

THE DESIGN OF A HANDHOLE MILLING MACHINE FOR USE IN
THE HEDGES-WALSH-WEIDNER COMPANY

by

Eugene Broughton Hyden

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The writer intends to explain the actual design of a special machine which is one of several to be used in the Hedges-Walsh-Weidner Plant for milling oval handholes in boiler headers.

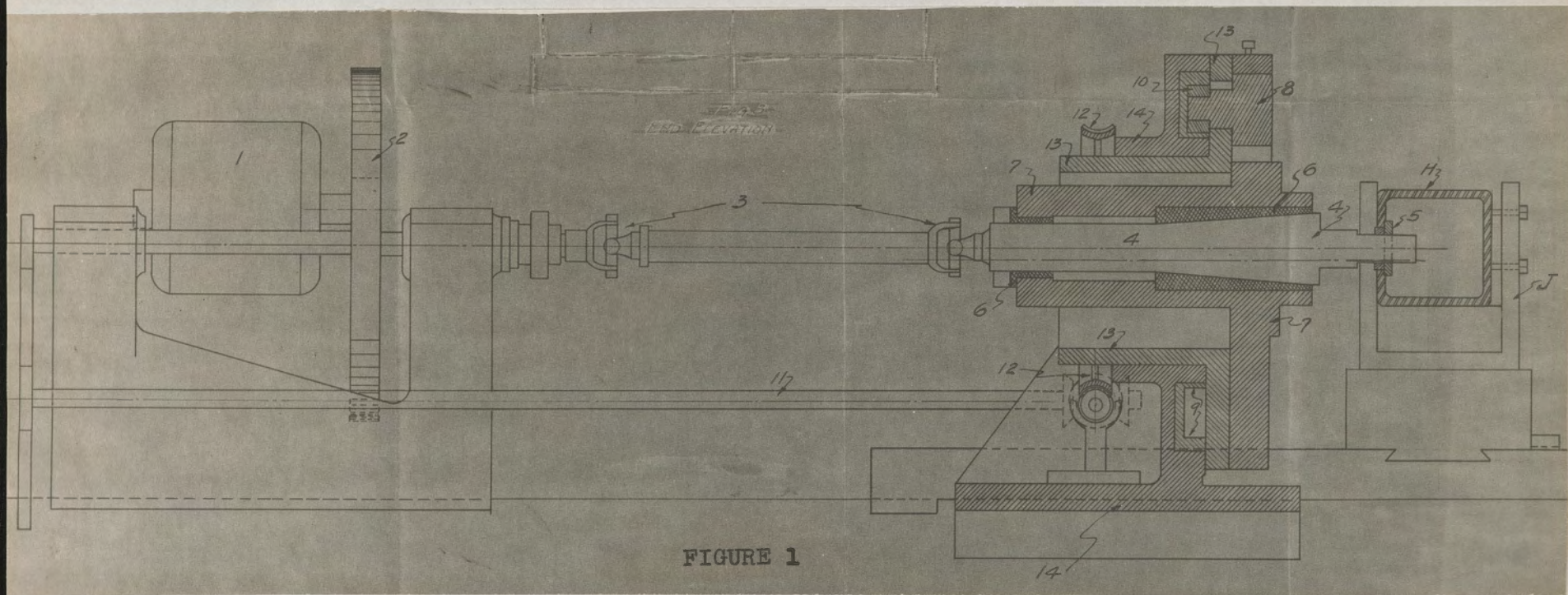
This machine was designed by Mr. Fred Krause, Plant Superintendent of the boiler company, with some help and suggestions from the writer. The writer made all initial drawings and traced most of these drawings for future reference. All calculations were made by the writer.

This machine was designed with the intention of supplanting four machines now in use at the above plants. These machines were also designed by Mr. Krause. The new machines are to be vastly superior to the existing machines, in ease of control, economy of space, and in speed.

Figure 4 shows the shape of the handhole which the machine is to mill.

A brief description of the existing machine will be given so that the design and improvements of the new machine may be better understood.

The old machine is shown in figure 1. This shows the side view of the machine which is its longest dimension. The numbers refer to different parts. Number 1 is a 5 horse power motor which runs the machine



with a silent link - belt drive shown in No. 2. Number 3 is a universal joint coupling which allows the spindle (4) and cutter (5) to follow an oval path as it rotates. "H" is a header, and (5) the cutter which mills the handhole and, at the same time, mills a seat for the handhole plate. No. 11 is a counter-shaft driven by the set of gears at the back. The worm wheel (12), which is turned by the worm, turns the bearing (13). No. 9 is the face cam which has been designed to make the cutter follow the oval path of the handhole. No. 10 is the roller which is on a pin fastened in the spindle bearing #7, and in which the spindle #4 is supported. This casting is made to slide in casting #13 as it revolves. The small cap screw shown in #7 at the top is for adjusting the machine for various size handholes. J is the header jug which is fastened to its base. This base slides in a plane perpendicular to the plane of the drawing in order to get the next handhole in front of the cutter. An intricate set of levers is necessary for this. This machine is about 14' long.

The advantages which the new machine offers are: greater compactness, requiring less than $\frac{1}{2}$ the space of the other one; a variable speed instead of one speed; more ease and less effort required of the operator; the jig and header do not have to be moved because the whole

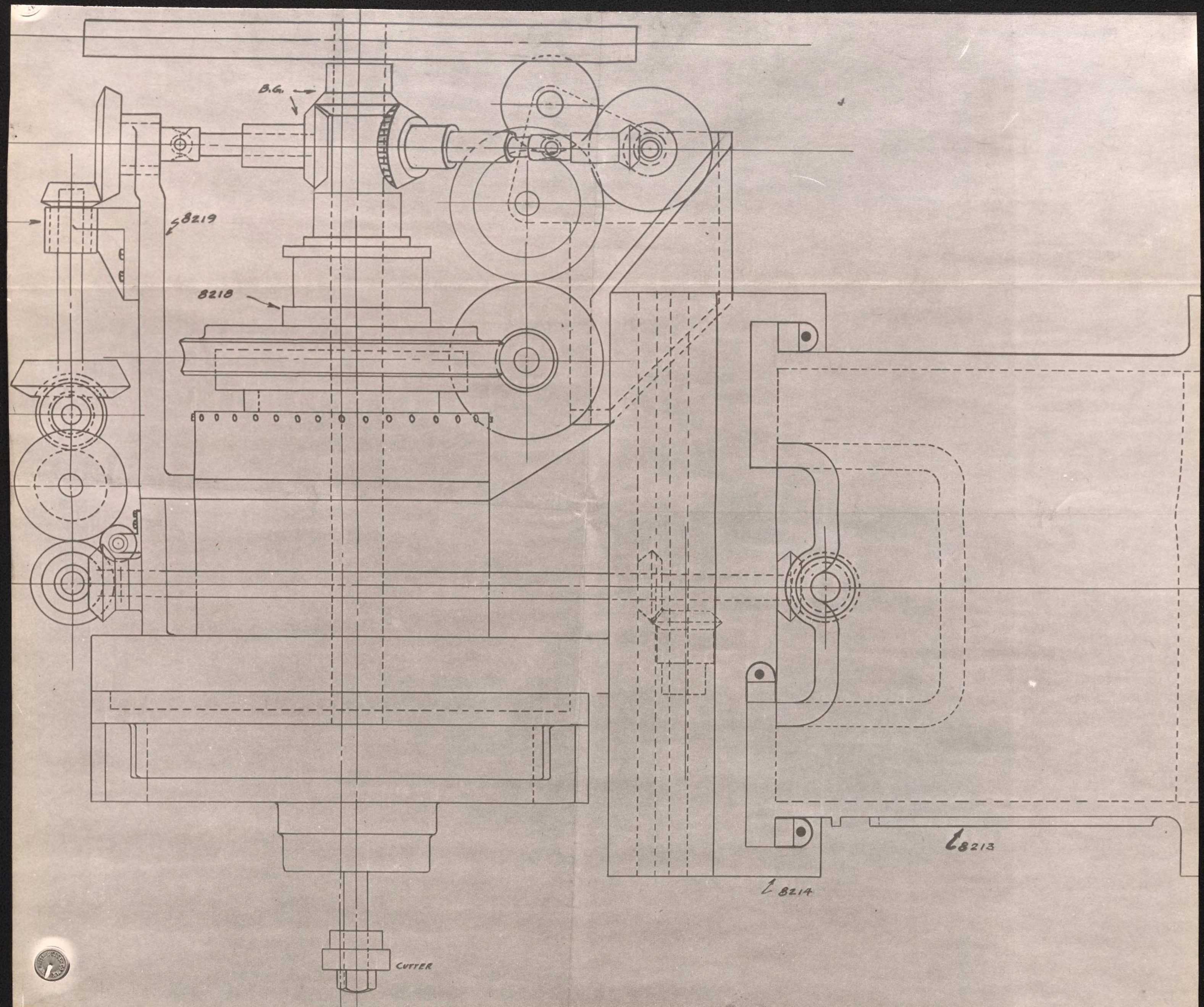
machine and motor moves, actuated by a quick-traverse system of gearing; and less chatter and vibration.

The time spent in the design and in making the drawings of this machine took about six weeks. The fact that Mr. Krause has had years of practical experience in designing several types of machines now in use in his own plant offsets to a great extent the lack of theoretical design of parts of this machine. His ability to closely judge the weight and thickness of various parts, coupled with suggestions in design and scaled drawings by the writer, has justified, in this case, the method of design used. That the design is successful, is shown by the fact that one of these machines is practically completed and that not one single fault in design has been found. The machine runs without chatter and vibration and just as it was expected to.

The design and construction of the machine will now be described. The work done in designing this machine was carried on in a small office out in the boiler shop and away from disturbances.

Two days were spent in studying the construction of the existing machine, and one of these machines was taken apart.

The first problem confronted was that of making the machine shorter. The universal joint between the



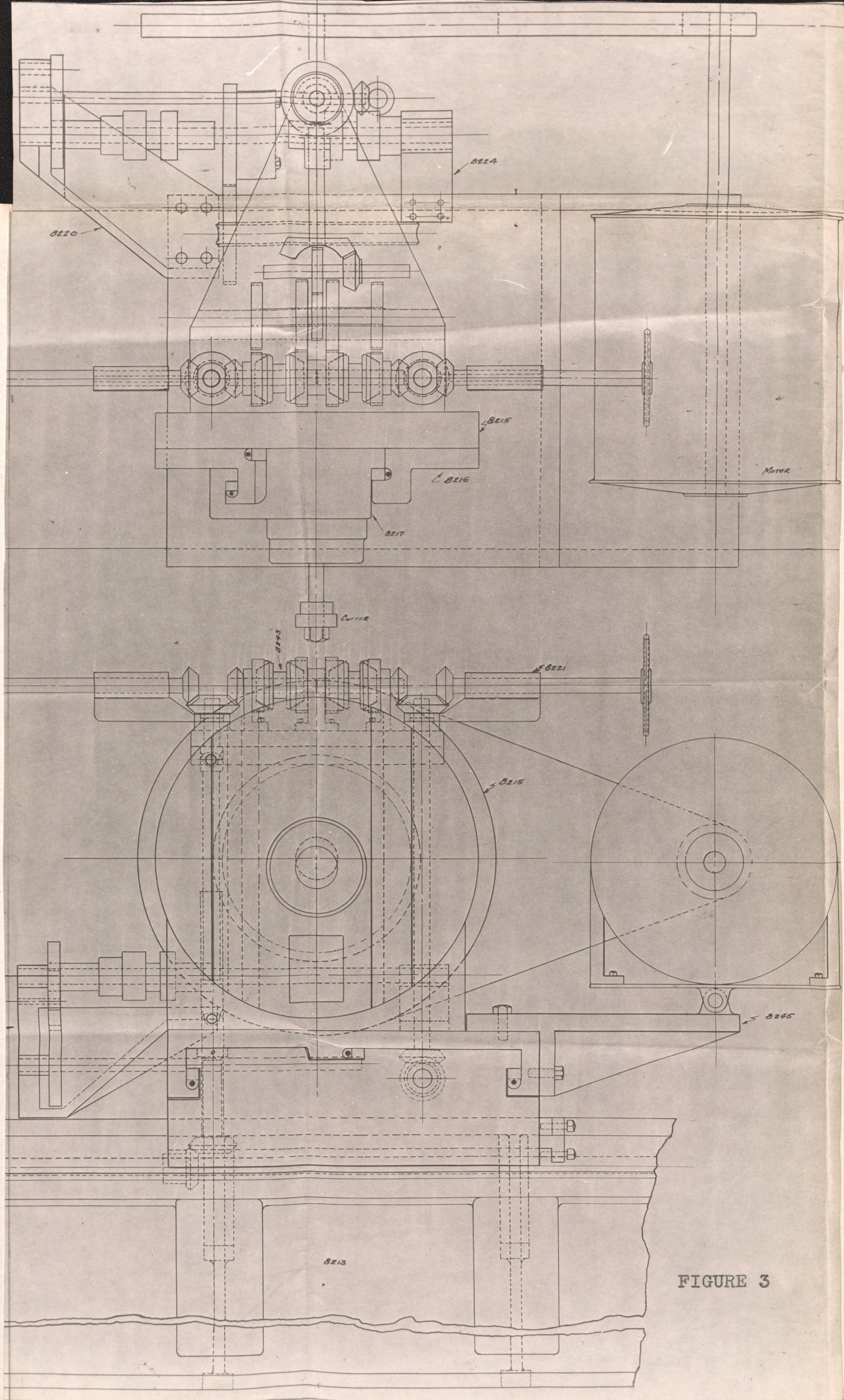


FIGURE 3

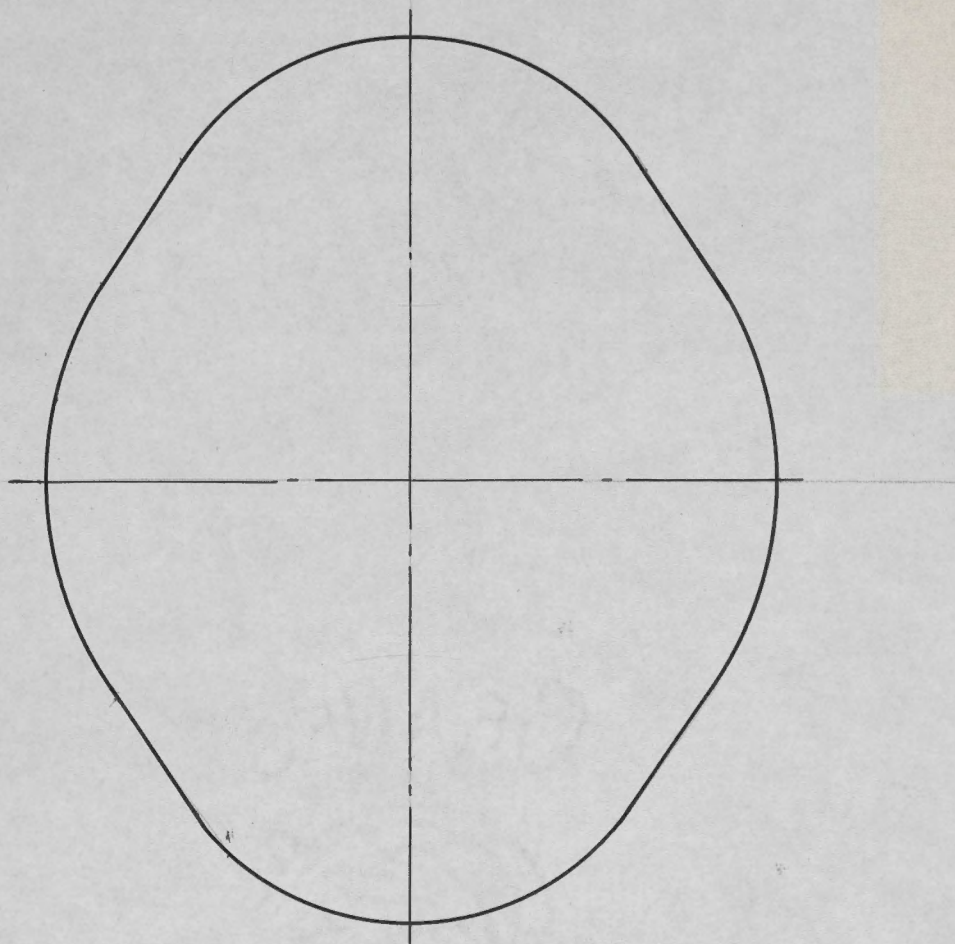
motor drive and the solid spindle shaft was the element which made the existing machines so long. This joint is shown in figure one. It was obvious that this joint had to be somehow eliminated so that the wheel driven by the motor could be moved close to the front. This would necessitate increasing the shaft (4) length so that the wheel could be keyed on it.

Immediately, other problems arose. Since the cutter shaft (4) followed an oval path as it revolved, how was the wheel (2) to be so connected to the motor that it could be driven and yet follow an oval path? Also, since the back set of gears, used to drive the shaft (11), could not be applied, what system of drive could be used for this auxiliary shaft? The first question was solved by the idea of mounting the motor on a rocking base. The second question was solved by a unique system involving a combination of a universal joint with a sleeve joint which will be described later. It is shown by the letter "a" in figure 2.

Another problem was that of improving or eliminating the awkward, intricate system of gears and levers necessary to move the jig and sub-base (shown as J and 5B in figure one) to bring the next handhole in the header "H" in front of the cutter in order to mill the handhole. The existing system was difficult to operate.

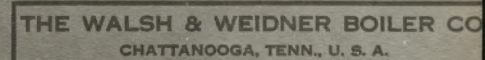
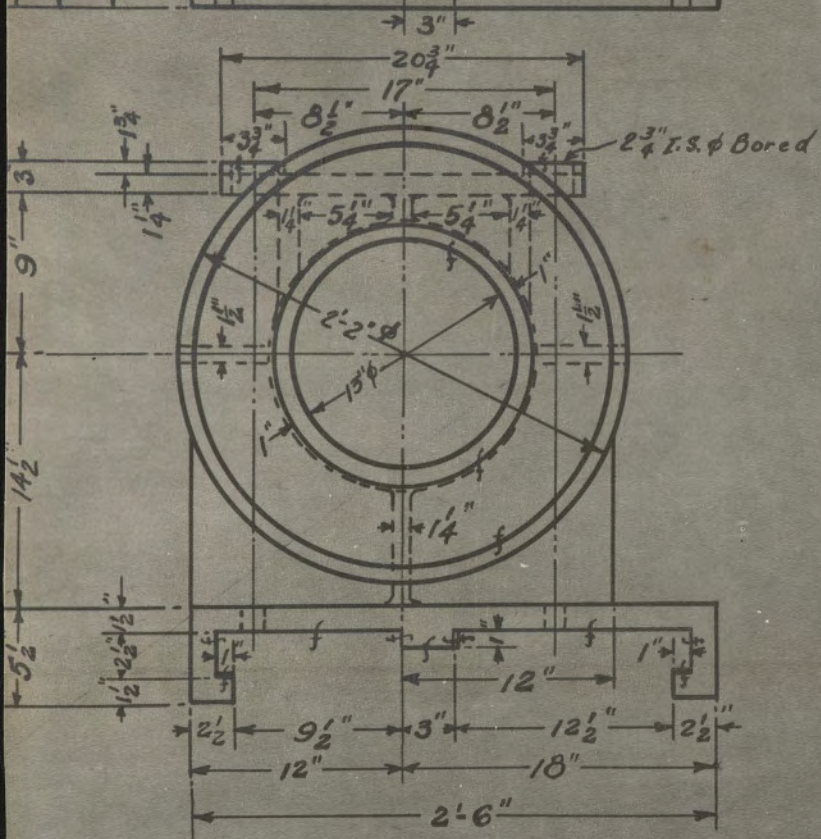
Several schemes were thought of and immediately dropped because they were impractical. Finally it was decided that the jig and header must remain stationary, and the machine itself designed to move along the header to each successive handhole. This called for a new design in the base so that its long dimension would be along the front; and also for some system of traverse which would run the motor along on its base and also backwards and forward on its sub-base, to take the cutter out and into the handholes. This system will be explained in detail later. This quick-traverse system introduced the problem of having good controls within easy reach of the machine operator.

A new feature of the machine was to be a variable speed of the movement of the cutter spindle in its oval path. This meant a variable speed of the worm and worm wheel shown in figure two. The fast speed was to be used on the part of the oval with the long radius, and the slow speed on that part of the oval with the sharper curve at the ends. This variable speed was to have been used with a bevel gear differential supplying the speeds, but due to difficulties a spur gear differential was designed to be operated by two Johnson clutches. The letter "d" in figure three designates the differential.



Shape of Handhole Milled

Figure 4



CAM SUPPORT FOR
HANDHOLE MILLING
MACHINE
DO NOT SCALE DRAWING

DRW. BY G. B. M.	SCALE 1/2" = 12'	CHK. BY
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After a study of the above problems had been made, a very general idea of the new machine was possible. Roughly, what was to be designed was a machine; whose length was to be about four feet in length instead of approximately eight and one-half feet from front to back; whose width was approximately thirty inches and which was to move along a bed with a travel of about twelve feet; whose cutter was to be driven by a motor with a link-belt drive and which was to rock back and forth as necessitated by the oval movement of the spindle; whose auxiliary shafts were to be driven from the cutter spindle; whose movements on its base and sub-base were to be governed both with a quick-traverse system and by hand; whose spindle was to have an automatically controlled variable speed for its oval travel; and which was to be capable of milling different size handholes with their major axes at any angle devisable by 15.

Figure 5 shows a detail of the final design of the cam support. The same cam is used in the new machine as in those now being used. This cam is a face cam in which the roller travels. The cam is not shown but the seat to which this cam is bolted can be plainly seen. The inner diameter of this seat is fifteen inches and the other diameter (outer) is $23 \frac{7}{8}$ ". This cam support is cast with the base which is designed to slide on the

sub-base, backwards and forward. It has been cast to the left of the centerline so that the motor base can be bolted to the cam support base. The motor base could not be cast to the cam base as one piece because of the weight would have been prohibitive; also the casting was easier as two pieces.

The platform shown cast to the top of the cam support is for the base of the quick traverse system. This platform is shown dotted in the front view. This quick traverse base was the last part of the cam support to be designed since the quick-traverse system was designed along towards the last; that is; after the first designs of the machine had been sketched. This casting is designated at #8215 in figure 3.

This casting had to be designed along with the spindle bearing guide shown in figure 6. This guide turns in the cam support, being rotated by the worm wheel shown in figure 2. The small 3" x 2" hole shown in the casting is the one through which the cam roller pin possess. Thus as this guide revolves, the roller is forced to turn in the cam and follow its path. The roller is on a pin which passes through this small hole and which is fastened to a heavy block which was placed in the 5½" x 4" hole shown in the casting of figure 7. This detail will be explained later. The threads on the back

Margins for Binding.

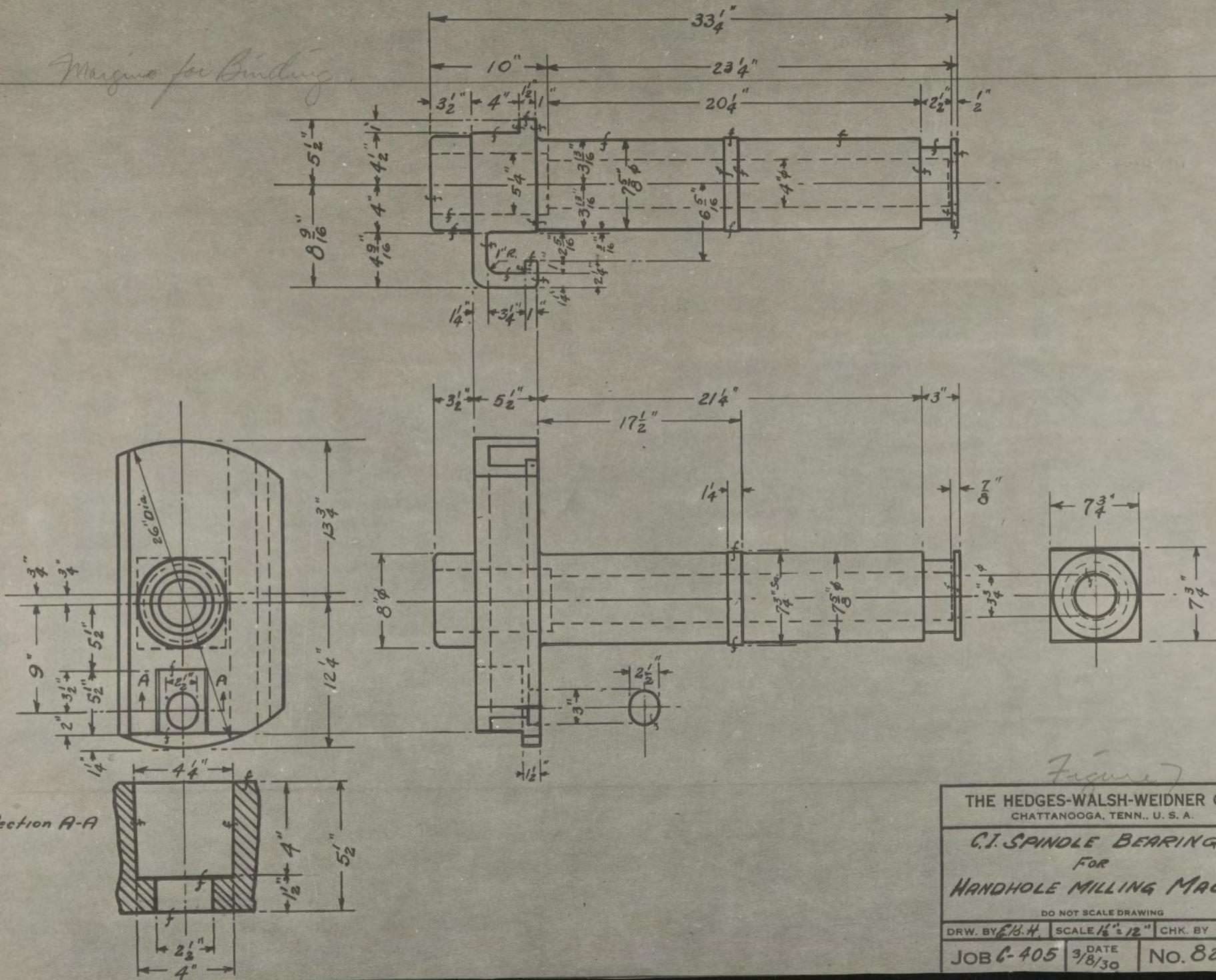


Figure 7

THE HEDGES-WALSH-WEIDNER CO.
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C.I. SPINDLE BEARING
FOR
HANDHOLE MILLING MACH.

DO NOT SCALE DRAWING

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of the guide in figure 6 are for a round nut which is tightened against a $\frac{3}{4}$ " thick ring which goes on this casting in order to bring the back of the 26" diameter part of the guide up against the face of the cam support. The front of the casting in figure 6 is the guide element. These guides were designed for the spindle bearing of figure 7 which, as it rotates with the casting of figure 6, slides up and down in the guides in order to follow an oval motion. The last part of this guide to be designed was the back part. Figure 6 shows that in the back of this casting is a groove cut in its circumference. This groove is for the "tongue" part of the supporting nut shown in figure 8. This nut constitutes a unique part of the machine and will be explained presently. In figure 3 the guide is shown as "8216" in the plan view. In this same view "8217" shows the spindle bearing as it works in the guide. The location of the gib keys is shown in this view.

An examination of figures 6 and 7 show that the inside diameter of the guide is approximately three inches greater than the outside diameter of the spindle bearing. This is to allow the spindle room to slide up and down as the cutter follows its oval path. Since the spindle revolves in this bearing, it is necessary that the spindle slide up and down in the guides of figure 6 as it revolves, so that the spindle will be able to move freely in its oval path.

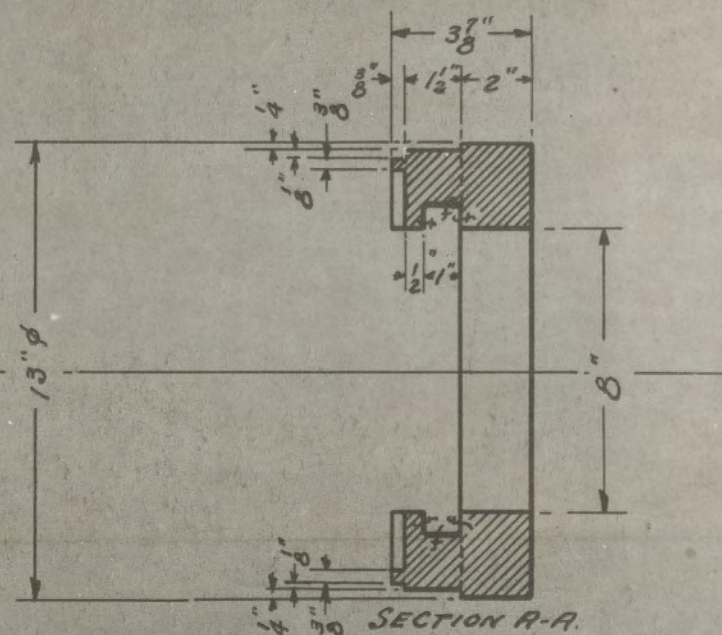
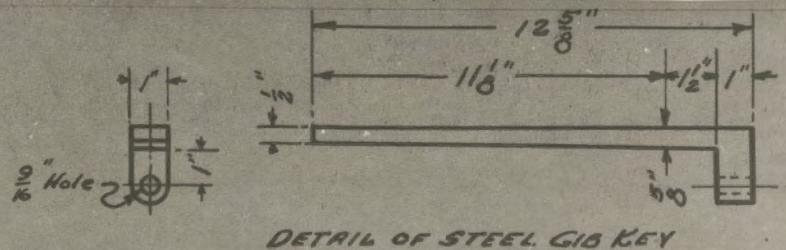
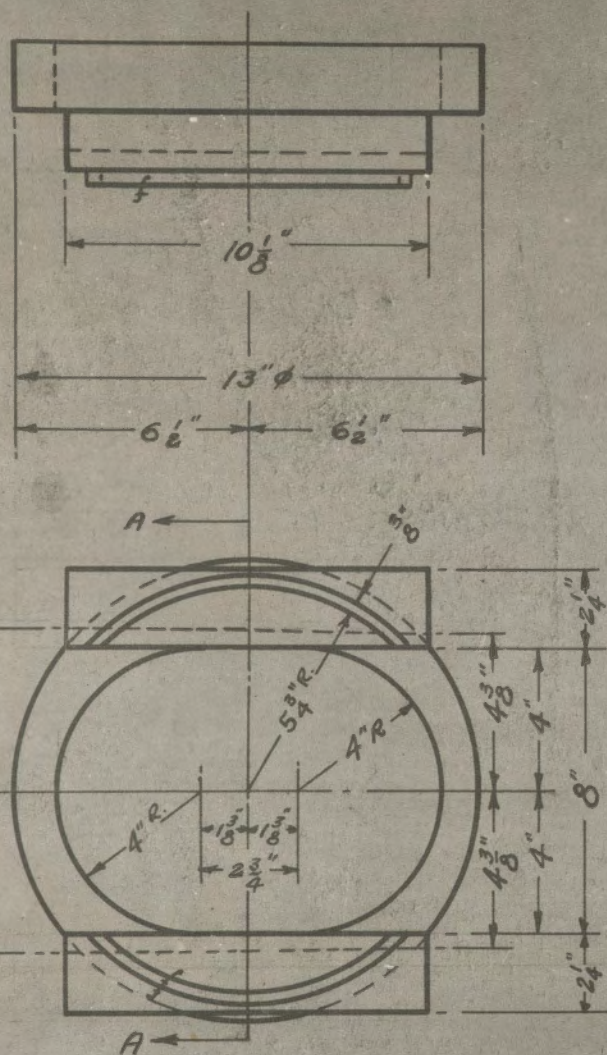


FIGURE 8

THE HEDGES-WALSH-WEIDNER CO.
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C.I. SUPPORTING NUT
FOR
HANDHOLE MILLING MACH.

A further examination of figure 6 and 7 shows that the bearing projects beyond the guide when they work together. Section A-A shows the seat in which the plate, to which the cam roller pin is fixed fits. This seat is $5\frac{1}{2}$ " long and is open at the end. The roller pin goes through the 3" by $2\frac{1}{2}$ " hole in the bottom of the seat and on through the same size hole in the guide casting to reach the cam. The plate to which the pin is fixed is less than $5\frac{1}{2}$ " in length so that distance between the center of the bearing and the center of the cam roller can be adjusted to mill the size handhole required. This is done by a set of adjustment screws in the pin plate. Thus, by tightening the screws, the bearing is forced closer to the center, thus making the oval travel of the bearing less, so that a smaller handhole is milled.

The $7\frac{3}{4}$ " square shown in figure 7 is for the supporting nut of figure 8. This nut is held to the square by two gib keys shown in figure 8. The tongue of this nut fits in the groove in the back of the casting of figure 6. Thus, this nut more or less binds the castings of figures 6 and 7 together, serving the purpose of stiffening the machine. This eliminates the necessity of a bearing at the rear for the spindle.

On this supporting nut the worm wheel is bolted. This is shown in figure 2. This worm has 112 teeth with a pitch diameter of 16 inches. The worm is single thread.

The end of the spindle bearing is designed to provide a place for a $2\frac{1}{2}$ " collar. To this collar is bolted a piece of bar steel attached to two slip rings around the motor. In this way the motor is prevented from suddenly swinging forward or backward as it pivots on its base. This arrangement is not shown in the drawing.

The spindle bearing is further stiffened by a nut, shown as "N" in figure 2, which is screwed up against the back of the bearing.

The motor selected for this machine is a Howell 5 horsepower induction motor using 440 volts. The full load speed is 580 revolutions per minute. The drive was so designed to give a cutter speed of 112 R.P.M. at full load. Actually, 5 H.P. is not consumed so that the speed is somewhat higher.

Figure 2 shows an assembly of the system which drives the worm and the variable speed. The lower shaft shown in figure 2 is driven by a set of mitre gears directly from the larger set of mitre gears at the cutter shaft, thus running at the same speed as the cutter shaft. The bevel gear, which meshes with that on the cutter shaft, is so designed that the shaft connected to the universal joint (designated as "a") will allow it to slip up and down on the shaft although it is keyed so that they both turn. This is to allow freedom of movement

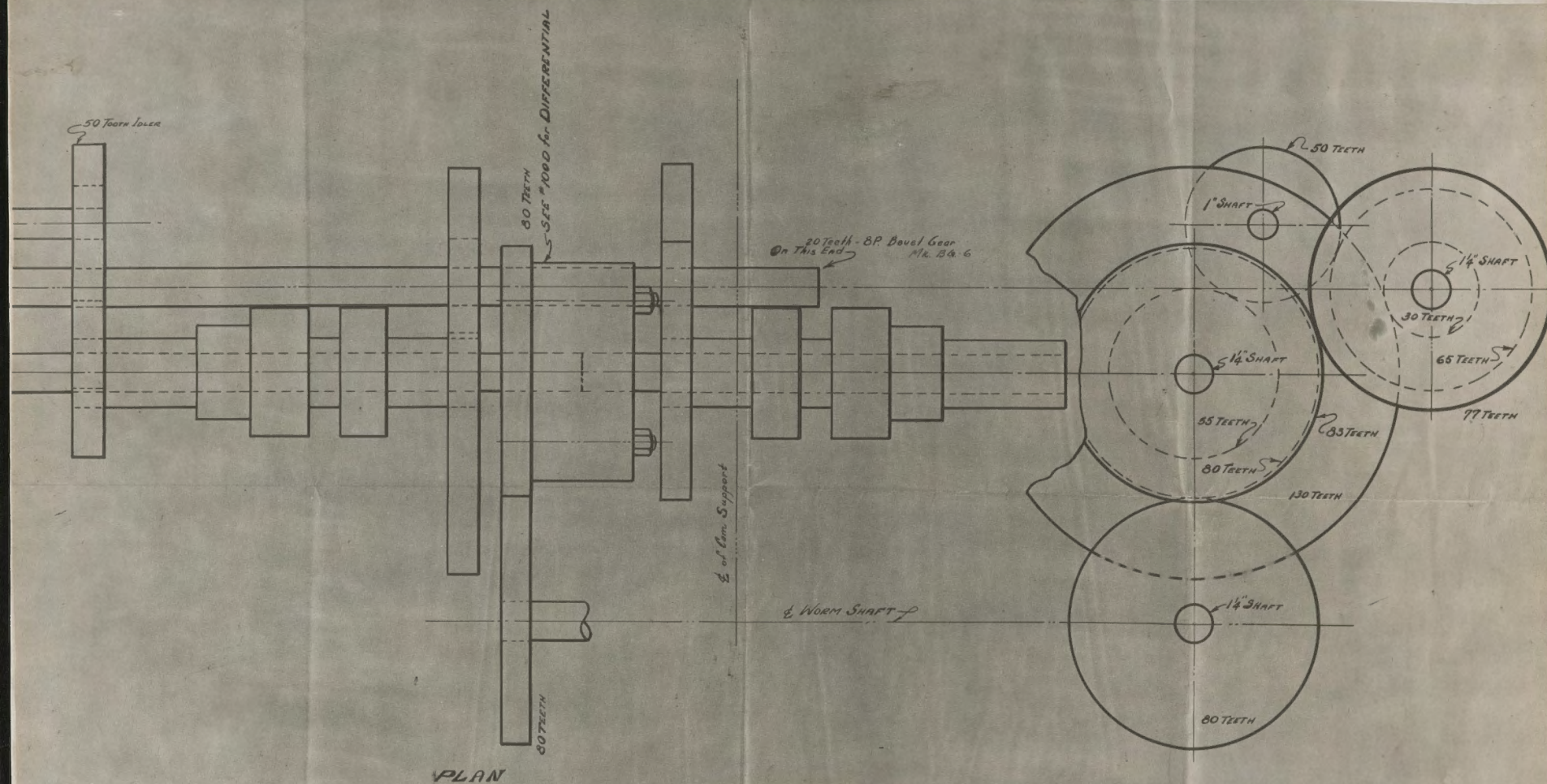


FIGURE 9

NOTE:

ALL GEARS SHOWN HERE ARE 10P WITH 1" FACE

of this gear as the cutter spindle follows its oval path. The lower bevel gear connected to the universal joint is held vertical by a bearing.

A plan view of these lower shafts is shown in figure 9. The bevel gear is not shown, but a notation explains where it is supposed to be. This shaft runs at about 112 R.P.M. at full load. The 77 tooth gear, just to the right of the differential shown, drives the right differential shaft with an 88 tooth gear. The end view shows this arrangement. To this gear is keyed a Johnson clutch whose other end is fastened in a bearing (8224 in figure 3). This clutch is that which operates the variable feed automatically. The operation of this clutch has not been drawn, since Mr. Krause had his own idea as to how it would be worked. The idea is to operate the clutch by an upright lever with a weight on it. This lever is to be fixed to the clutch and actuated by a cam-like device on the worm wheel. Thus the lever will be brought up to a vertical position and, at the moment which it passes this position, the weight will throw the lever on over, causing the clutch to shift instantly. Likewise, when the lever is brought back to the vertical position, the weight will throw it the other way, thus throwing in the other speed. The faster speed is for that part of the handhole with the greater radius, while the slower speed is for the ends.

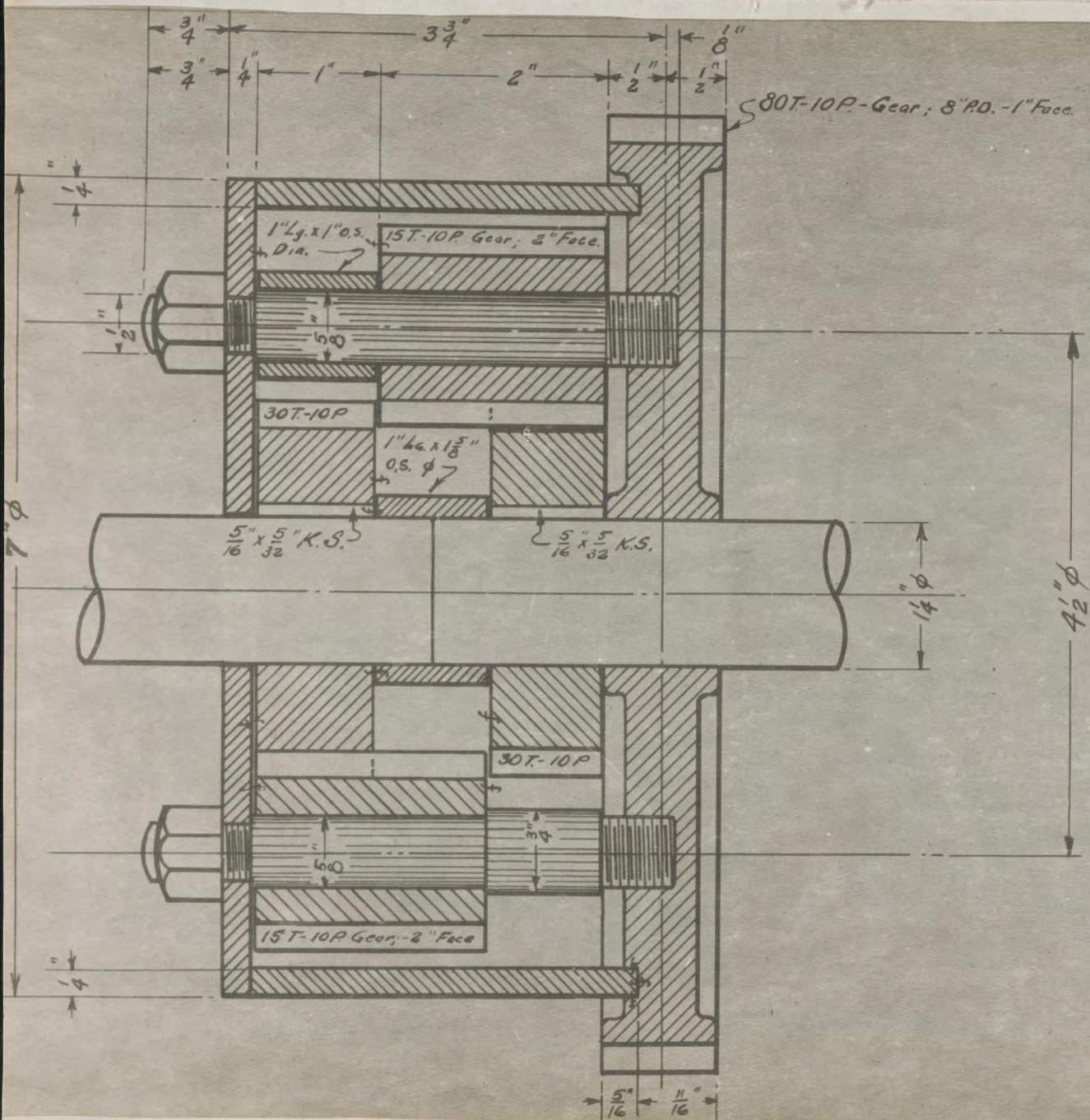


FIGURE 10

THE HEDGES-WALSH-WEIDNER CO.
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DETAIL OF SPUR GEAR
DIFFERENTIAL

The left differential shaft is the slow speed shaft. The driving gear from the lower shaft is a 30 teeth gear. The driven gear has 130 teeth, and is keyed to the left Johnson clutch. The left end of this clutch is keyed to a 55 teeth gear which is one of the gears of the reversing system. These three gears which make up the reversing system are clearly shown in figure 9. These three gears are in a combination bearing designed by the writer and shown as 8220 in figure 3. The 50 teeth idler, of course, reverses the direction of the shaft. This Johnson clutch is operated from the front of the machine by a lever and yoke and is the starting clutch. Johnson clutches were selected because of their compactness and serviceability.

Figure 10 shows a detail of the spur gear differential. Each of the two 15 teeth gears mesh with another 15 teeth gear, not shown in the drawing, and each of these gears mesh with the 30 teeth gear which its mate does not mesh with. The principle is very much like the automobile bevel gear differential. At first it was thought that a bevel gear differential could be used, but the spur gear differential is much simpler and easier machined. The 15 teeth gears revolve loose on the pin or bolt which holds the casing to the 80 teeth gear. The 30 teeth gears, each keyed to the

respective shaft, are the drive gears. The action of these gears inside the casing revolves the casing, thus revolving the large gear which is loose on the shaft. This large gear drives a gear of the same size on the worm shaft, thus driving the worm. The arrangement is shown in figures 2, 3, and 9.

When the worm is at its fastest speed, both shafts are running and both clutches are in towards the differential. The worm then turns approximately 82 R.P.M., thus turning the worm wheel approximately $\frac{5}{4}$ R.P.M. When the worm is at its slowest speed, the left clutch is still in; but the right clutch is thrown over to the right so that the shaft "a" in figure 10 is now held stationary. This turns the worm at about 26 R.P.M. and the worm wheel at about $\frac{1}{4}$ R.P.M. When it is necessary to reverse the worm wheel, and this is seldom, the left clutch is thrown to the left to engage the reverse gears. The reverse speed is very, very slow, the worm wheel reversing at the rate of 0.2 R.P.M.

After careful consideration, a quick traverse system was designed to be placed at the top of the machine to facilitate operation from the front of the machine. This system is shown at the top of figure 2 and also in figure 3.

The drive from the cutter spindle is similar to that drive to the lower shaft of the variable speed

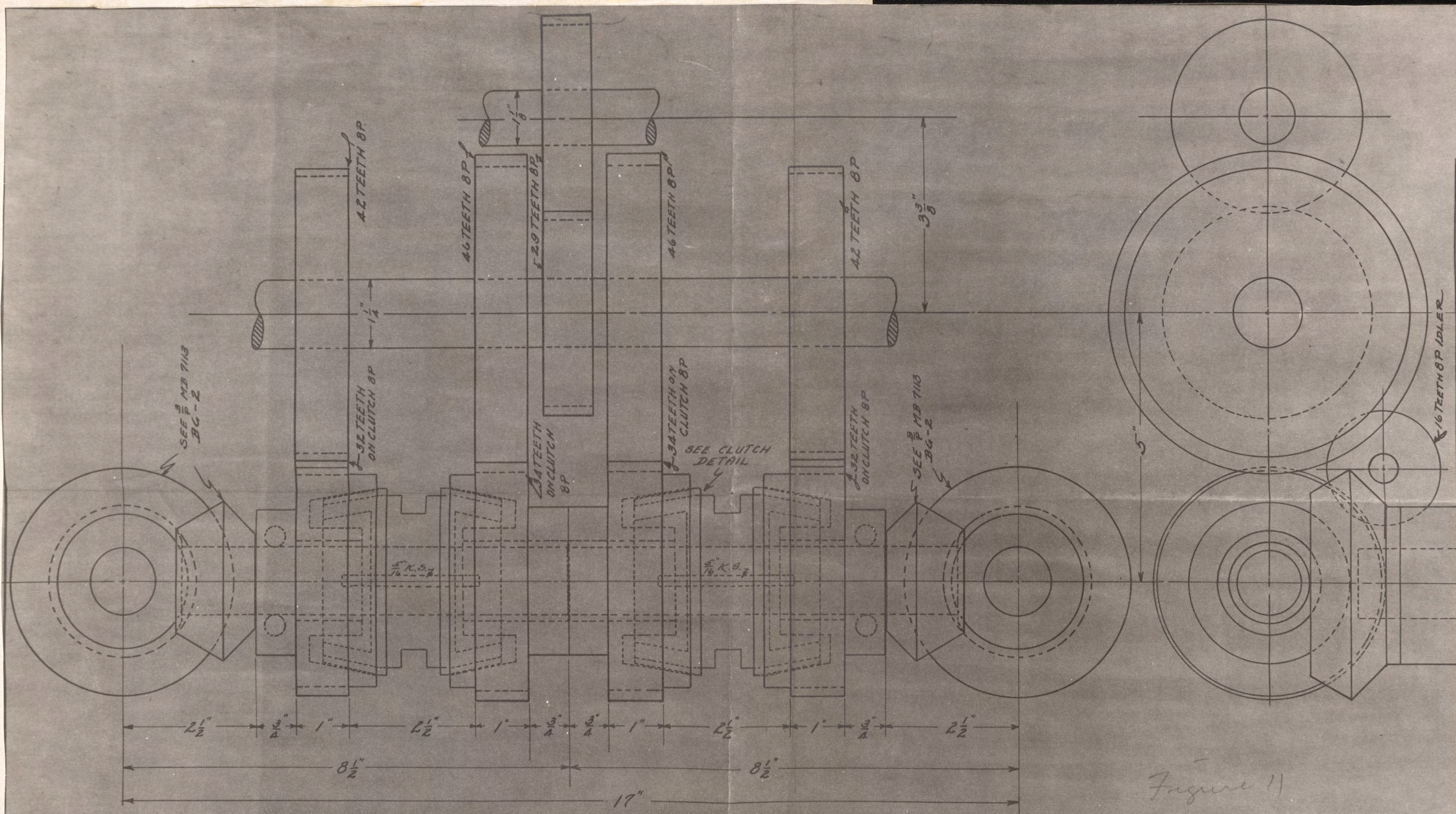


Figure 11

system, namely, by a universal joint and slip joint.

The rear shaft on the top platform is driven from the vertical shaft by a 48 teeth bevel gear. The driven gear has 24 teeth so that, at full load, the rear shaft has a speed of 224 R.P.M. This shaft then drives the next shaft, which is perpendicular to it, at a speed of 448 R.P.M. at full load, the larger bevel gear being a driver of 48 teeth. An examination of this gear in the plan view of figure 3 shows that a spherical portion of this gear has been cut out to allow a saving of space and to allow the 29 teeth spur gear on the driven shaft to rotate in this spherical space as shown.

The rest of this system, including the 29 teeth spur gear, is shown in detail in figure 11. The next shaft also runs at 448 R.P.M. since the driven gear also has 29 teeth. This shaft drives the front shaft on which two friction clutches are keyed as shown.

On the right end of the front shaft is shown the 24 teeth bevel gear which drives the 32 teeth gear keyed to the vertical shaft shown by dotted lines in the front elevation of figure 3. This spindle is the drive shaft for the bevel gear which rotates on the travel screw in the intermediate base or slide. This travel screw does not rotate. A groove is cut in the intermediate slide to provide for the travel of the bevel gear on the travel screw. When the right friction clutch is shoved to the

left, the machine moves forward on the travel screw at about the rate of $9\frac{1}{2}$ ft. per minute. When the clutch is shoved to the left, the machine moves backward at a speed slightly less than $9\frac{1}{2}$ ft. per minute. The small 16 teeth idler allows the change of direction between the driving and driven gear necessary to reverse the machine.

On the left end of the front shaft the 24 teeth bevel gear, by the same system and preparations, drives the vertical shaft which in turn drives the bevel gear that travels on the travel screw in the main bed. The travel screw extends through the whole length of the bed and does not revolve. Both travel screws are $1\frac{1}{2}$ " in diameter, 4 threads per inch. When the left clutch is shoved to the right (the lever is shoved to the left) the machine moves to the left at a speed of about $9\frac{1}{2}$ ft. per minute. When it is thrown to the left the machine travels to the right.

The two clutches were designed as slip clutches to prevent injury to the machine; so that if the machine, in its course of travel, were to strike something and stop, the clutch would slip. That part of the clutch which has the teeth is made to run free on the shaft. A brass bushing is used. The clutches are thrown by levers. The levers are not shown in the drawing, but rather long leverage is required to force the clutch to engage tightly.

Figure 3 shows the base or platform for the quick traverse system to be triangular in shape. This base is $18\frac{3}{4}$ " long and $1\frac{1}{4}$ " thick and the greatest width of this support is $20\frac{3}{4}$ ".

A hand control had to be designed for this traverse system in order to bring the cutter in exact alignment or position for milling. This is shown by the hand-wheels on the shafts extending on each side of the machine. The bearing for the hand-wheel shaft is shown, in figure 3 as 8221. This shaft is $1\frac{1}{4}$ " in diameter. The hand drive to the travel screw is by bevel gears at the top of the vertical shaft. The end of the bearing is $8\frac{1}{2}$ " from the center of the vertical shaft. This bearing has its seat in the traverse support and just under the vertical bevel gear. When the hand feed is needed for any movement of the machine, the hand-wheel can be swung around to the front, to be easily operated by the machine operator simply by turning the hand-wheel. The bearing 8221 of course provides the necessary stiffness and swings without any trouble. The wheels are about 12" in diameter. When not in use, the hand-wheel is swung back to the side.

Figure 12 is a detail of the intermediate slide carriage for this machine. The cam support base slides upon the upper part of this casting. The lower part is designed to slide on the bed shown in figure 13. The

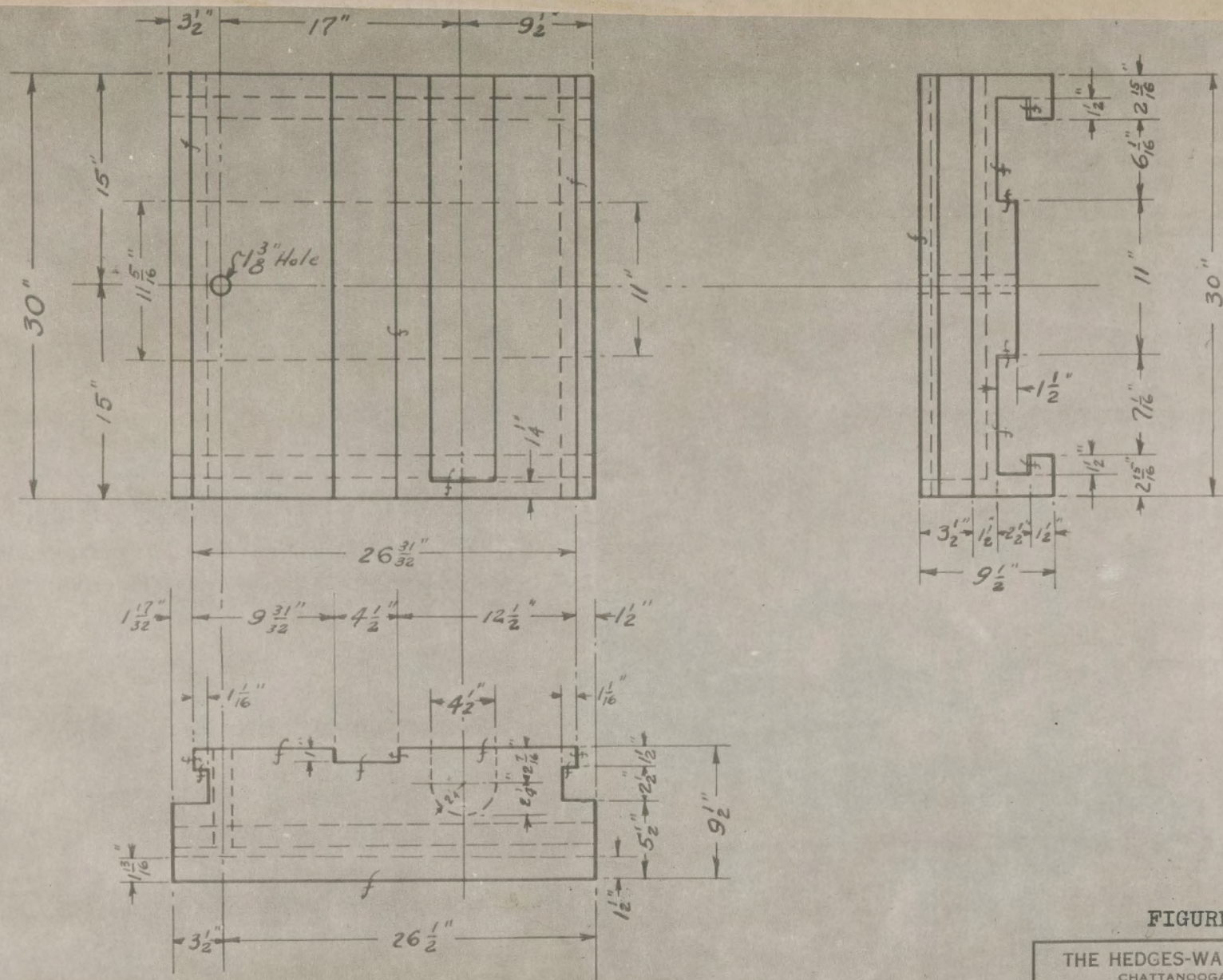


FIGURE 12

THE HEDGES-WALSH-WEIDNER CO.
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C.I. INTERMEDIATE SLIDE
CARRIAGE FOR
HANDHOLE MILLING MACHINE

$4\frac{1}{2}$ " wide trough in the carriage is for the travel screw, with allowance for the bevel gear and bearing. The $1\frac{3}{8}$ " hole is for the vertical shaft, of the quick traverse system, which drives the gear on the travel screw in the bed.

Figure 13 shows a detail of the bed with stiffening ribs and provisions for the travel screw. The 7" x 15" raised portions on the front are for the brackets to be bolted to which holds the header jig.

Figures 2 and 3 show how the ways of the bed and carriage were designed. The first machines, now being used, had the dovetail ways. The baseness caused by wear in this type of ways could not be taken up. The "rectangular" ways are better suited to the machine because any looseness or vibration due to wear in the ways can be taken up by the gib keys shown in place in figures 2 and 3. The same reason for this selection of ways applies to the similar design in the spindle bearing and the spindle bearing guide. The gib keys are designated as "G" in the drawings of figures 2 and 3.

In figure 12, the trough for the travel screw is left open to allow the travel screw to be put in when the machine is fabricated. Then a bearing plate is put in.

In figure 5, a 7" by $1\frac{1}{2}$ " hole is shown in the base of the cam support. This is to allow the cam support to move backward or forward without interference with the

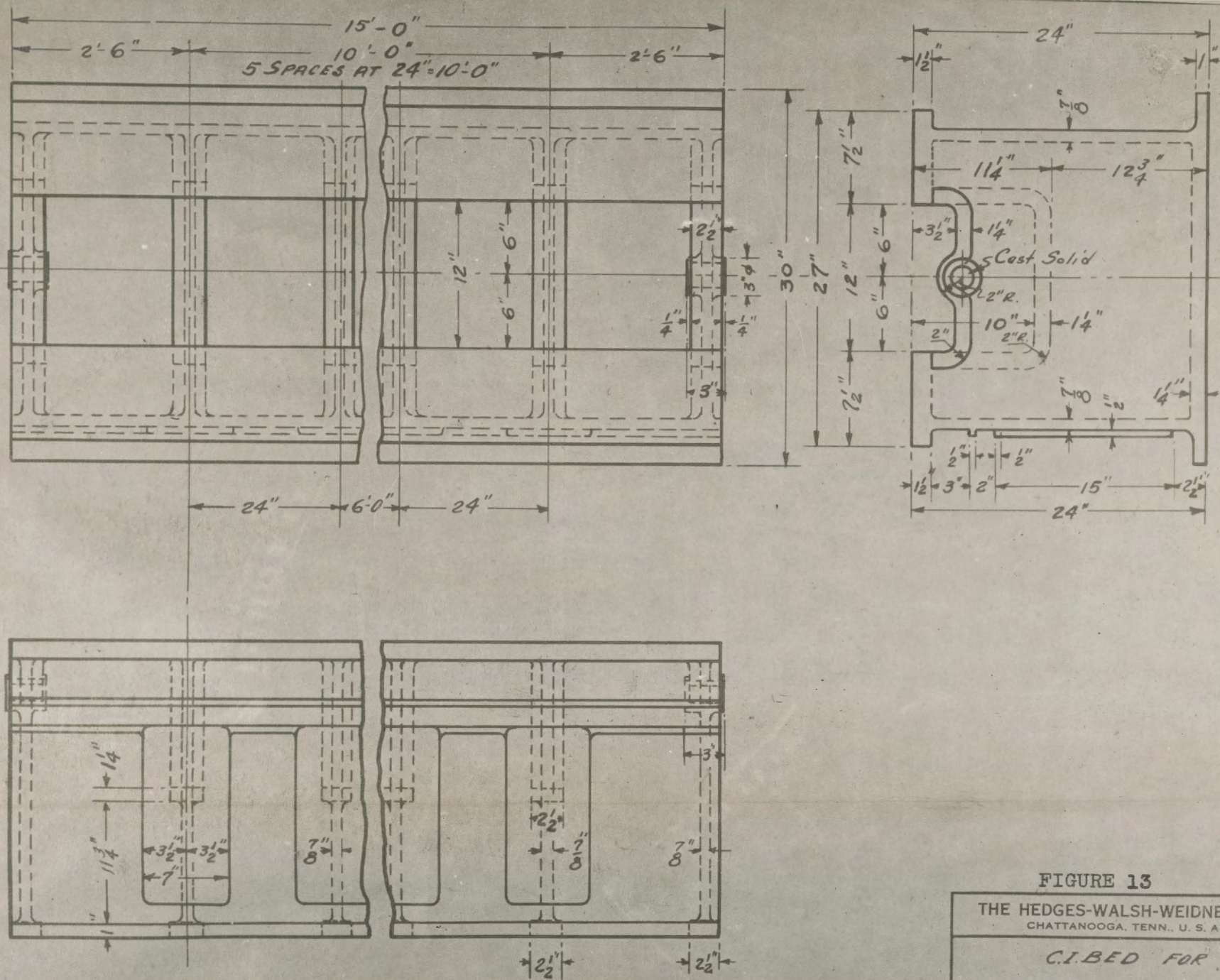


FIGURE 13

THE HEDGES-WALSH-WEIDNER CO.
CHATTANOOGA, TENN., U. S. A.

C.I. BED FOR
HANDHOLE MILLING MACHINE

the vertical shaft, of the quick traverse system, which has to pass through the support to the travel screw in the bed.

In the left side of the "head" or round part of the cam support is cut a $\frac{1}{2}$ " slot extending about 4" on each side of the horizontal centerline. This is not shown in the drawing. This 8" x $\frac{1}{2}$ " slot is cut through the head just at the base or back of the cam seat. In the cam itself, which is bolted to the seat from the back, are cut slots every 15 degrees around the left half of the circumference. The slot midway between the top and bottom ones is in exact alignment with the center of the 8" slot in the support head when the major axis of the handhole, to be cut, is horizontal. The slots in the cam are marked as 15°, 30°, 45°, 60°, 75°, or 90° with the horizontal. Thus, when any angle (divisible by 15) other than the horizontal or zero angle is required, the corresponding slot in the cam is brought in exact alignment with the center of the 8" slot. This is done by taking out the six bolts from the back of the cam head and turning the cam in its seat by means of a $\frac{3}{8}$ " x $1\frac{1}{2}$ " bar inserted in the cam slot opposite the 8" slot. The slots in the cam plate itself are only $1\frac{9}{16}$ " wide. The $\frac{3}{8}$ " x $1\frac{1}{2}$ " bar is just about 18" long, long enough for leverage to turn the cam in its seat when the bar

is inserted in the cam slot through the 8" slot of the cam support. Thus a handhole can be milled with its major axis at any angle with the horizontal which is divisible by 15. When the cam has been set at the desired angle, it is again bolted to its seat with the six bolts.

In figure 7 the first 10" of the spindle bearing has an inside diameter of $5\frac{1}{4}$ " which is larger than the remainder. This is for a 10" bearing whose inside diameter is tapered to fit the tapered part of the cutter spindle. At the back of this bearing the spindle is 3" in diameter, and a short bushing is inserted for this diameter at the end. Thus, the cutter spindle itself does not touch the spindle bearing.

The question has probably come into the reader's mind as to the way in which the 3 bevel gears, marked B G, are held together. This is not shown on the drawing. These gears are held together by a pair of bearings, the gear on the cutter spindle being common to both of them. The bearing in which the center bevel gear turns also turns in the other bearing so that the bearings do not restrain any necessary radial motion of the gears.

All bevel gears are 8 pitch, heat treated, and hardened.

All spur gears are 10 pitch, heat treated, and hardened.

The height of the cutter from the bottom of the base is about 45".

The most common size of handholes milled are $5 \frac{1}{8}$ " along the major axis and $4 \frac{1}{4}$ " along the minor axis.

The machine, including labor, costs approximately five thousand (\$5,000) dollars. The weight is about 10,000 pounds.

The performance of the machine now being completed will be watched with interest. It has been run several times and Mr. Krause has told me that the design seems to be good in every respect.

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name W. R. Woolrich

Title Prof. Mech. Eng.