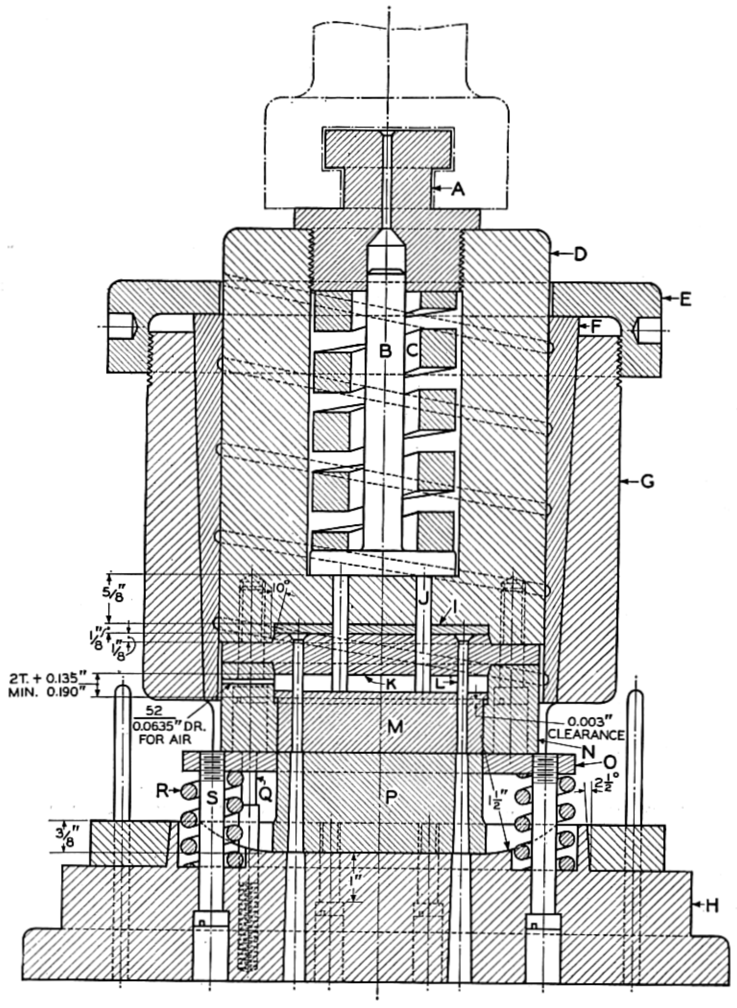

Fig. 3—Cross-sectional view of standard design for sub-press compound punch and die illustrating principal parts.

shedder. The material is then advanced to the next position and the operation repeated.

If no positive provision is provided in a punch and die for securing fixed alignment of the cutting members, considerable care and skill is required in order to adjust and set the tool in the press so as to bring the die opening into its proper position with respect to the punch. Also, after the tool is set there is the possibility, especially in the case of the higher speed presses operating at about 300 strokes per minute, of the die shifting during operation and resulting in the "shearing" of the cutting edges of the die and punch. To overcome this difficulty the liner pin type of construction illustrated in Fig. 1, and the sub-press type shown in Figs. 2 and 3 are used in the better grade tools, and especially where a very small clearance must be maintained between the punch and die opening. In the former the arrangement consists of two or more round guide rods or liner pins fastened in the

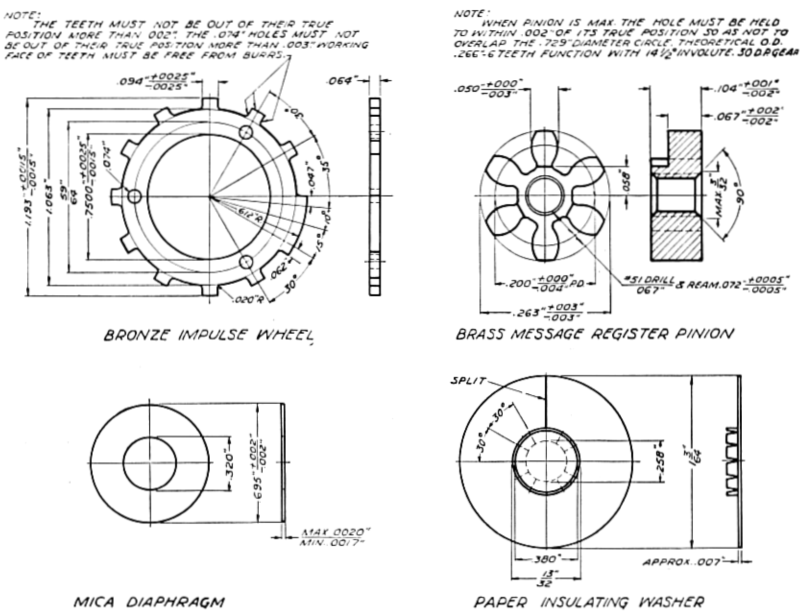

Fig. 4—Sketches of typical piece parts requiring accurately built punches and dies

bottom part of the tool and passing up through accurately bored holes in the top part, thus insuring that both members are always in their proper relative position. While the liner pin type of tool affords a very satisfactory alignment in most cases, the sub-press type is the better construction which, because of its "piston and cylinder" design, insures a more positive alignment. This is illustrated in Fig. 3. The plunger *D*, to which is attached the die *N*, perforators *L*, etc., slides in the bushing *F* in the housing *G*, and is therefore always in alignment with the base and the punch attached to it. This type of construction is followed largely where the part is small enough so that it can be adapted to standardized housings, which are stocked, and especially where the tool is to be operated on high speed presses.

In order that a better appreciation may be obtained of some of the more exacting requirements which are being met in building tools of this kind, several of the important reasons for accurate workmanship to limits as close as a few ten-thousandths of an inch or less on some of the tool parts, together with typical examples, will first be considered.

Meeting the Accuracy Required of Piece Part. In order to obtain the correct functioning of the apparatus or equipment and also to insure interchangeability in assembly, many piece parts must be made with a

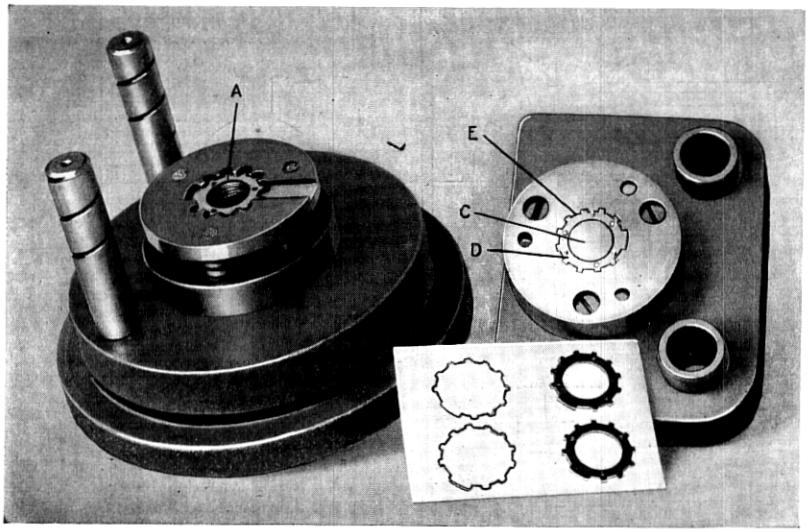

Fig. 5—Shaving and perforating punch and die for impulse wheel.

considerable degree of accuracy, often within limits of $\pm$ .001 in. or less for some of the dimensions. This is one of the most important and common reasons for accurately built tools, especially in the case of parts made in sufficiently large quantities to require a number of similar tools producing the same part, as the product of each tool must be interchangeable with that of any other provided for the same operation, and also for subsequent operations.

The bronze impulse wheel for No. 2 type dials and the pinion used in message registers, Fig. 4, are typical examples. Both of these parts are given shaving operations—the wheel after being blanked, and the pinion after being cut to length and swaged—in order to secure the required accuracy and smoothness of contour. Fig. 5

shows the shaving and perforating punch and die for the impulse wheel, together with an illustration of the part and the stock removed from the outer edge in the shaving operation which amounts to about .008 in. This tool is built to have a clearance between the shaving punch *A* and the die opening *B* of only two to four ten-thou-

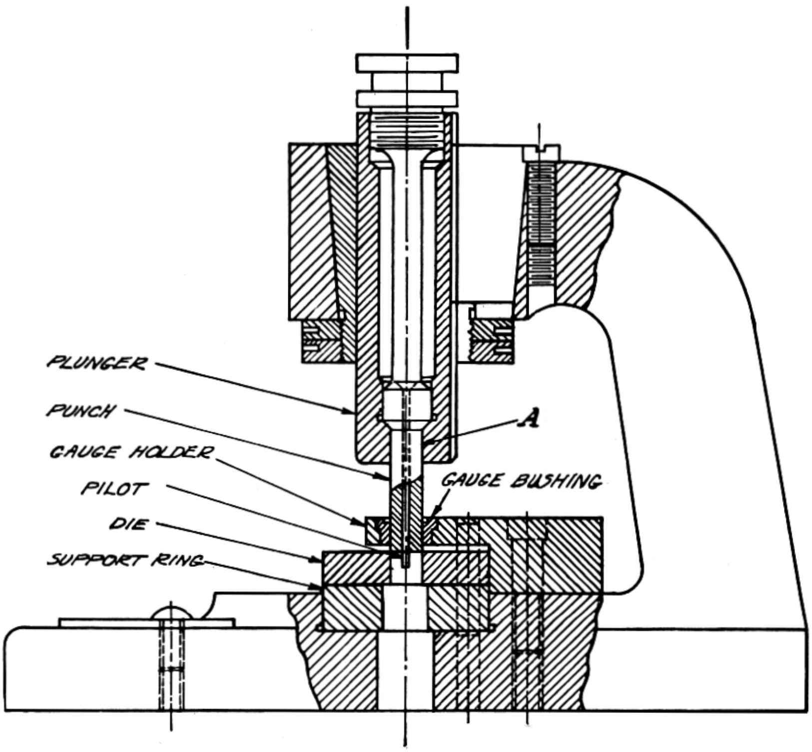

Fig. 6—Cross-section of second operation shaving punch and die for message register pinion.

sandths of an inch all around, and the punch must be located very accurately so that it will center in the die within this amount of clearance. The shaving perforator *C* for the center hole also has practically the same limit as has also the shedder *D*. Holes or openings in the die are held to as close as .0005 in. of their nominal dimensions and also with respect to each other. Fig. 6 is a partial cross-section of the second operation shaving punch and die for the message register pinion, which is made to similarly accurate limits. However, the close workmanship on parts of this tool is also necessary in order to insure interchangeability of tool parts, which will be referred to later.

One of the best examples of a high grade tool needed to make parts within close limits is the compound punch and die shown partially completed and disassembled in Fig. 7, for perforating and blanking complete in one operation the multiple bank terminal strip shown in front of the tool in the illustration. This terminal strip is $36\frac{3}{4}$ in. long and has 30 common terminals on each side spaced on $1\frac{1}{4}$ in. centers and 129 perforated holes. The design of the part requires that all terminals and some of the holes be held to within limits of $\pm$ .004 in.

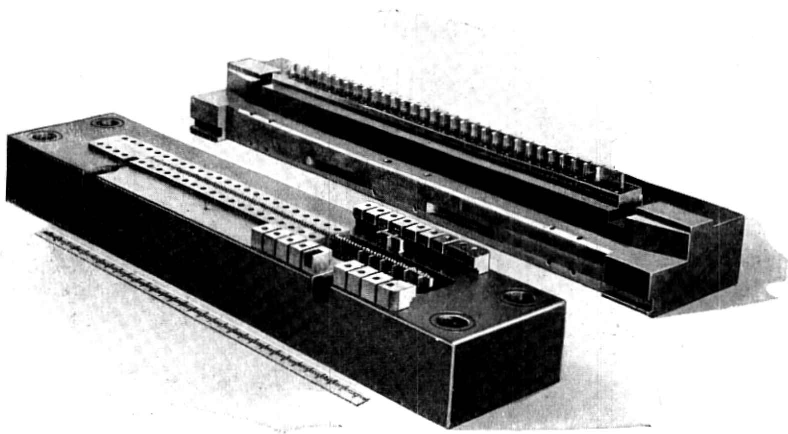

Fig. 7—Compound punch and die for blanking and perforating multiple bank terminal strip.

of their correct location with respect to a designated hole at one end of the strip. A limit of $\pm$ .004 in. for a single dimension is ordinarily not a difficult one to work to, but in this case the fact that any inaccuracies are accumulative makes it a very difficult limit to meet.

To make this tool with the required limits of accuracy, it is necessary to make the punch, die, shedder and punch plate sections, as shown in the illustration, so nearly to their exact dimensions that they are practically interchangeable. In fact, the variations are so small that if all the sections were removed from the tool and reassembled in different positions and combinations, the changed tool would not vary more than $\pm$ .0002 in. from the previous dimension over the entire length of the sections. In assembling the sections, it is necessary that they be carefully cleaned, as a slight amount of oil or dirt between them would throw the tool outside the desired limits. When it is considered that the tool must be made to much closer limits than the piece part, that all of the 103 sections, as well as the perforators, must fit together within an overall limit of + .001 − .000 in., that the punches and perforators must be accurately centered in the die openings with a clearance all around for the punches of .0003 in. to

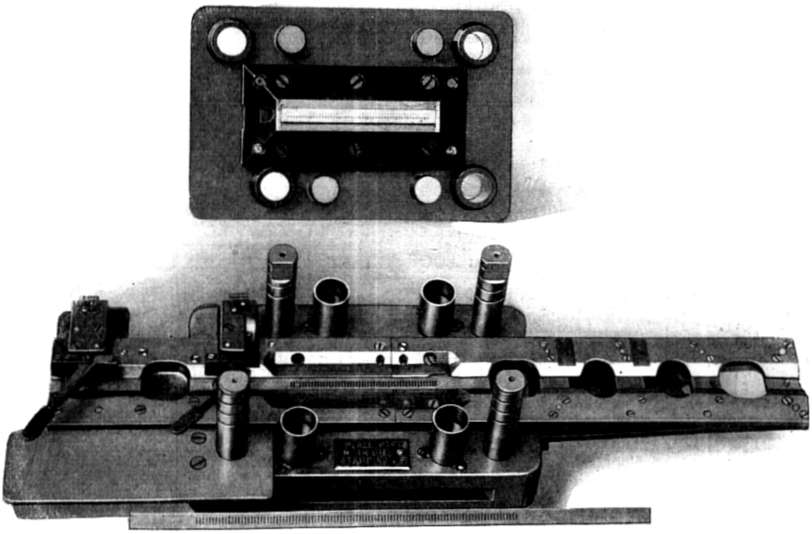

Fig. 8—Second operation punch and die for perforating holes in rack.

.0005 in. and for the perforators about .0001 in., it is apparent why, with the possibility of the errors being accumulative, each individual section must be made very accurately, the majority not exceeding a

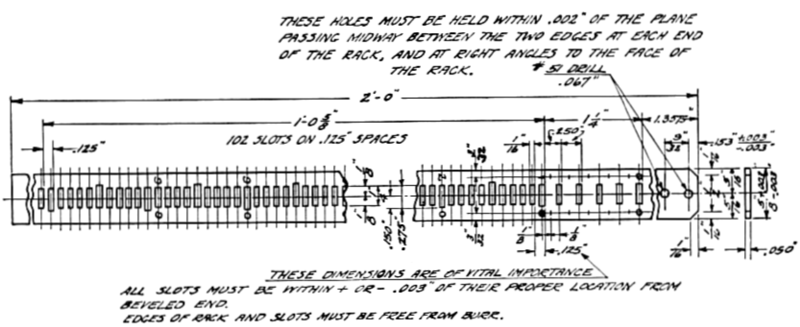

Fig. 9—Phosphor bronze rack for panel dial equipment.

limit of ± .00001 in. In addition, the slot in the die holder which holds the die, shedder, and punch plate sections, is made to almost exact dimensions and must have its sides parallel with each other and perpendicular to the bottom surface.

Another tool of this kind is the second operation perforating punch and die shown in Fig. 8, which perforates the slots in the rack for elevator apparatus shown in Fig. 9, and also in the illustration of the tool. The requirements of this part specify that all of the 107 slots 1/16 in. wide and spaced on .125 in. centers must be within ± .003 in. of their proper location from the beveled end, which is a difficult requirement to meet on account of the nature and thickness of the stock, and, like the multiple bank strip, there must be practically no accumulated error. The tool has fifty perforators, fifty-one die and fifty-two shedder sections which are made with a degree of accuracy comparable to that of the multiple bank strip tool.

Insuring Accurate Gaging in Subsequent Operations. This is a reason which sometimes requires the tool maker to work to closer limits or to hold certain dimensions to closer limits than would be otherwise required. In such cases the tool must produce piece parts which are sufficiently accurate at certain gaging points used later in other tools or in the apparatus assembly fixtures, to insure the proper results from the subsequent tools and in assembly. This may require an accuracy of from .0005 in. to .001 in. An example is the bank contact for step-by-step type banks. In order that the parts may be made sufficiently accurate at certain points so that proper bank assembly may be obtained with the assembly fixtures, the blanking die openings are made to a limit of + .001 in. − .000 in. for the width at the ends, the length, and the offset dimension, although the apparatus requirements for the piece part do not necessitate this degree of accuracy.

Production of Satisfactory Blanks from Thin Stock. Typical piece parts of this kind are the mica diaphragm .0017 in. to .002 in. thick used in transmitters, and the oiled red rope paper insulator .007 in. thick for coil spool assemblies which are shown in Fig. 4. In order to obtain clean-cut blanks, with practically no rough edges or burrs, from thin material of this kind, it is necessary that the clearance between the blanking punch and the die for the insulator does not exceed .0002 in. and the diaphragm .0001 in. all around, and the perforators nearly the same. In fact, these die parts are made to fit so closely that they will cut wet tissue paper. Accurate working fits are necessary between the other moving members, such as shedder, liner pins, etc., which mean that it must be possible to just push the parts together with no perceptible shake or clearance. The general construction of these tools is of the standard compound liner pin type similar to Fig. 1.

Interchangeability of Tool Parts. Some tools are so designed that certain parts, which on account of the design of the part being produced are of fine construction, may be readily replaced in case of breakage or wear. In this case it is necessary that the parts be made accurately where they fit together, in order to insure interchangeability of the tool parts, without affecting the satisfactory operation of the tool or the accuracy of the parts being produced. The shaving punch and die for the message register pinion previously referred to and shown in Fig. 5 is a typical example, the construction and limits being so that parts such as the punch, die, gage bushing, and pilot may be easily replaced. For instance, in order to insure interchangeability of the punch, the dimensions of the plunger and punch at *A* are held within a limit of .0002 in., and other parts to correspondingly close limits.

Feeding of Material and Properly Formed Part in "Tandem" or "Follow" Type of Dies. In this type of tool the operation is a progressive one. While one part of the die notches, embosses, forms, or

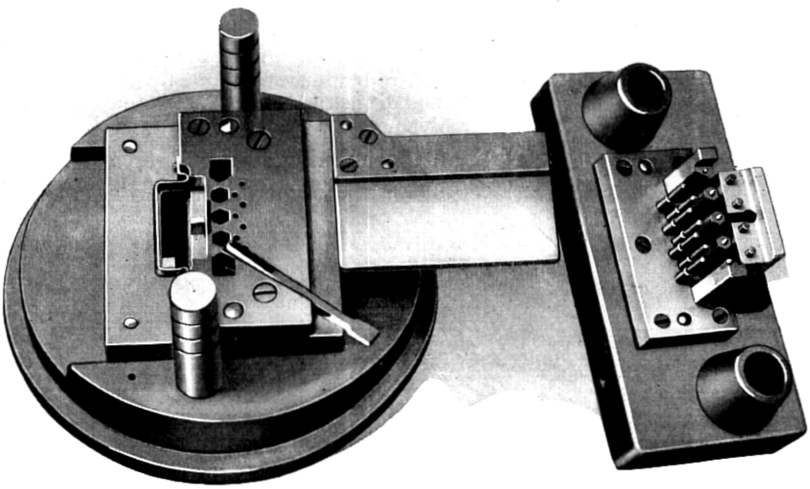

Fig. 10—Multiple perforating, blanking, and clipping punch and die for 3/8″ brass hexagon nuts.

perforates the stock, another part blanks out the parts at a place where, at a former stroke, the preceding operations have been performed, so that complete parts result from each stroke of the press, although, of course, more than one operation has been performed on the parts before completion. This is illustrated in Fig. 10, which shows a multiple perforating, blanking, and clipping punch and die for making 3/8 in. brass hexagon nuts. As will be noted from the construction of the tool and the sequence of operations shown in Fig. 11, seven nuts are made with no scrap skeleton remaining at each stroke of the press, three of the parts falling through the blanking openings and the others through the rectangular opening after being clipped off at the edge of the die.

1st Step
Perforate 7 holes and clip edges of stock

2d Step
Perforate 2d set of holes, blank out 3 nuts and notch out nuts along edges of stock

3d Step
Perforate 3d set of holes, blank out 2d set of 3 nuts, clip off 4 nuts and cut 2d notch along edge of stock

Fig. 11—Steps in the manufacture of brass hexagon nuts by scrapless punch and die method

On this tool, accuracy, from a tool making standpoint, is necessary in order to insure proper feeding of the material and an equal sided

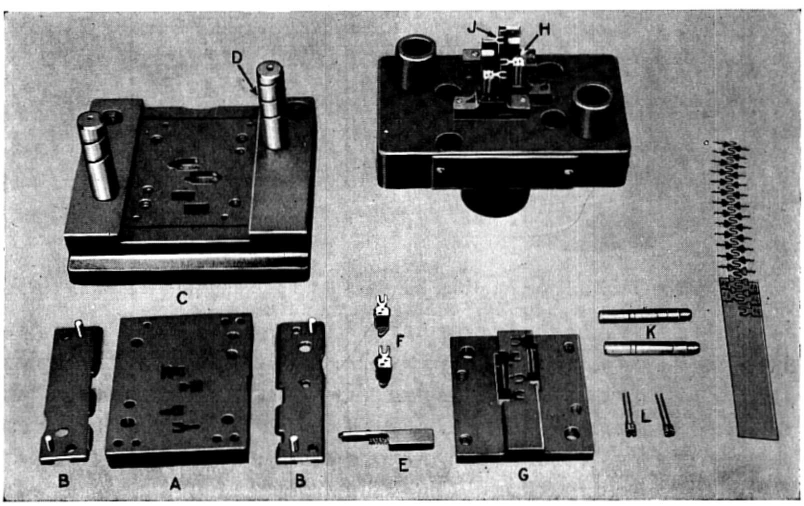

Fig. 12—Punch and die for shearing, blanking, and forming solderless cord tip

product. When the first tools were built, it was found necessary to develop very accurately the distance between the perforator and blanking openings on account of the elongation or "creep" of the material. An error in a tool of this type is detected very easily in the product, and it requires only a very small amount to make the hexagon nut irregular in shape or "lop-sided" with respect to the center hole. It is therefore necessary that the tool maker work to close limits in maintaining the relationship between the perforator and the blanking openings and clipping edge, and the total variation between any of these is not more than .0008 in. to .001 in. It is not only necessary that this accuracy be held on the die section, but also on the punch plate and stripper, in order to insure the proper clearance between the punch members and die openings, which is .0015 in.

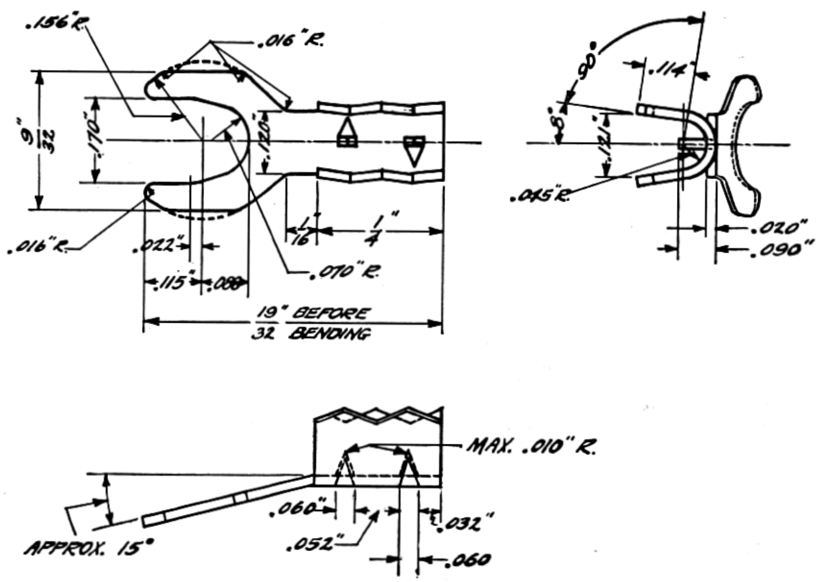

Fig. 13—No. 92 solderless cord tip.

Another example is the shearing, blanking, and forming punch and die shown partially dismantled in Fig. 12, which is used for making the solderless cord tip, Fig. 13. The parts of the tool, as shown in the figure, are *A* die, *B* stock guides, *C* die holder, *D* liner pins, *E* finger stop, *F* shedders, *G* stripper plate, *H* punch holder, *I* blanking punches, *J* forming punches, *K* dowel liner pins, *L* shearing or perforating punches. The blanked strip in the illustration shows the sequence of operations, the parts being first blanked and sheared two at a time with the blanks remaining in the scrap skeleton. The stock then advances until the blanks register with the forming die where the saw tooth portion of the part is bent up, two complete parts being made with each stroke of the press. The location of the forming section with respect to the blanking section in this tool must be very accurate, as otherwise the blank will not register exactly under the forming punch and an incorrectly formed part will result. Also, the forming punches must be located accurately so they will center in the die openings. Other features

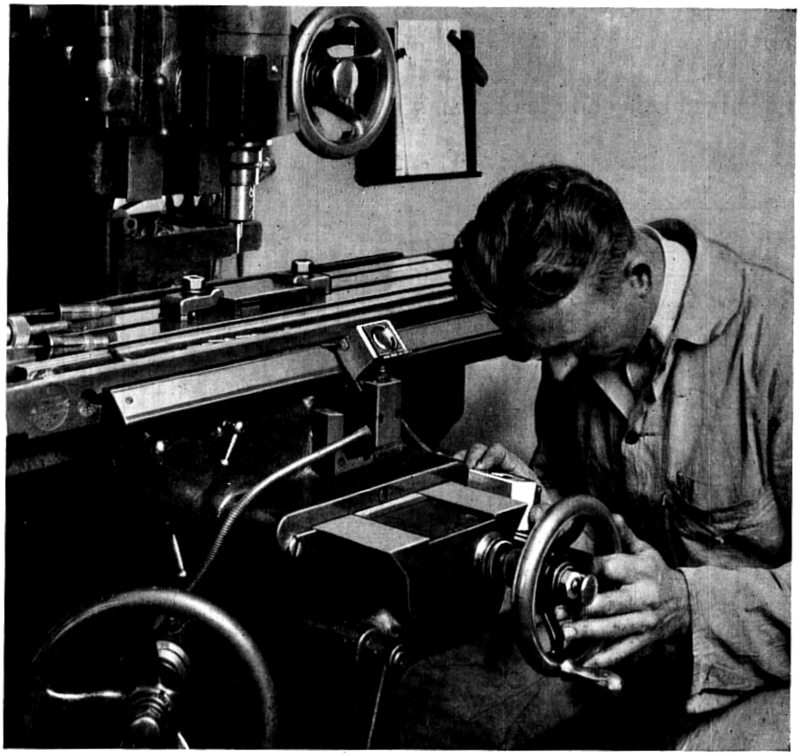

Fig. 14—Boring datum holes in master plate on veneer milling machine

regarding the workmanship required on this tool are included in the description of its construction given in the following paragraphs. Stock is fed to the punch and die by an automatic roll feed with an adjustment provided such that a precision feed within $\pm$ .0005 in. of the nominal may be obtained, which insures each part being located in the proper position for forming.

Making Punch and Die Sections

Various methods may be used in the making of punch and die sections depending on the character of the work, accuracy required, etc. The use of templates and the vernier height gage in laying out work centers and outlines, the application of the master plate method, the use of micrometer heads and verniers on milling machines and various systems of end and distance gages are all found of value in this work. A brief description of several of the operations performed in making

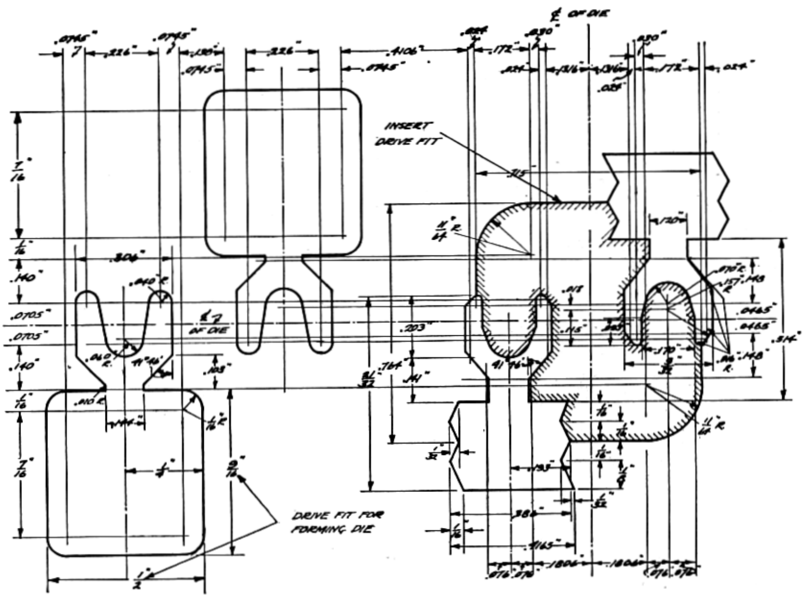

Fig. 15—Layout of die openings for solderless cord tip punch and die

the punch and die sections for the solderless cord tip punch and die previously described, will serve to illustrate the common practices followed in producing high grade work.

The first operation is the making of a tool steel master plate having all the datum or reference holes necessary for accurately locating the holes and contours of the openings in the die. The blank plate, after being squared and the sides finished parallel to each other, is mounted on the vernier milling machine shown in Fig. 14. This machine is equipped with magnifying lenses over the positioning vernier scales for adjusting the position of the table. The vernier scales read to .001 in. and by interpolation it is possible for an operator to adjust the table to within a few ten-thousandths of an inch. From the layout of the die opening as shown on the tool drawing, Fig. 15, the required datum holes are then located by means of the vernier scales and bored to complete the master plate, as shown in Fig. 16. The

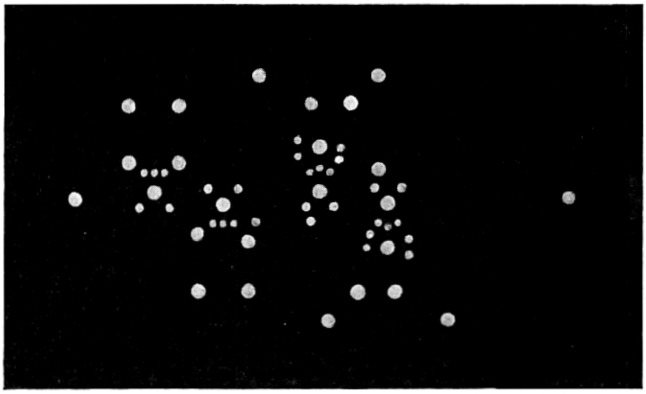

Fig. 16—Master plate for solderless cord tip die.

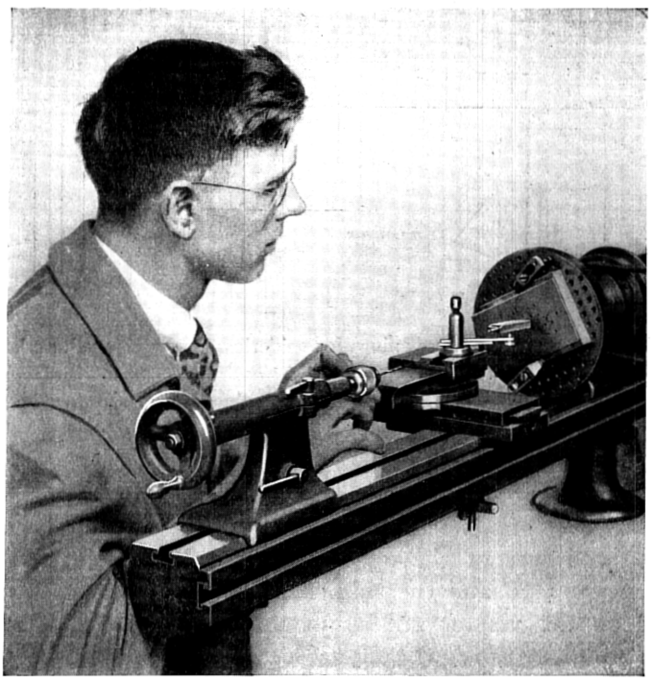

Fig. 17—Transferring datum holes from master plate to die block on bench lathe.

practice on master plates of this kind and other similar parts is to locate the various holes so that the error in any case is well within .001 in.

The master plate is mounted on the die block and located by means of two snug fitting pins driven into the block and projecting into the two aligning holes near each end of the plate. The die block and plate are then attached to the face plate of a bench lathe, as shown in Fig. 17. Each datum hole in turn is accurately centered with the lathe center by means of the indicator shown in the figure, the master plate removed, and the hole bored in the die block. In centering with

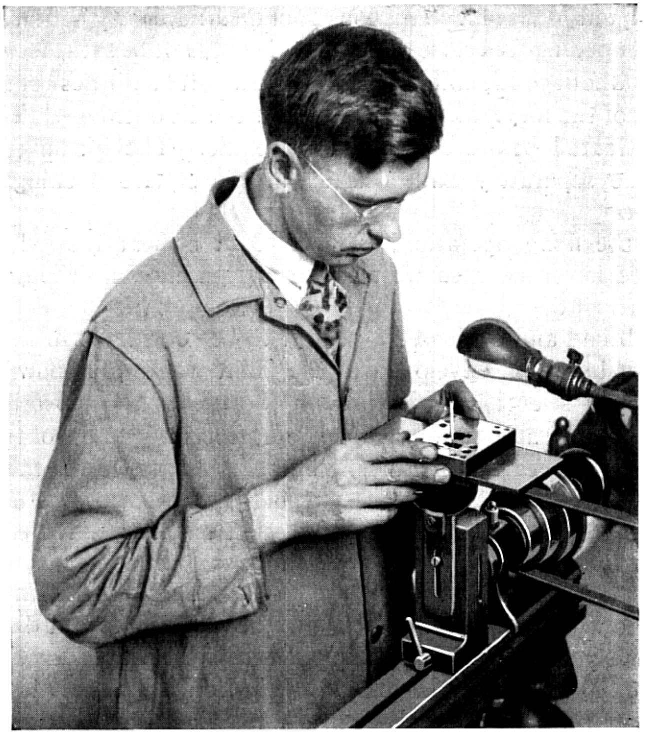

Fig. 18—Filing out die openings with filing attachment on bench lathe.

the indicator, the lathe is rotated and the master plate and die block shifted until the indicator pointer shows but little, if any, movement. With an indicator multiplying the movement 100 times, shifting the plate .0001 in. would move the pointer over the scale .010 in. or .0001 in. eccentricity of the hole would show a pointer movement of .020 in. The master plate gives a permanent precise outline of the important holes, radii, contours, etc., which can be utilized to considerable advantage in checking after heat treatment, and especially in making additional tools or replacement die sections.

After the boring of the holes in the die block is completed, the die openings are worked out roughly by drilling a series of holes corresponding to the shape required and brought to about .001 in. of the nominal by means of the lathe filing attachment, as shown in Fig. 18, or a standard bench filing machine. The perforating and blanking contour which is the one being filed in the illustration conforms only partially to the finished openings on the die as shown in Fig. 12, and the correct outline is obtained by means of an insert indicated on the die layout in Fig. 15. This construction is necessary because the two blanking openings are close together and could not be satisfactorily heat treated without considerable distortion. Also, it facilitates considerably the work of the tool maker in working out the die openings. The insert is heat treated before assembly in the die. The forming dies are also made separately and inserted in the square openings in the die block.

After the filing operation, the die block is heat treated and the upper and lower surfaces are then ground parallel. Although proper heat treatment is an important factor in the production of fine tools, it is too broad and extensive a subject to be considered in this paper, as the art has been developed to the point where it is now done on practically a scientific basis through the use of the most improved equipment and automatic temperature recording and control, with many different heating methods, etc., being employed for the various grades of steels and the different purposes for which they are used.

The next operation after heat treatment is the grinding of the die block openings, which is done on the bench lathe by means of the grinding attachment shown in Fig. 19. By this means the surfaces are brought to within .0003 in. to .0004 in., the most important dimensions as previously mentioned being those which affect the distance between corresponding surfaces of the blanking and forming die openings. The surfaces are then stoned or lapped by hand with about .0002 in. or less being removed as required, to give the final finish and accuracy, and the insert and forming dies, which are made with a similar degree of accuracy, fitted in place.

As can be seen from the foregoing, the highest precision work requiring the most expert workmanship comes in the final grinding, lapping, and fitting. The degree to which this must be carried, of course, depends on the requirements of the particular tool being made. In the case of the multiple bank strip and the rack tools previously described, the punch and die sections are ground to within .00005 in. of the required size and then lapped to the final dimensions, using a flat cast iron block or some other soft metal charged with an abrasive dust, such as emery, carborundum, or diamond.

An idea of what this class of workmanship means can be appreciated when it is considered that 10 degrees Fahrenheit difference in temperature will change the length of an inch block more than this .00005 in. limit. Since the change per inch in steel is about seven-millionths of an inch per degree Fahrenheit, the heat of the hands or machines may, in extremely accurate work, make sufficient difference so that

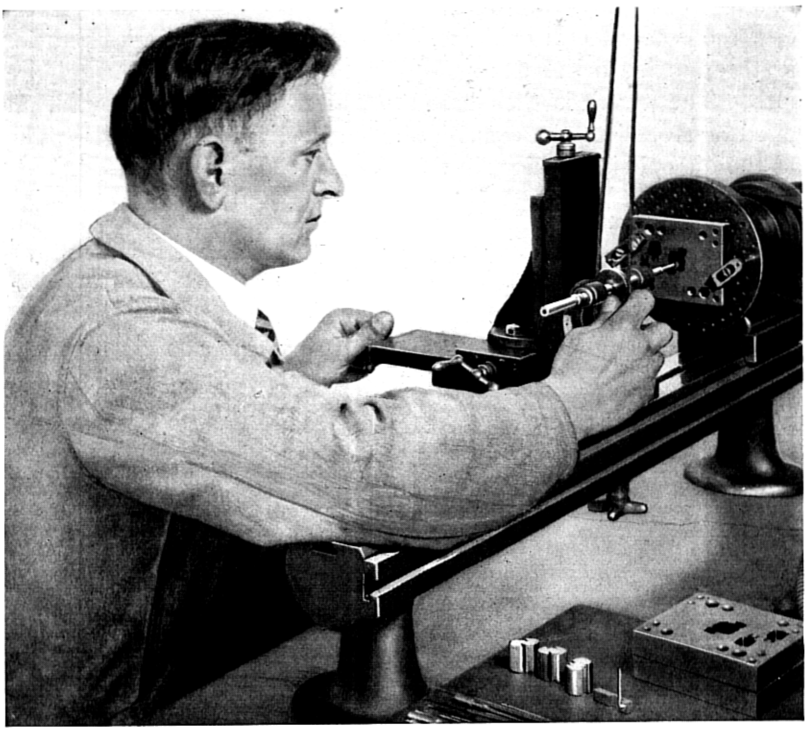

Fig. 19—Grinding die block openings after heat treatment.

parts have to be laid on steel blocks to attain room temperature before the dimensions are checked, in order that they will be of the same temperature as the master gages used. The temperature is also an important factor in producing accurate plane surfaces with a surface lap. Unless the temperature of the lap and the work is the same, a convex surface will usually be produced even though the lap itself is an accurate plane.

In making the blanking punch for the solderless cord tip tool, it is first rough milled to within 1/64 in. of the nominal dimensions, as shown in Fig. 20. By means of a screw press, the punch is then forced into the die opening already completed, to a depth of approximately 1/64 in., and an accurate impression of the correct punch section obtained, as shown in the figure. The punch is then milled to form on the bench milling machine to within about .0005 in. to .001 in. of the nominal, the outline of the impression being used as a guide in this operation. The final shearing of the punch in the die, which amounts to practically a shaving operation, is accomplished in several steps, the excess metal being removed by filing after each operation, and the punch worked down until it enters the die to the required depth. The punch is then hardened, after which it is ground, and lapped or stoned to the exact clearance required between the punch and the die opening, which, in this case, is .0005 in. all around.

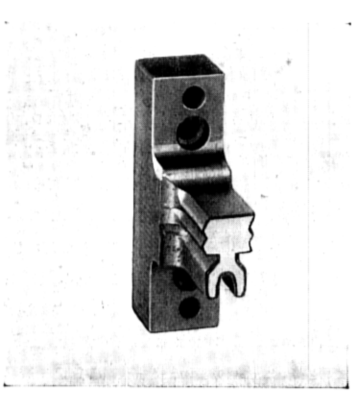

Fig. 20—Rough milled blanking punch, solderless cord tip punch and die

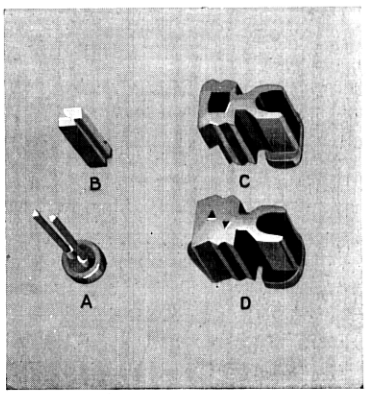

Fig. 21—Shedder, insert, and perforator punch for solderless cord tip punch and die

Fig. 21 shows "*A*" one set of the perforators for producing the two sharp projections in the cord tip stem, "*B*" the insert, and "*C*" and "*D*" the shedder before and after the insert is in place. The blanking punch also has die holes for the perforators, as can be observed from the general view of the tool in Fig. 12, and these are similarly formed by means of an insert. The perforators, which are working fits in the shedder, are .06 in. wide, $1\frac{7}{16}$ in. long and of triangular cross-section. It would, therefore, be very difficult to work out the holes straight and accurate. To facilitate the tool making work, the shedder and punch are made as shown and the insert added. This is a good example of some of the means employed for overcoming difficult tool making problems.

Making Die Blocks for Sheathing Lead-Covered Cable

The making of the die blocks used in the hydraulic presses for sheathing lead-covered cable is of interest on account of the method used. The milling of the die contour, which is irregular in shape, is done on a die sinking machine shown in Fig. 22, the upper die being

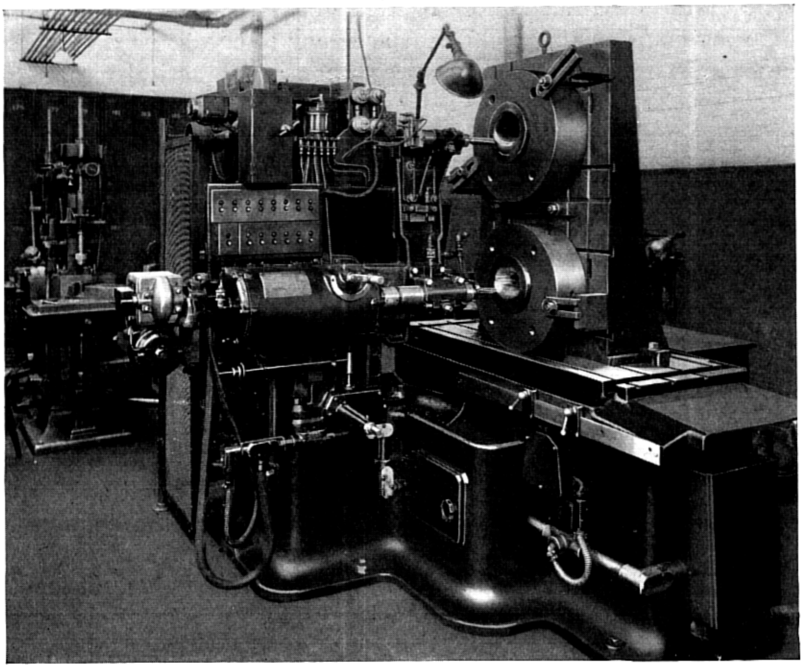

Fig. 22—Milling on die sinking machine the contour of die block for sheathing lead-covered cable

the master and the lower the die being profiled. The principle of the machine is that of having the cutter or milling tool automatically controlled and guided by means of a very sensitive tracer, which follows the contour of the master. This is accomplished by having individual motor drives and electrically operated clutches for each of the feeds, which are controlled by the movement of the tracer making and breaking the electrical circuits as it comes in contact with the surface of the master. This results in the feeds operating to move the table holding the dies and the slide holding the tracer and the cutting tool in such a manner that the tracer will follow the outline of the master die. The milling out of the opening is done by a series of either horizontal or vertical cuts, the machine automatically reversing at the end of each cut. With this machine a set of die blocks, which would require approximately 300 hours to machine by the hand finishing method, can be completed in 80 hours. This machine was used for working out the openings of the moulding dies for the new hand set.

Precision Measuring

One of the essential factors in high grade tool work is precision measuring instruments of sufficient accuracy to check the dimensions to the limits required. The most common and practical method of making precise measurements is by comparison with standard known dimensions and most of the instruments used on a commercial basis for measuring to limits of .0001 in. or less employ this principle.

The standards used for comparison are "Hoke" or "Johanssen" gage blocks made in 81 sizes as shown in Figs. 23 and 25. The blocks are arranged in four sets, the first consisting of four blocks 1 in., 2 in., 3 in. and 4 in. in length. The second set of 19 varies from .050 in. to .950 in. in .050 in. steps. The third set of 49 varies from .101 in. to .149 in. in .001 in. steps and the fourth set of 9 varies from .1001 in. to .1009 in. in .0001 in. increments. In combination any dimension may be obtained within the limit of the set in .0001 in. steps.

The surfaces of these gages are so flat and smooth that if two or more are wrung together so as to expel the air, they will adhere to each other and resist separation at right angles to the contacting surfaces with a force of over 20 pounds per sq. in. The precision of these gage blocks at 68° F. is within .00001 in. per inch of length of the dimensions stamped on the blocks for the larger sizes and .000005 in. for the smaller sizes under one inch. Although the gages are standard at 68° F., it is of course not necessary to use them at this temperature, or make corrections when measuring metal of the same coefficient of expansion. However, as previously mentioned, it is essential that the work to be measured be at the same temperature as the gages. In addition to being used as standards for checking parts in the different measuring instruments, a variety of other uses are made of the gage block in laying out and measuring the work directly. By the use of accessories and attachments, which are furnished for holding the blocks, they may be made into inside and outside calipers, shape and height gages, etc. One of the sets which has been checked and certified by the Bureau of Standards is maintained as a standard for checking the other sets and also other master gages.

One of the most frequently used measuring instruments is the upright dial indicator gage. The part to be measured is placed on the accurately lapped surface plate of the instrument and brought into contact with the vertical plunger, which operates the universal dial indicator through a lever arrangement. The movement of the pointer is about 1/16 in. for each .0001 in. vertical movement of the dial plunger. By noting the difference between the dial reading for a standard gage block of the size required and the part being measured, a comparison between the two may be made to within .0001 in. and by interpolation between the calibration marks to within a few hundred-thousandths of an inch. The universal dial indicator is also frequently used by the tool maker with a standard surface plate, and a suitable arm for holding the indicator, when checking work in process.

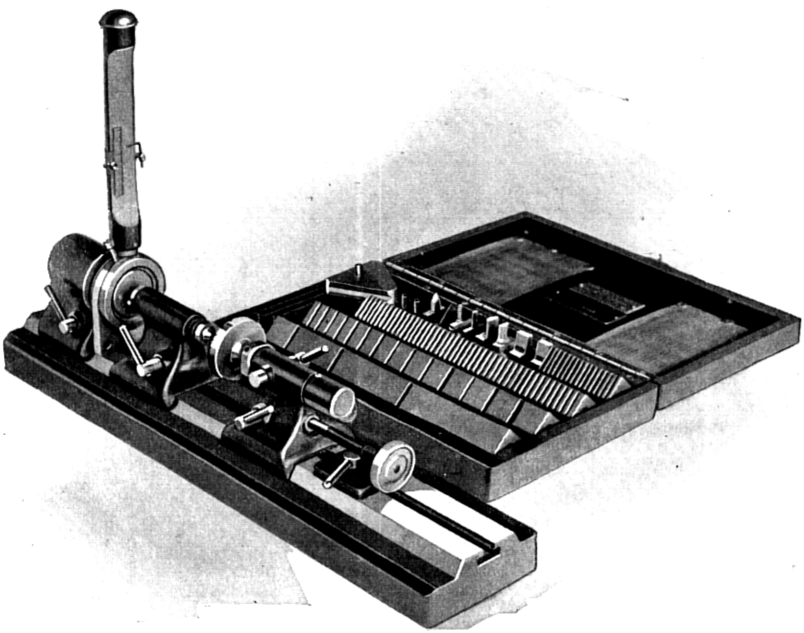

Fig. 23—Precision measuring instrument with fluid gage and "Hoke" gage block set.

If greater accuracy is required, parts are sometimes measured by comparison with the standards, using the liquid gages shown in Figs. 23 and 24. The instrument in Fig. 23, which has a multiplying ratio of 2200 to 1, was made in the Hawthorne Works Tool Room, while the other is a commercial liquid gage or prestometer. However, the comparator most generally used at present for this class of work is the optimeter shown in Fig. 25. This instrument makes use of an optical system to magnify small measurements without the use of a vernier or other mechanical means, and due to its construction is dependable and probably less liable to variation than the liquid gage. Most of the errors due to play between mechanical parts such as gears,

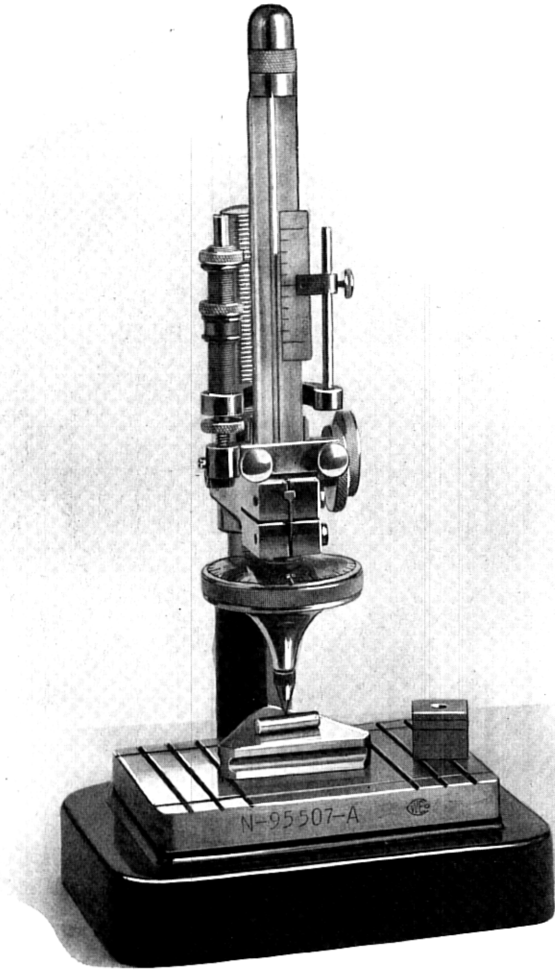

Fig. 24—Fluid gage or "prestometer" showing tool part in position for measuring

micrometer screws, knife edges, diaphragms, capillary tubes, etc., have been considerably reduced. The only moving part except the measuring feeler is a small mirror which is tilted by the upper end of the feeler and reflects the image of a stationary glass scale. The feeler has a constant pressure of 7 or 8 ounces against the work, thus eliminating the "sense of touch" factor. Variations of the size of a part within a range of ± .0035 in. may be read directly to .00005 in. and by interpolation to within one or two hundred-thousandths of an inch.

The instrument just described illustrates the use of light for making precise measurements by the optical lever method. Another method is by the use of a lens or projection system, whereby beams of light are controlled in such a manner as to form on a screen enlarged images of objects with a high degree of geometrical similarity between the

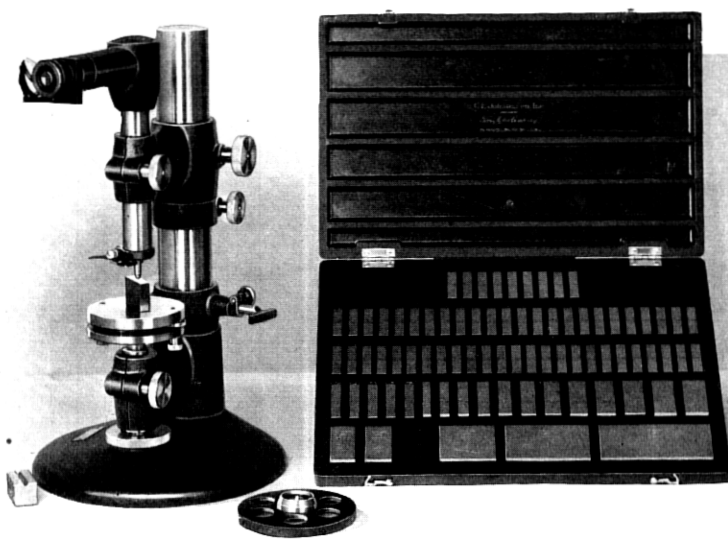

Fig. 25—Optimeter and "Johanssen" gage block set

image and the object. As the errors or variations in the object are magnified the same amount, they become correspondingly easier to observe and measure or check against a standard template, contour plate, limit chart, or accurately made scale drawing of the object. With a magnification of 250 diameters an error of only a thousandth of an inch will appear as a quarter of an inch and an error of one ten-thousandth can be readily observed. This method is particularly adaptable for measuring to close limits irregular shapes and contours, screw thread and profile gages, gear teeth, etc. The instrument used for this purpose is the contour measuring projector, the magnified image of an object being projected either on a vertical screen or the horizontal table attached to the instrument.

Two of the characteristics of light are the constancy of its wave length for a given color and its property of interference, which together establish the fact that each interference band produced by the reflection of light, as shown in Fig. 26, represents a very small definite separation

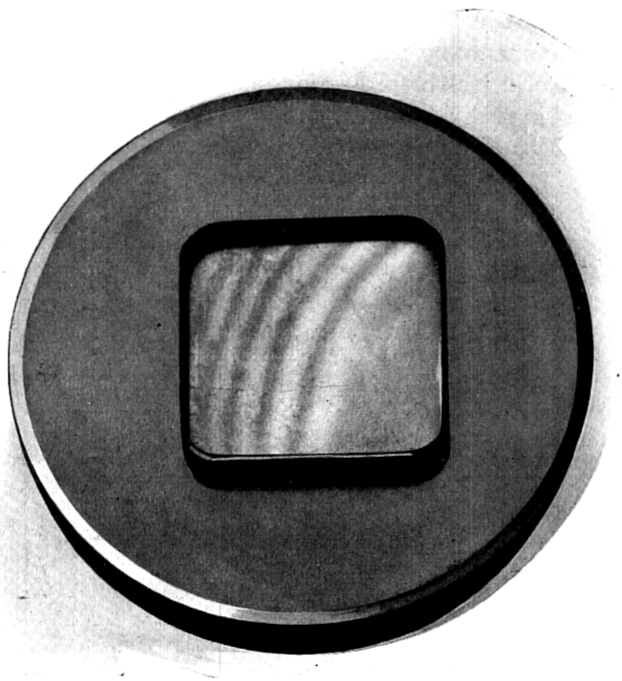

Fig. 26—Interference bands produced by the reflection of light waves

between the surfaces producing the reflections. As this separation or distance is a function of the wave length of the light used, the application of this principle permits extremely accurate measurements to within a few millionths of an inch.

Fig. 27 illustrates the application of this method in measuring a .375 in. plug, the equipment used being an optical glass flat, a metal flat on which the parts rest, a .375 in. master gage block, and a monochromatic light, usually red or green, having wave lengths of .000025 in. and .000020 in. respectively. In order to simplify calculations, the plug is placed so that its center is a distance from the gage block equal to the width of the latter. Unless the gage and the plug are exactly the same size, dark interference bands will appear across the gage block when the light falls upon it, due to the wedge-shaped air space formed between the upper flat and the top surface of the gage block. In accordance with the theory of interference, the distance between the flat and the gage at the first band adjacent to the edge where contact between the two surfaces is made, is one half the wave length of the light used, which if red would be .0000125 in. The distance at the second band is then one wave length or .000025 in. If there are a total of three bands, the distance at the edge of the block

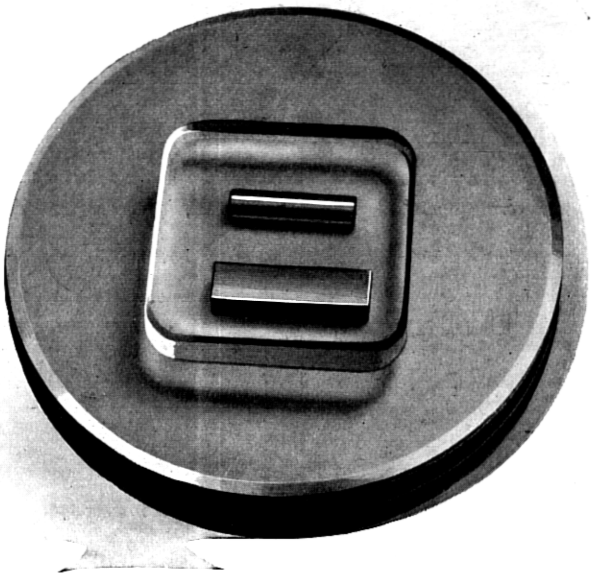

Fig. 27—Metal flat, optical glass flat, and gage block in position for measuring .375″ plug by light wave interference method

is .000037 in. or the difference in size between the plug and the gage is .000074 in., since the distance between them is twice the width of the block. The interference method gives a reliable and permanent unit of measurement and is probably one of the greatest refinements in precision measuring. In addition to measuring lengths, it can be used for checking the accuracy of flat surfaces, tapers, etc.

For more precise comparisons of gages and for the direct measurements of gage blocks in terms of wave lengths of light there is available a special form of the Michelson interferometer made by Zeiss, having a monochromator for selecting the particular wave length to be used, Fig. 28. This instrument is a comparatively recent development and to our knowledge there are only two in this country at present, the other one being in the Bureau of Standards.

The light is furnished by the helium tube "*A*." The particular wave length to be used is selected by rotating a glass prism inside the case by means of the cylinder "*B*" graduated to read the wave length directly. The gage block to be measured is located at "*C*" and the interference bands are observed through the eyepiece "*E*."

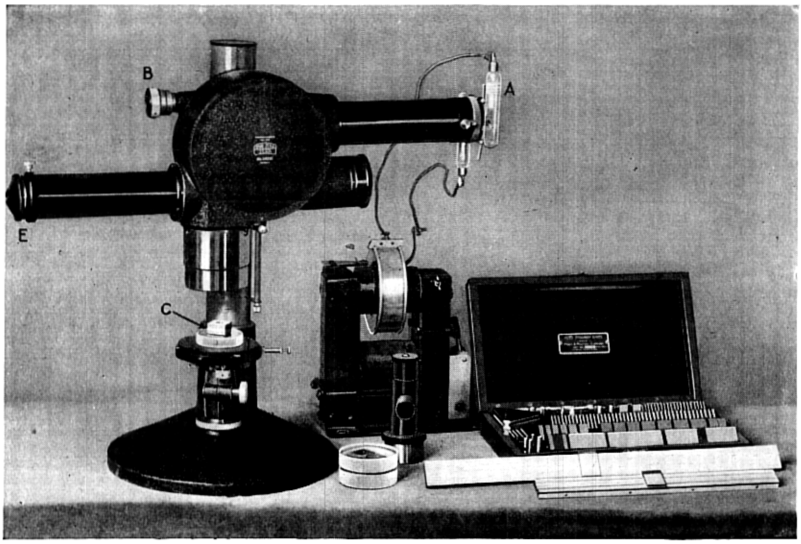

Fig. 28—Laboratory interferometer

To make a direct measurement of the length of a gage, observations are made using five wave lengths, and by computing the results obtained the length may be determined to an accuracy of about two millionths of an inch. In working with this degree of precision, the instrument is used in a constant temperature room and corrections made for temperature, humidity, and barometric pressure.

Conclusion

Tool making in all its branches as carried on in the tool rooms of the Western Electric Company is a comprehensive subject, regarding which several volumes might be written if covered in detail. In the foregoing description an effort has been made to give briefly, and by considering only one branch of the work, a general picture of the high grade workmanship required and some of the equipment and instruments employed. Similar precision is required on many classes of tools, such as jigs, fixtures, screw machine tools, milling cutters, etc., and especially gages employed in interchangeable manufacture.

This paper would not be complete without mentioning the fact that the high degree of workmanship, technique, and precision found in the product and methods of the Western Electric Company's tool rooms and many of the novel features of tool design are in a large measure due to the Works Technical Organizations operating the tool rooms. The writer is indebted to these organizations, as well as to other groups in the Manufacturing Department, for much of the material presented in this paper.