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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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# Development of Metalworking Industries in Developing Countries

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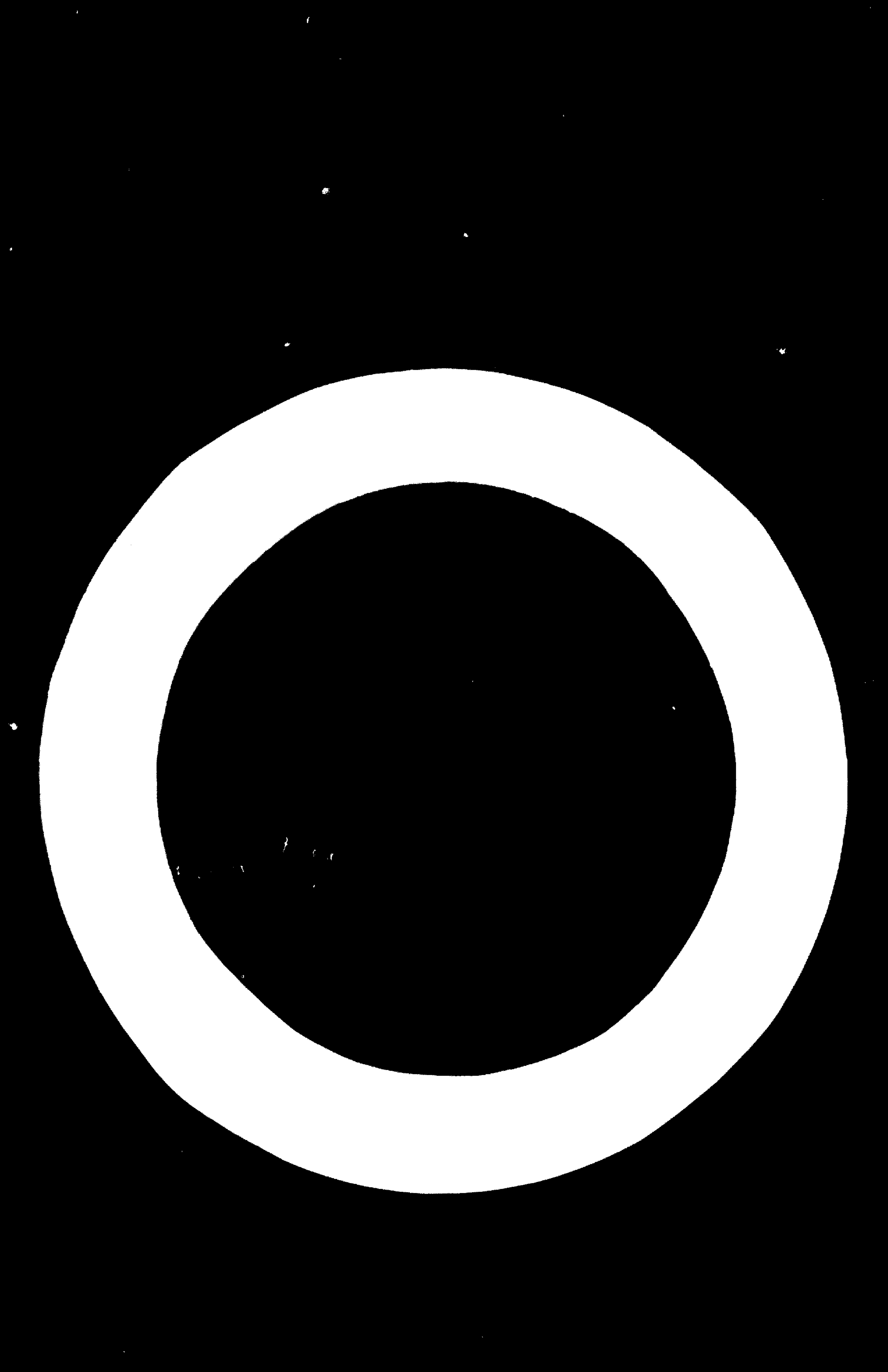

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# AN EXAMPLE OF MACHINE-TOOL PRODUCTION METHODS

*C. A. Sparkes, H. W. Kearns and Co., Ltd., Manchester, England*

## INTRODUCTION

The machine-tool works of H. W. Kearns and Co., Ltd., is situated in the county of Cheshire, about ten miles from Manchester, a city which may be regarded as being approximately at the hub of the industrial revolution. Therefore, for generations it has been considered one of the world centres of engineering, as well as the birthplace of a number of prominent machine-tool manufacturers. Manchester has also been noted for many years for its university, together with its college of science and technology, whose interests have been closely related to the engineering industries of the district. The strong engineering and educational influences have, in the author's opinion, been of considerable value to the engineering companies in and around Manchester, particularly H. W. Kearns, who have benefited from the excellent technical and practical skills which have had such fertile ground in which to develop.

Against this background, H. W. Kearns' factory was established on its present site in 1907. The original factory was 140 feet wide and 160 feet long; it had five bays and a steel framework which was arranged so that the buildings could be extended lengthwise. This careful planning has enabled the company to continue to operate on the original site, although the main building has been extended periodically until it now has a total length of 460 feet. There are four bays of 25 feet and two of 40 feet. More recently, a further extension, with a bay of 50 feet, has been added. The total floor space now occupied is approximately 110,000 square feet. New office accommodation is available in a two-storey building covering an area of about 15,500 square feet. There are also an independent pattern shop and associated pattern stores covering an area of roughly 8,000 square feet. The factory is completely equipped with overhead cranes, the largest of which has a capacity of 20 tons.

As already indicated, for almost sixty years the company has concentrated its total design and manufacturing facilities on the production of horizontal boring machines. These now range in size from 1 to 50 tons and in price from roughly £2,000–£50,000. Long experience in the manufacture of machine tools indicates that the first essential for creating a satisfactory manufacturing programme is a sound design policy. In the case of universal horizontal surfacing and boring machines, this is a complex problem because of the comprehensive range of operations which they are expected to undertake. Those engaged in the machine-tool business are also well aware of the difficulty of accumulating service experience on a particular design because of the limited number produced; moreover, these machines are rarely engaged in a similar type of production for a sufficient period of time to disclose any obscure weakness in their construction. Furthermore, if a successful machine-tool design policy is to be followed, it must be carefully planned not only to cater for the differing factors, but, at the same time, to take advantage of the latest research information. Fortunately, H. W. Kearns' case is slightly simplified by the decision to concentrate all manufacturing facilities on the production of horizontal milling and boring machines. A study of this type of machine reveals that it has two characteristic features which have a considerable influence on its design. These are the work-holding capacities of the table and the metal-removing ability of the headstocks.

## 1. DESIGN POLICY AND MANUFACTURING PROCEDURE

Obviously, for machining large slender frames or thin box-sections, a maximum work-holding capacity is required with, generally, a light metal-removing duty. Conversely, for heavy cast-steel components and similar items, a limited-capacity machine with maximum cutting power is needed. A combination of these two extremities is also a possibility. A solution to these apparently contradictory conditions has been found by using a carefully planned system of unit construction.

To meet the wide range of power and work-holding capacities, the machines are designed with three separate groups of units, falling approximately under driving horsepower inputs of 7.5, 15 and 25. Figure 1 illustrates these groups of units, together with a maximum/minimum work-holding capacity. The small number in the frame denotes the capacity of the machine in cubic feet. The disposition of the five main units used in each group is shown in this view. Stocks of patterns, castings and steel are kept to a minimum by arranging for a definite number of increments in the traverse length. In this particular design, the increments are generally limited to give approximately sixty-five sizes in the smallest group, with forty-five in the middle range and roughly thirty in the highest horsepower group. As typical examples of this design policy, figure 2 shows the smallest machine in the 7.5 horsepower group (it has the capacity of approximately 12 cubic feet) and figure 3 illustrates the largest machine in the 25-horsepower range (capacity of 1,500 cubic feet). In considering this design policy in relation to manufacturing, care has been taken that the completed machines are capable of accepting the simplest type of measuring systems while, at the same time, a minimum of alteration is necessary in order to accommodate the latest arrangement of numerical control. An additional

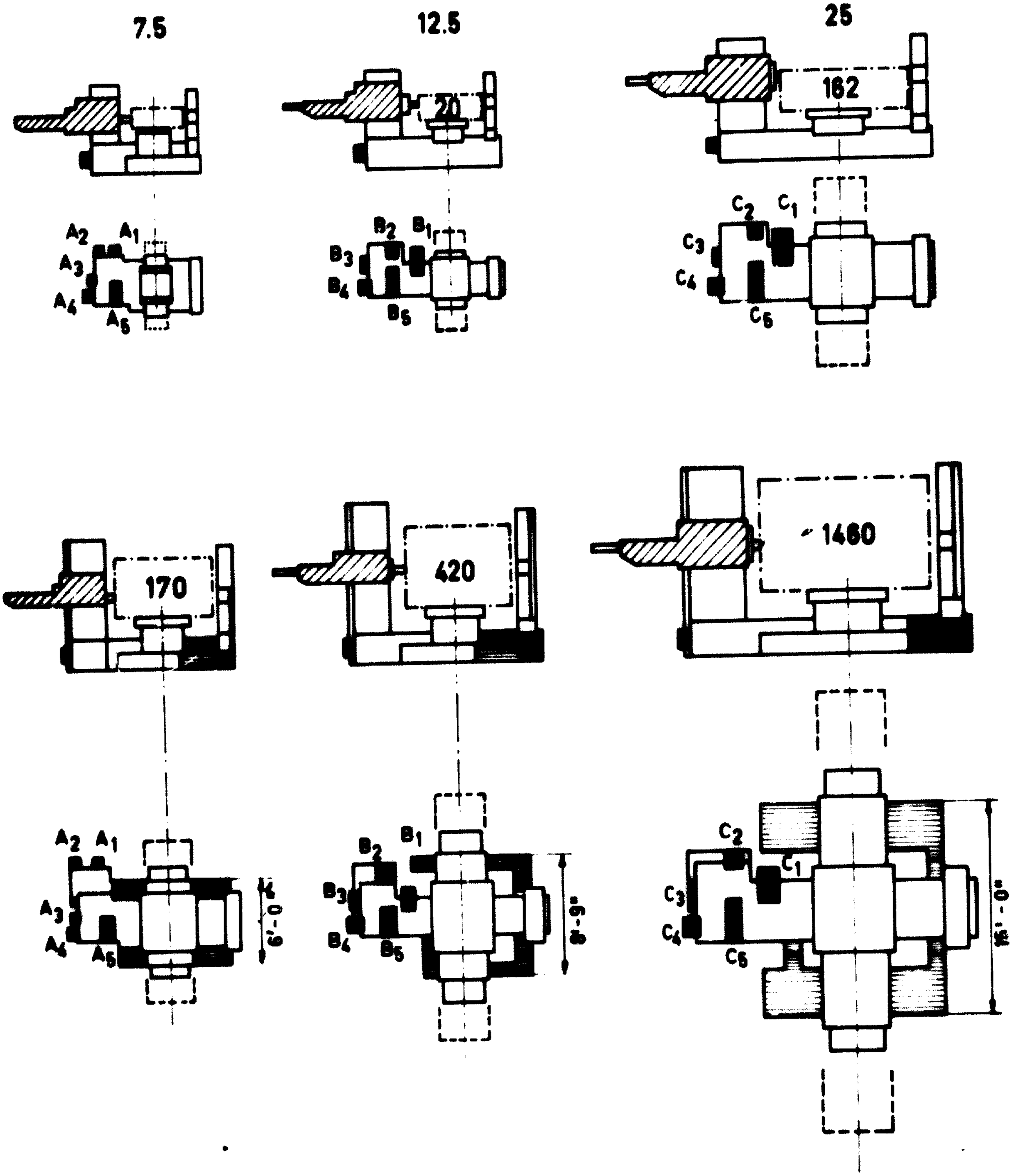
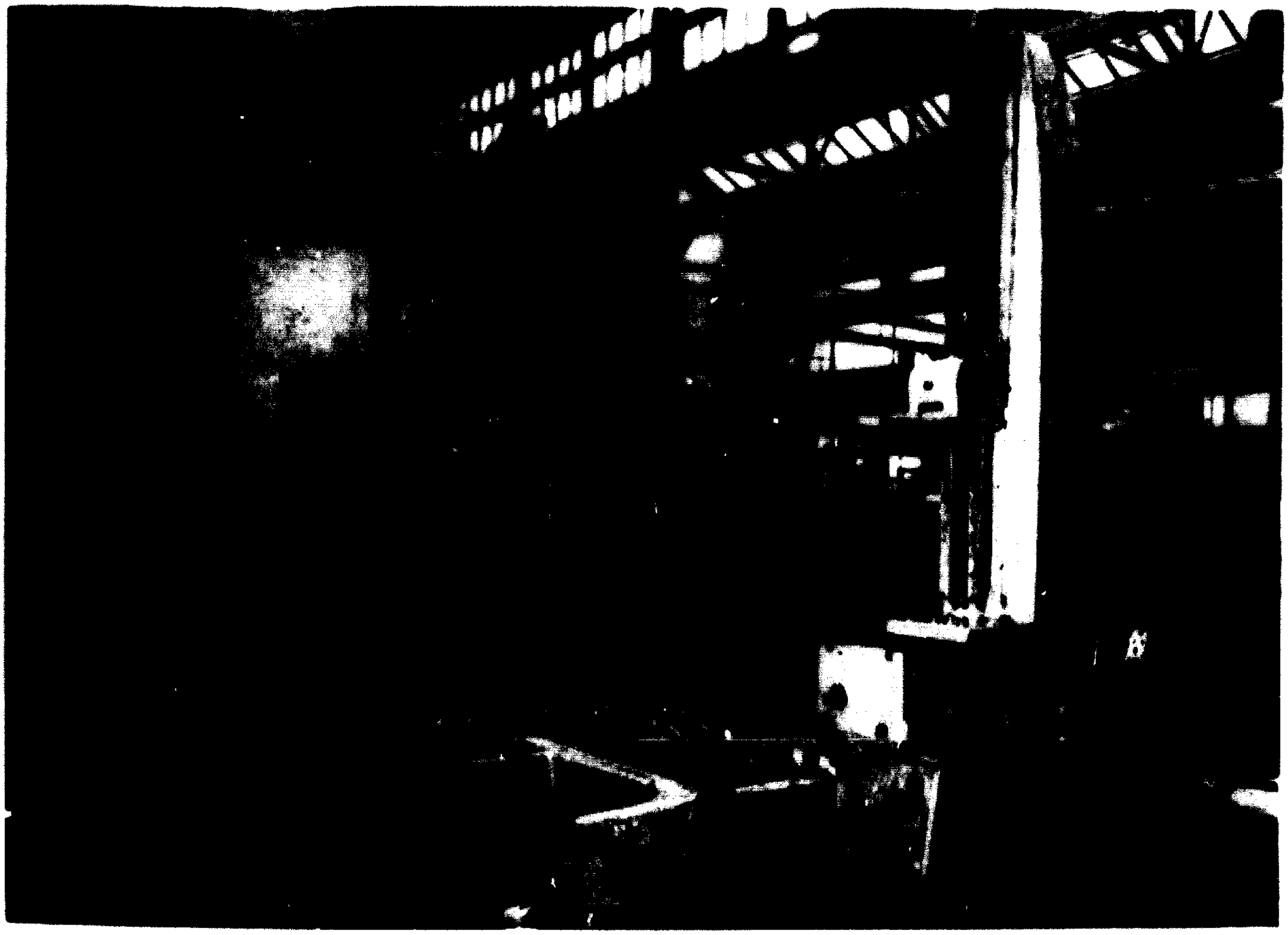



*Figure 1*
GROUPS OF UNITS

*Figure 2*
SMALLEST MACHINE IN 7.5-HORSEPOWER GROUP

*Figure 3*
LARGEST MACHINE IN 25-HORSEPOWER GROUP



advantage of this unit construction of manufacture is its help in keeping work in progress and stocks to an absolute minimum. This is extremely important when considering the high skill content and the currently increasing cost of the more complicated optical, electrical and hydraulic mechanisms which are now being provided with these machines. Recent indications are that the factory has approximately £100,000 of work in progress with stocks approaching £300,000.

The value of following a closely integrated design policy with manufacturing methods is perhaps best illustrated by the example of the main bed of the 7.5-horsepower group of machines. Figure 4 shows the arrangement for milling a bed on a plano-milling machine having a capacity of 14 ft × 6 ft × 5 ft. All slideway surfaces, including the location of facings for the main gear-boxes, are milled at this stage, and the cutter is set with reference to a template mounted at the end of the milling machine table using a 0.010-inch gauge. The template is carried on slides that provide for transverse and height adjustment, which may be necessary for conveniently setting the template in relation to the castings. From this illustration of the main bed, it will be noted that the facings are carefully arranged on a minimum number of planes in order to reduce machining times. Furthermore, by employing a system of unit construction, it is possible for the gear-boxes and other items to be manufactured at the same time the main bed is in production and, therefore, to reduce the total over-all time necessary to produce the machine. Figure 5 shows this main bed with a number of the units in position. These include the distribution box, together with the main

*Figure 4*

MAIN BED FOR 7.5-HORSEPOWER GROUP ON PLANO-MILLER drive and rapid traverse units. Final assembly of these separate units is undertaken alongside the main assembly bays, and a general view showing these in the course of manufacture is given in figure 6.

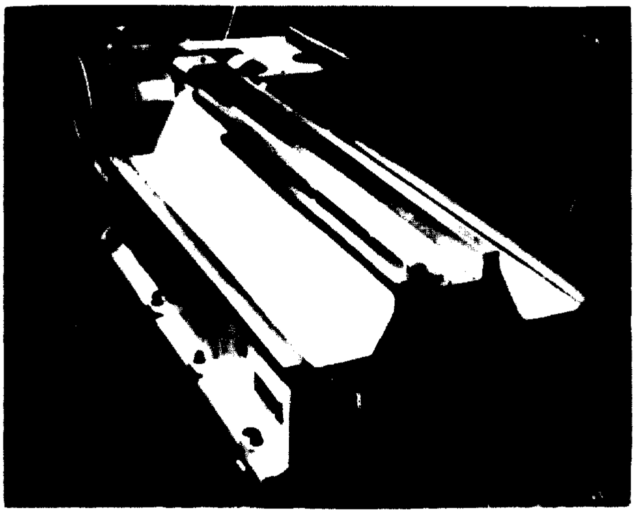


*Figure 5*

BED WITH UNITS IN POSITION

As mentioned previously, the machines are designed to be capable of accepting not only a simple vernier-scale system of measurement for setting, but also the most advanced numerical control and optical arrangements. To meet these exacting requirements, it is necessary for the slideways and guiding surfaces to be machined to an accuracy of within .0005 inch over a distance of 50 inches. To achieve this high degree of accuracy with a minimum of hand operations on these main bed components, they are ground on the machine shown in figure 7. It has been found essential to complete all the machining operations on this bed, including the drilling and any boring necessary, leaving only the slideway grinding as the final operation. Furthermore, it has been found essential to eliminate all clamping bolts and when the main bed is on the grinding machine, only end location stops are used for maintaining the component in position on the grinding-machine table.

A further interesting point is the supporting of this main bed casting, during the grinding operation, on its actual levelling screws, which will be used when the machine is installed in the customer's works. This method of support on the actual levelling screws to be used during its final assembly ensures that the sliding ways will be correct when the machine is placed in

*Figure 6*

UNIT ASSEMBLY BAY

*Figure 7*

GRINDING MAIN BED

position on its own foundation. No attempt is made to carry out any system of normal or artificial ageing of this main casting, following a full and complete investigation into this subject with the British Cast Iron Research Association. Their findings indicated that in view of the metal distribution on this casting, no significant benefit could be obtained by artificial or normal ageing methods, providing the metal removed from the machined surfaces was in the region of ½ inch and the chemical composition of the cast iron was such as to give a Brinell figure in the region of 180 without the need for excessive chilling. Where chilling must be undertaken, this is accomplished by the use of refractory brick or similar material in preference to heavy cast-iron chills.

Reference was made earlier to the system of unit construction. In the case of this main bed, the units employed are a mechanical main-drive box containing nine spur gears to give a corresponding number of speeds to the ouput bed pulley and a main feed gear-box containing a spur-gear system and clutches providing a total of twelve feeds to all motions on the machine. In this main bed, there is also fixed a well or distribution box, which provides a feed drive to the vertical, longitudinal and transverse movements of the compound tables. Finally, there is a rapid traverse unit consisting of a constant-speed, alternating-current (AC) motor, which drives the cross shaft in order to provide rapid traverse to the three motions just mentioned. The reference planes for fixing these various units in position on the main bed are the top surface of the main bed and the guiding edge in the centre channel. These boxes are located in place by means of a simple fixture on which are provided location faces to suit those already machined on the various units.

A special and patented feature of this main bed is the use of a centre channel for supporting the saddle on which the compound tables are mounted. This channel, in addition to supporting and guiding the saddle in the longitudinal direction, also carries the longitudinal screw and shaft, all of which are immersed in the oil with which this centre channel is filled. The outer ways of this bed support the saddle on four large-diameter rollers mounted on anti-friction bearings. To facilitate assembly of this saddle, master bed sections are installed in the main fitting bay, a typical example of which is shown in figure 8. Each saddle is first carefully set to the central guideway and checked for squareness with a master saddle section mounted on the bed before the taper gib strip is fitted. This master saddle section is clearly visible in the main saddle unit. The anti-friction bearings in these rollers are carried on an eccentric shaft. This shaft is rotated

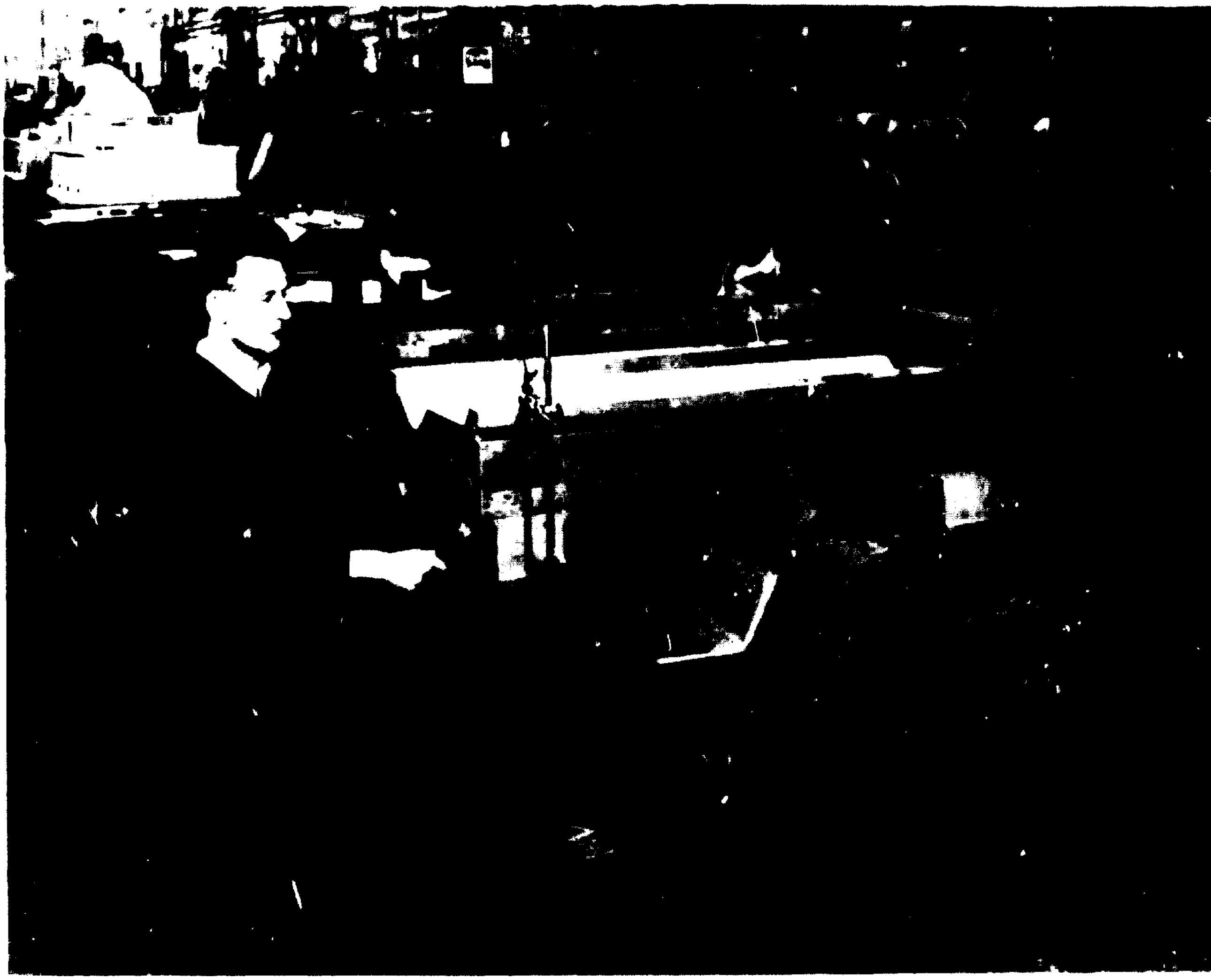


*Figure 8*

SADDLE ROLLER ASSEMBLY

until the top surface of the saddle is parallel with the main bed sliding ways. When this position has been found, the eccentric shafts are fixed in position by means of four small screws. Lubrication on all slideways is given special attention: and the oil grooving, which is of the chicken-ladder pattern, is machined on a router, as illustrated in figure 9. A cutter with two teeth equipped with Wimet Grade N carbide is employed and operates at a speed of 2,000 rpm. The shape of each groove is controlled by an aperture in a sheet-metal template clamped to the work. The depth of the groove is governed by a stop to which the cutter head is set down under hydraulic power. This machine is also employed for the light facing of casting guards and similar components made from aluminium-based materials, of which a considerable number are now being used.

Because of their high efficiency in manufacturing operations, a large number of boring machines are employed in the production of various components. A number of these horizontal boring machines, all of which are of the Company's manufacture, are fitted with trip systems, punch-card control or punched paper tape operation. A typical example is the boring of a large 8-inch square revolving table for use on one of the machines with larger capacity. The machine used for this purpose is illustrated in figure 10. From this photograph, it will be noted that this model is equipped with servo-motors for the vertical and transverse motions controlled by a direct-current (DC) drive system. All positioning is obtained by special microptic units. The table being machined in this case weighs approximately 10 tons and is carried on one of the latest multiple-jack revolving tables, which incorporate six jack screws for carrying the load when rotating this unit on a large-diameter ball race. The ball-tracks are not constrained, in order to prevent interference with the centre pivot pin on which the table is rotated and controls the accuracy of rotation. Certain machines have their built-in facing chuck mounted on a large-diameter sleeve carried on plain bearings. The headstock containing these bearings are machined by the method illustrated in figure 11. The semicircular tool-holder is fitted with a pre-set tool fixed to position in the tool-room. This holder is mounted in an angular groove in the boring bar and a socket-head screw in this

*Figure 9*

OIL GROOVING ON ROUTER MACHINE

*Figure 10*

BORING A LARGE REVOLVING TABLE

bar passes through the large end of the keyhole slot in the boring head. Bearing on the bottom of the groove and located endwise by the side faces, the holder is turned to engage the screw with the small end of the keyhole form. In this position, the screw is then tightened to lock the holder in the bar. This method of tool holding has proved extremely successful and permits holes to be machined with a variation of less than 0.0005 inch for bores up to 10 inches in diameter. In view of the importance of spindle bearings, a careful schedule of operations is prepared for the fitting and mounting of these facing-chuck sleeves into the large-diameter plain bearings. Figure 12 shows one of these sleeves being locked into the main bearing. This bearing, which is approximately 7.5 inches in diameter, operates over a speed range of 4 to 250 rpm, and the clearance is less than 0.0005 inch.

Special care is taken with the lapping compound, which, in this case, is of the water-bound type and 320 grade. All traces of this must be removed before the machine is finally assembled. One precaution which is taken to meet these conditions is the filling of the recesses of the various screw holes for holding the phosphor-bronze bush in position with a compound which fills these cavities level with the main bearing surface. Before final assembly, the bearing is thoroughly washed in order to remove completely all traces of the lapping compound. Special tests using the latest research techniques have been employed to examine the success of this washing process, and these show that bearings manufactured by this method are capable of operating for over ten years without any appreciable wear. On the smaller range of machines, the spindle is carried on a sleeve which is mounted in high-precision anti-friction bearings. In order to achieve the accuracy required, these housings must have a finish which is equivalent to the outer race and must be round to at least 0.0001 inch. This rather difficult production

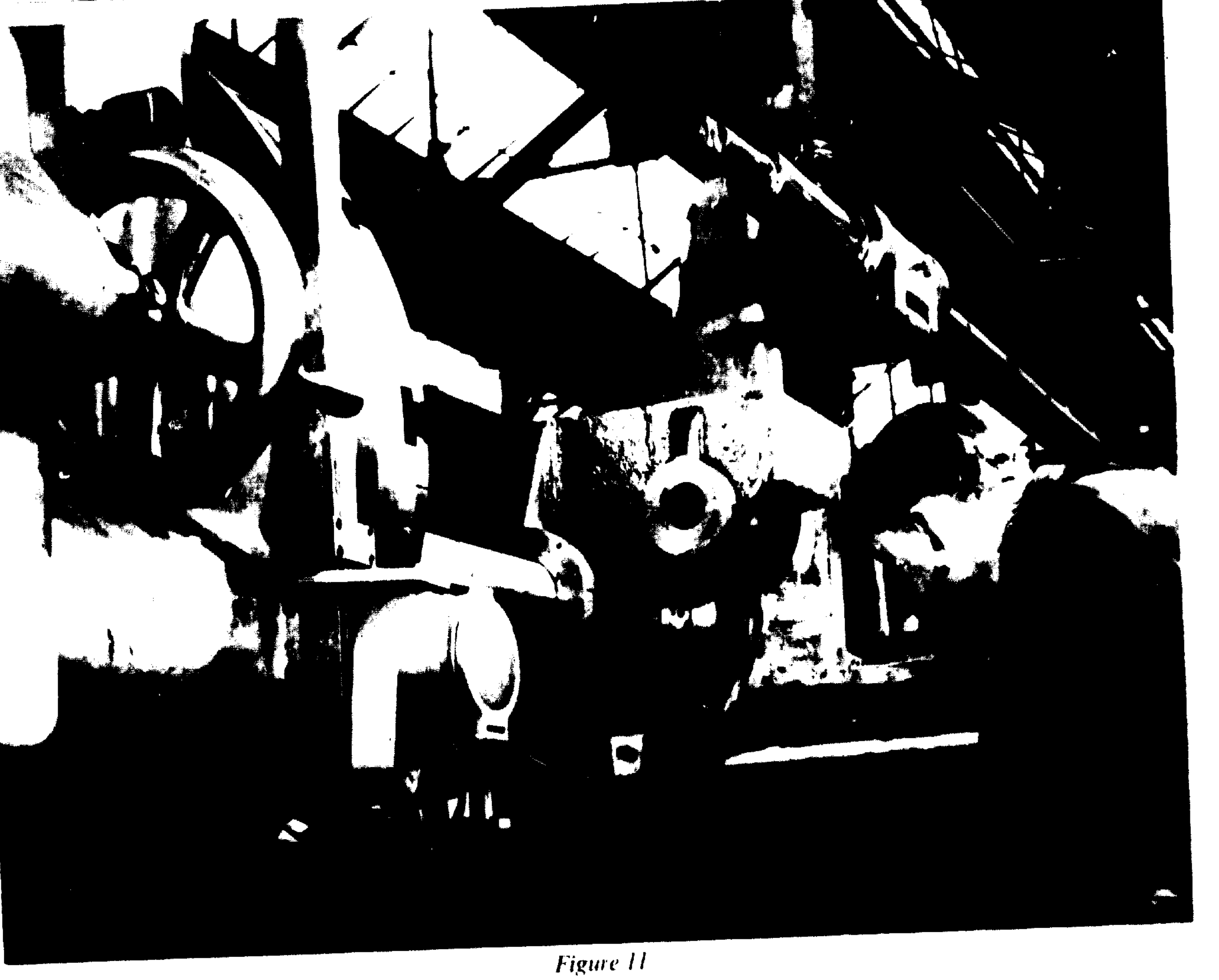


*Figure 11*

BORING MAIN SPINDLE BEARINGS WITH PRE-SET TOOL HOLDERS

problem, especially with large-diameter ball races, is overcome by the use of a special hydraulically adjusted lap, which remains circular throughout its full range of adjustment.

Equally important is the alignment of the front and rear bearing housings and this is obtained by using a large-diameter piloted bar for the lap, the free end of which is supported in a three-point steady. Figure 13 shows a lap of this type in use on a 7.5-inch diameter bearing housing of the small spindle slide unit. One of the most important items on a horizontal boring machine is the main travelling spindle. In the case of the Kearns machines, their size is 3–6 inches in diameter and 3–12 feet in length.

The company's recent patent on the special device for tool clamping and hydraulic release to these spindles has led to a demand for this arrangement in preference to the normal Morse tapered arrangement. Figure 14 shows a sectional drawing of this tool-holding arrangement. From this drawing it will be noted that a hole is required throughout the full length of the travelling spindle and this is achieved by a trepanning method of machining, which produces a round and accurate hole. This is essential in order to minimize the out-of-balance when rotating the spindle at high speeds. These spindles are manufactured from a nitriding steel, which, during the process of manufacture, is returned to the steel suppliers for a suitable heat-treatment process following the first rough turning operations. Before grinding, the two taper key-ways are produced on a planing machine with a special setting device. This is necessary in order to ensure that the two key-ways will be exactly 180° apart and to ensure also that the taper sides of the key are in correct relationship with each other. Figure 15 shows a photograph of this operation. From this, it will be noted that a setting gauge is inserted in the taper socket at one end of the spindle. One face of this is carefully set parallel to the top of the planing-machine table. A cross member on this gauge is set horizontally with the aid of a precision level, and feeler gauges are then used to align the planing tool with a slot in one side of the member, which is on the vertical axis of the work. On completion of the first key-way, the spindle is turned 180°, the cross member is relevelled and the tool is set in relation to the slot in the opposite side of the gauge for the planing of the second key-way 180° from the first. On completion of this opera-

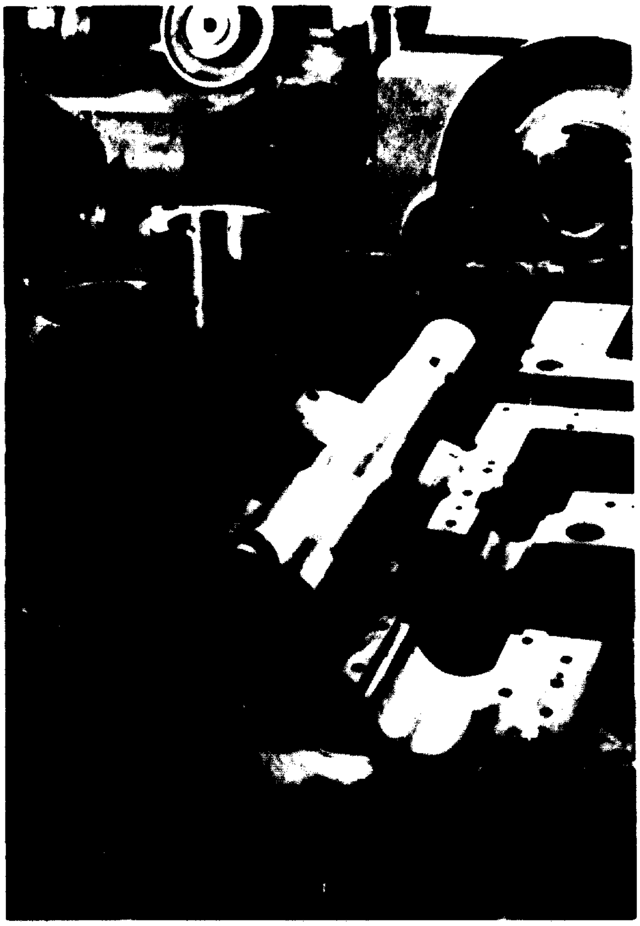


*Figure 12*
LAPPING THE MAIN SLEEVE IN THE BEARINGS

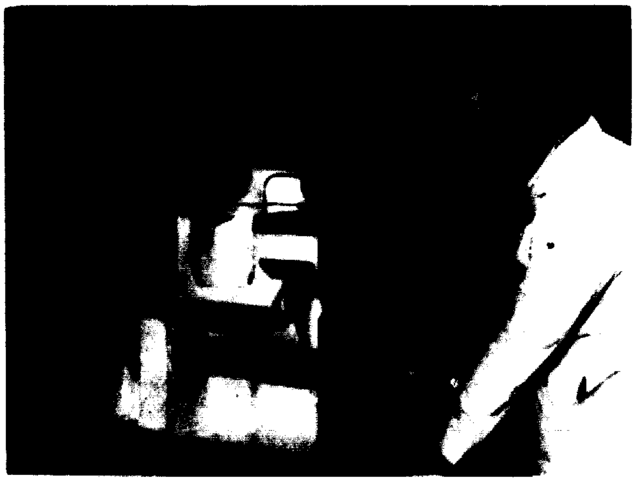


*Figure 13*
LAPPING BEARING HOUSING

tion, the spindle is sent to the grinding department before being dispatched to the steel suppliers for a nitriding process. On return to the factory, the previously planed taper key-ways are ground on the machine shown in figure 16. This particular machine was constructed in the company's works, mainly from standard units used in the manufacture of horizontal boring machines. The main bed and table are units from the planer-table type of machines, and the two vertical columns have been made from normal outer supports. On this machine, the table is hydraulically traversed from an independent unit, which is remote from the machine in order to minimize the difficulties of distortion due to heat. From the illustration, it will be noted that a circular cross-rail carries the wheel head, which can be rotated to provide a fine height adjustment. For coarse movement, the rail is moved by power or manually. The grinding head has two spindles, one horizontal and the other vertical, and these are driven by a 3-hp built-in stator and rotor units. As in the case of the planing operation, the key-ways are carefully located by means of a gauge inserted in the Morse taper end of the spindle.

Modern high-speed horizontal boring machines demand that the finish on the spindles should be at least to an accuracy of 3 to 5 microinches. This is achieved by a simple superfinishing machine, also built in the company's works and illustrated in figure 17. A spring-loaded stone carrier is employed and water is used as a lubricant. During lapping, the spindles are rotated at approximately 150 rpm and the slide on which the stone carrier is mounted is operated by means of a yoke mechanism driven from a separate electric motor. The slide is supported on a carriage, which is moved along the bed by a central feeding-screw. This machine, which operates automatically, is attended to by one of the grinding-machine operators. The majority of the machines produced in the works have a simple slide with a facing chuck combined with a travelling spindle. In order to achieve a compact, yet powerful, feeding mechanism to this facing slide, considerable design and development work has been done on this unit. The most recent and patented arrangement now consists of a single large-diameter worm gear into which engage two spirals. Into these engage two helical racks which are bolted on to the facing slide. Figure 18 shows the three units in position. This system of using two helical racks for the final feed-drive provides a robust arrangement which is capable of transmitting the full horsepower of the main driving motor during heavy facing operations. One extremely important component in this mechanism is the large-diameter worm gear. Figure 19 shows this component being produced on a 36-inch vertical turning and boring mill. The gear to be machined is manufactured from a ring forging in

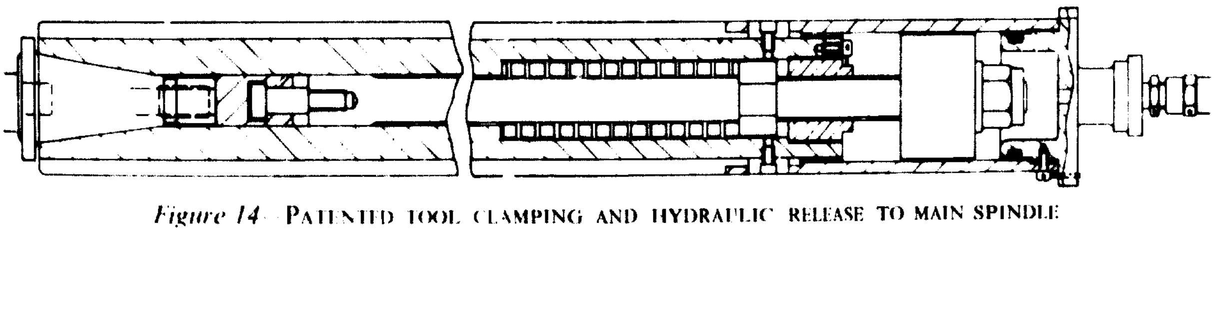


*Figure 14* PATENTED TOOL CLAMPING AND HYDRAULIC RELEASE TO MAIN SPINDLE

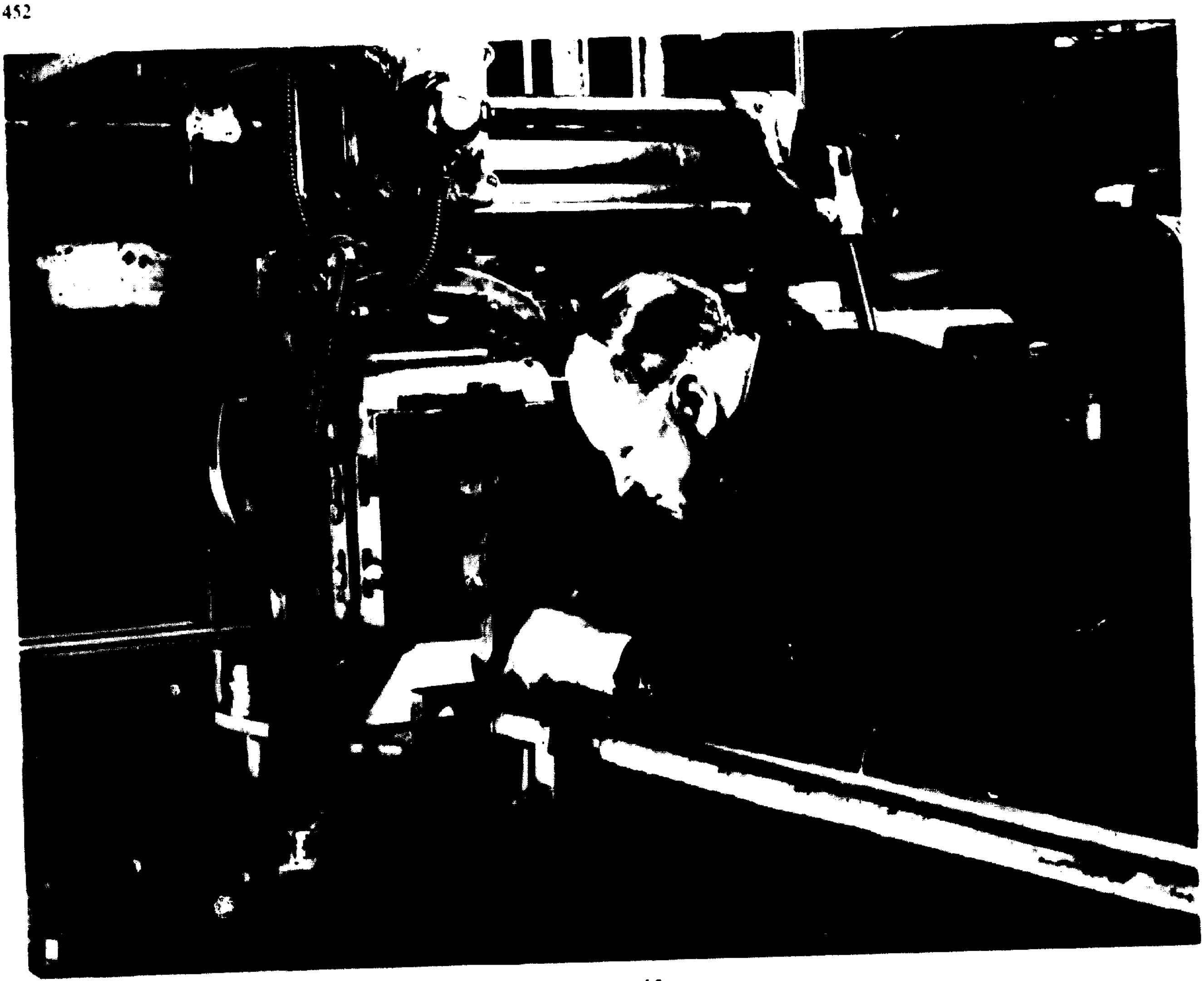


*Figure 15*

PLANING TAPER KEY-WAYS IN MAIN SPINDLE

EN9 steel and includes the cutting of the ½-inch pitch Acme thread, which forms the worm tooth. One complete turn of the thread in excess of the actual requirements is cut in order to minimize distortion, and this is finally removed on a simple milling machine. Roughing and finishing cuts are taken, using a special threading tool-holder, with each shank being finished separately and a maximum of 0.005 inch of metal being removed during the final machining.

The two spiral gears which are shown in figure 18 engaging with the single-thread worm gear are manufactured from aluminium bronze, which has a reasonably high tensile strength, in this case, approximately 15 tons per square inch. It has good shock-resisting properties also and, therefore is capable of absorbing intermittent loads during facing operations on components with an irregular surface to machine. The helical teeth in these spiral gears are cut with the rack type of cutter which is being used on the vertical boring mill mentioned previously, thus ensuring that the two-toothed sections are identical. Special care is taken during the assembly of the facing chuck in order to minimize any backlash which, if present, would be an embarrassment when using the machine for accurate bore-diameter setting.

In order to reduce the time required to fit the two helical racks into the facing slide, these are provided with a slightly tapered face at either end, so that a small key with a similar taper surface is used to move the racks longitudinally in order to reduce the backlash in the mechanism to a minimum. The large-diameter sleeve, which carries the facing chuck in which this feeding mechanism is incorporated, calls for a high degree of precision in its manufacture. This is essential if the bearings carrying the inner spindle, which are mounted on the inside of this sleeve, must rotate accurately not only in relation to the sleeve, but also in relation to the main spindle bearing in which the facing-chuck sleeve is mounted. During final inspection tests on the finished machines, a concentricity of less than 0.0005 inch is achieved between the facing chuck and spindle.

Special precautions are necesssry during the manufacture of this facing-chuck sleeve, in order to achieve this high degree of concentricity between the anti-friction bearings of the spindle mounted inside the sleeve and the

*Figure 16*

GRINDING TAPER KEY-WAYS IN MAIN SPINDLE

*Figure 17*

SUPERFINISHING THE MAIN SPINDLE

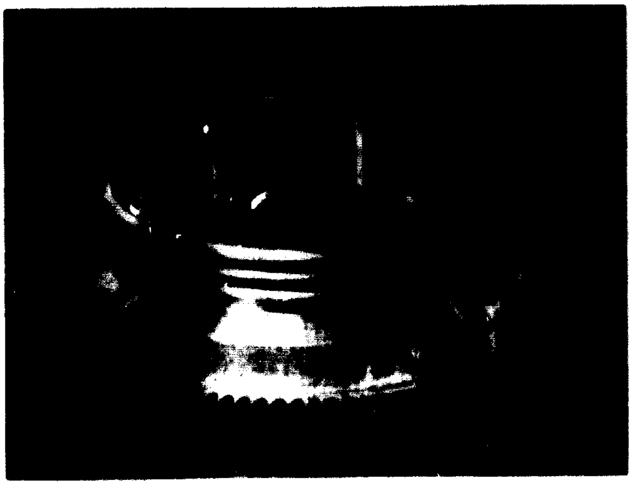


*Figure 18*

FACING SLIDE FEEDING MECHANISM

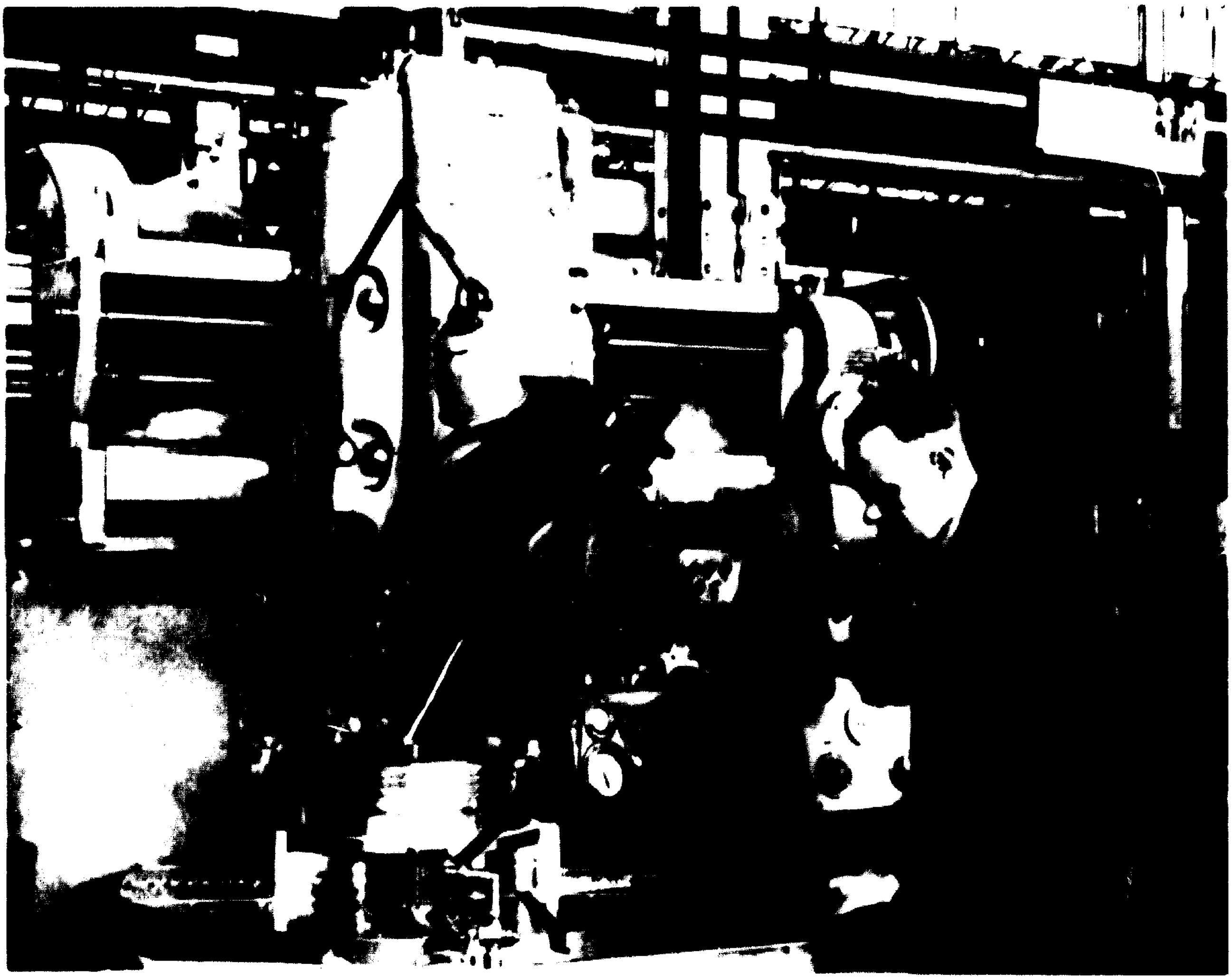


*Figure 19*

MACHINING LARGE-DIAMETER WORM FOR FACING MECHANISM

outer diameter, which rotates in the plain bearings illustrated earlier. The first operation on the sleeve, which is produced from a forging, is to rough-machine it all over and, when finished, to turn the outside diameter in a centre lathe, which is followed by a grinding operation on the bearing diameters. This sleeve is then returned to the centre lathe and, with one end mounted in the chuck, the other is supported in an accurate steady. The final bores for the main spindle anti-friction bearings are then produced on the lathe, being truly concentric with the outer diameters which have previously been ground. The forging from which the facing-chuck sleeve is manufactured is made from a 45/50 ton tensile strength high-carbon steel. Considerable service experience in using these large-diameter plain bearings has indicated that they have an extremely long life, but that they are exceptionally critical to the type of oil used, which, in this case, is a low-viscosity compounded oil with a mineral base.

One extremely important feature of the Kearns range of horizontal milling and boring machines is the policy of reducing to a minimum the motors or high-speed gearing and shafts in the headstock. This is in order to reduce to a minimum any distortion of the spindle bearings due to heat generation from unnecessary shafts and mechanisms in the headstocks. This design policy allows these headstocks to be made with exceptionally large proportioned facing-chuck sleeve and spindle bearings and also enables the designer to provide for the maximum stiffness in the headstock in order that the bearings should remain in a true position, especially under heavy cutting conditions. This is also essential if the very fine bearing clearances are to be maintained without the risk of seizing due to the generation of undue heat caused by a physical contact when using the low-viscosity oil mentioned above.

The vertical column on which this headstock slides is provided with square guides, and these are produced on a plano-milling machine similar to that previously described. The top and bottom faces of this upright are produced on a horizontal boring and milling machine similar to that illustrated in figure 20. From this illustration, it will be seen that a large milling-cutter, in this case, 20 inches in diameter, is bolted directly on to the facing-chuck body. Feed rates in the order of 15 inches

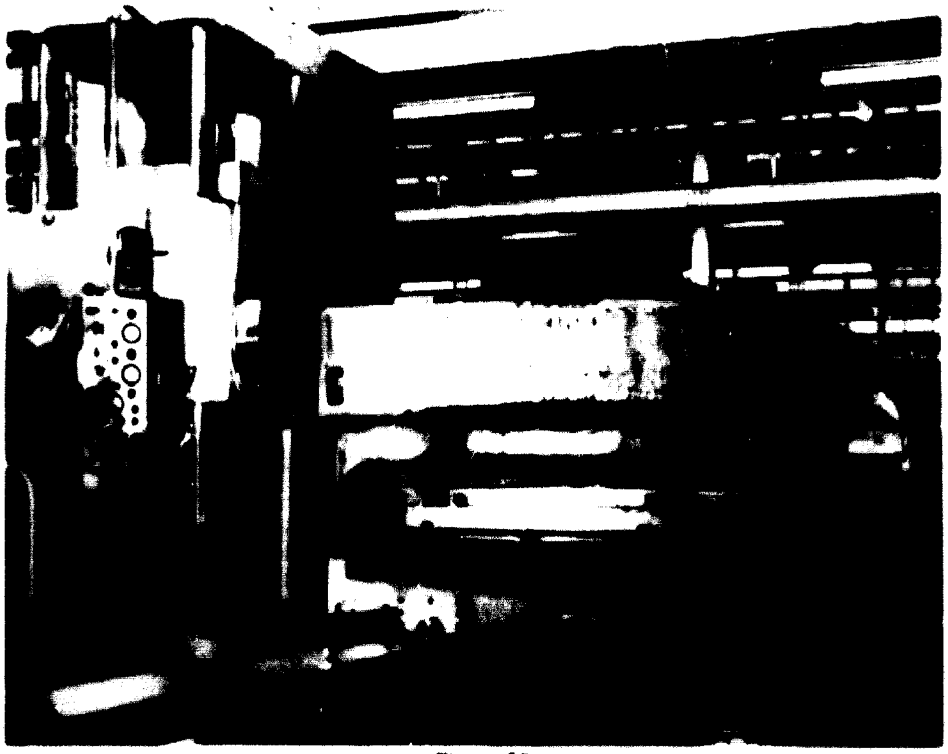


*Figure 20*

MACHINING VERTICAL-COLUMN BASE

*Figure 21*

FITTING THE SPINDLE SLIDE TO THE UPRIGHT ON VERTICAL COLUMN per minute are employed, and the metal removed approximately ½ inch. On completion of this operation, these uprights are placed on a test bed and are checked for vertical squareness from the base. Should any adjustment be necessary, the part is returned to the machine shown in figure 20, and the sliding ways are set to the required angle in order to give the necessary correction when milling the upright base. When received at the factory, all castings, including this upright column, are first shot-blasted and then given a priming coat of paint before being sent round the factory for the machining operations just described. Following the inspection test referred to above, the column is returned to the paint shop, where the necessary filling and final painting are completed. In the case of the upright, this is then sent to the fitting bays, where the vertical screw is set in position by means of a simple fixture. This method of setting is clearly illustrated in figure 21.

As previously noted, a large number of boring machines are employed for the production of various components. A typical example is the boring of an eight-speed gear-box on the machine illustrated in figure 22. This model is equipped with servo-motors for the vertical and transverse motions, and is controlled by a DC-drive system. All positioning on the vertical and transverse motions is obtained by means of punch cards prepared by the planning office. This machine, which is typical of those which have now been in service for over ten years, is capable of positioning to an accuracy of less than 0.0002 inch.

At this stage, it might be valuable to review the design and production of the major cast iron units which are similar to the upright just described. Earlier, reference was made to the policy of unit construction throughout the full range of the Company's products. A more detailed explanation of these various units as used on the 3, 3.5 and 4 inch spindle machines will be obtained from examining the two diagrams shown in figures 23 and 24. The numbers in the lower left-hand corner of each outline drawing denote the work-holding capacity, which is obtained by calculating the product in cubic feet, the distance from the spindle nose to the outer support, the vertical traverse of the headstock and the transverse traverse of the table. Where two work-holding capacities are given, alternative tables can be used. The disposition of the five standard units are shown in the

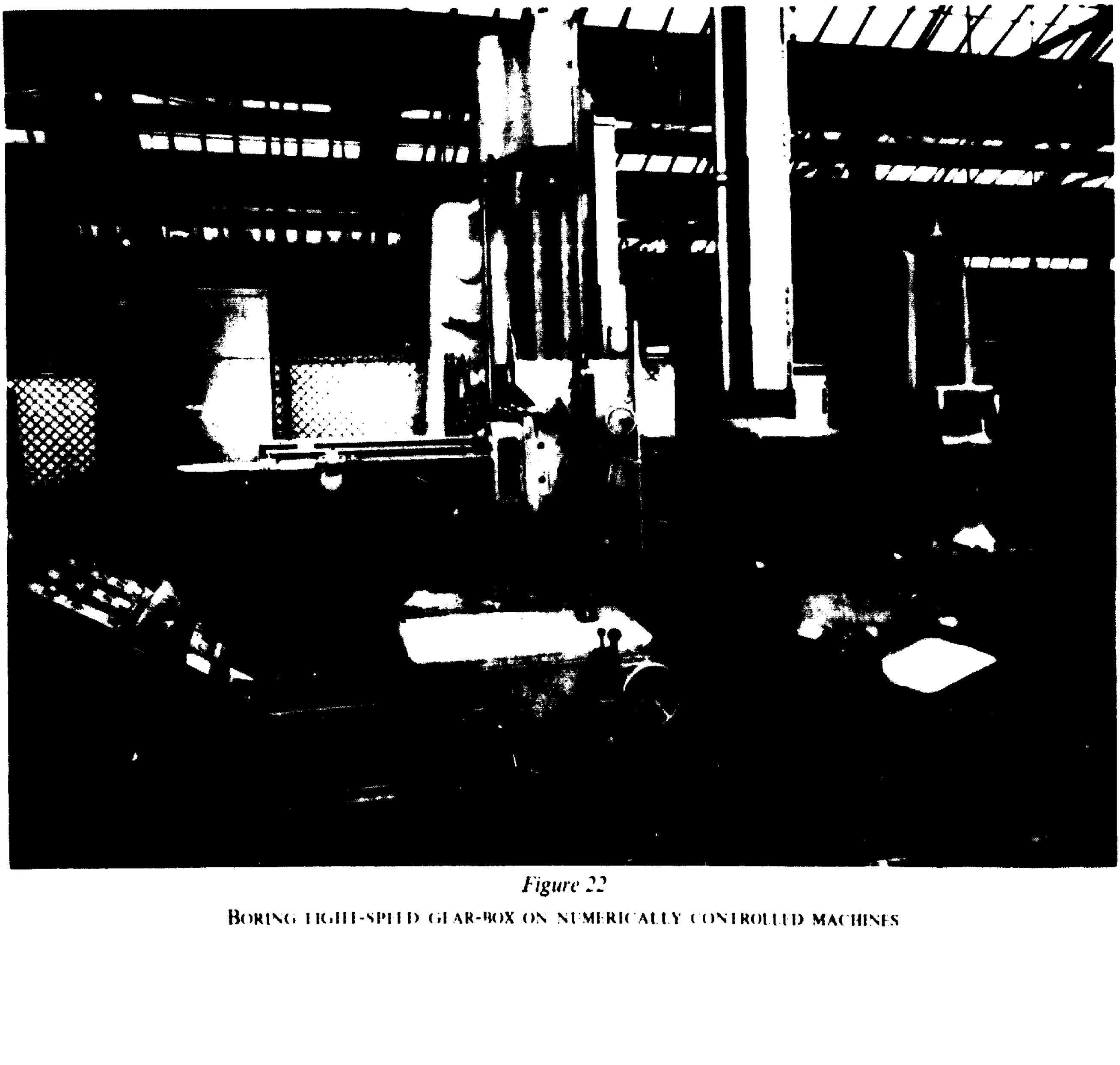


*Figure 22*

Boring eight-speed gear-box on numerically controlled machines

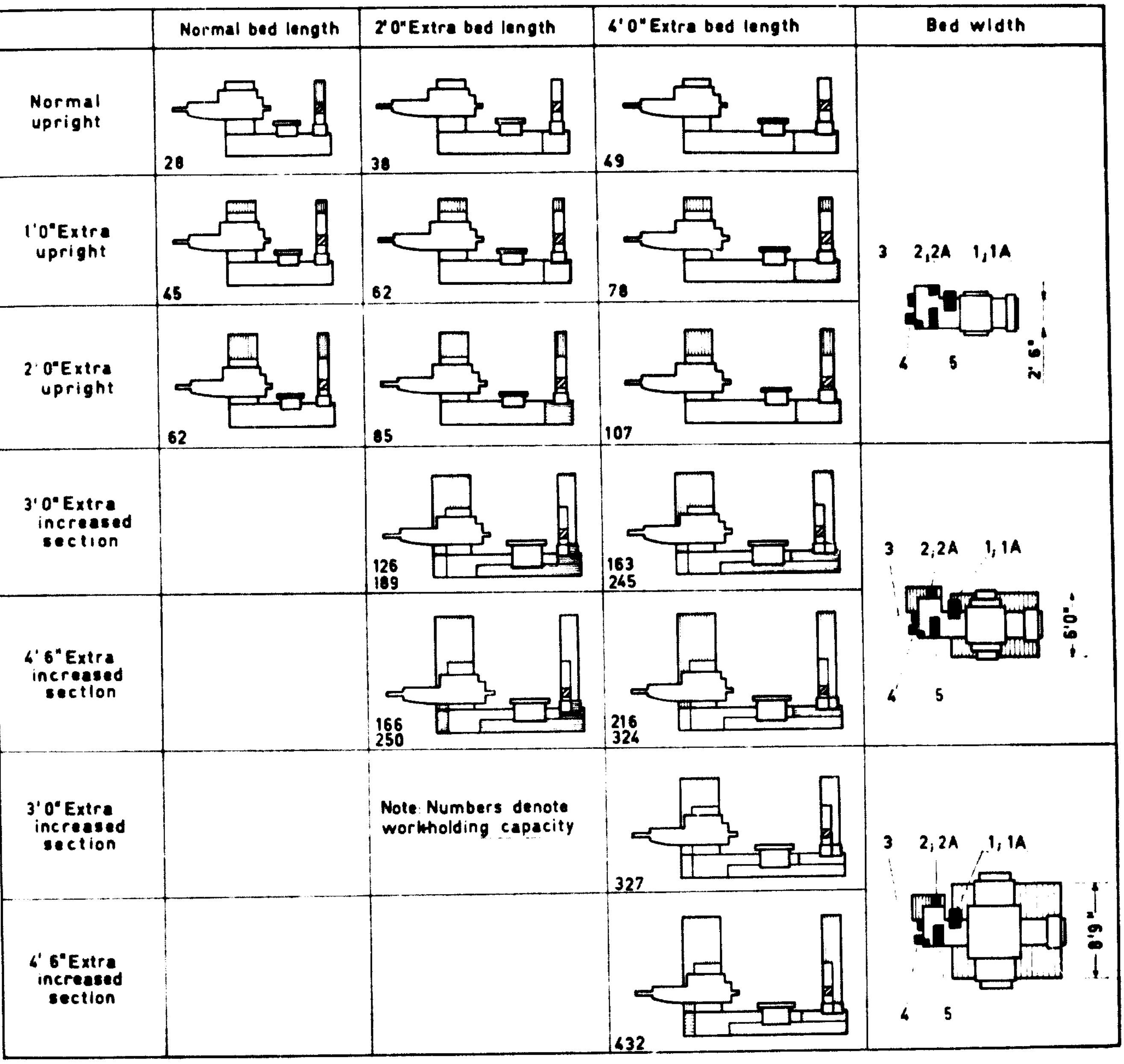



*Figure 23*

UNIT CONSTRUCTION DIAGRAM FOR 3-INCH SPINDLE MACHINE

right-hand column. The work-holding capacity of these machines ranges from 28 to 560 cubic feet and their metal-removing ability is of two orders, dependent upon the size of the headstock, yet five standard design units are used in their construction. These are as follows (as numbered in figures 23 and 24):

1. Eight-speed reversible main drive box;
1A. Eight-speed reversible main drive box with built-in electric motor of the stator and rotor type;
2. Mechanical rapid-traverse box;
2A. Rapid-traverse box with built-in stator and rotor unit;
3. Feed drive box.
4. Twelve feed and screw-cutting gear-box;
5. Distribution gear-box.

The Company does not have its own foundry, but these various patterns are produced in its own pattern shop. The method of construction adopted in this pattern shop for the manufacture of the upright and main bed patterns is very similar. Figure 25 shows the upright pattern in the course of manufacture. From this illustration, it will be noted that the pattern is constructed with long beams fixed to the base and sliding into the main body of the pattern.

When the base of the pattern is close to the body a casting of normal height is produced. With the beams fully

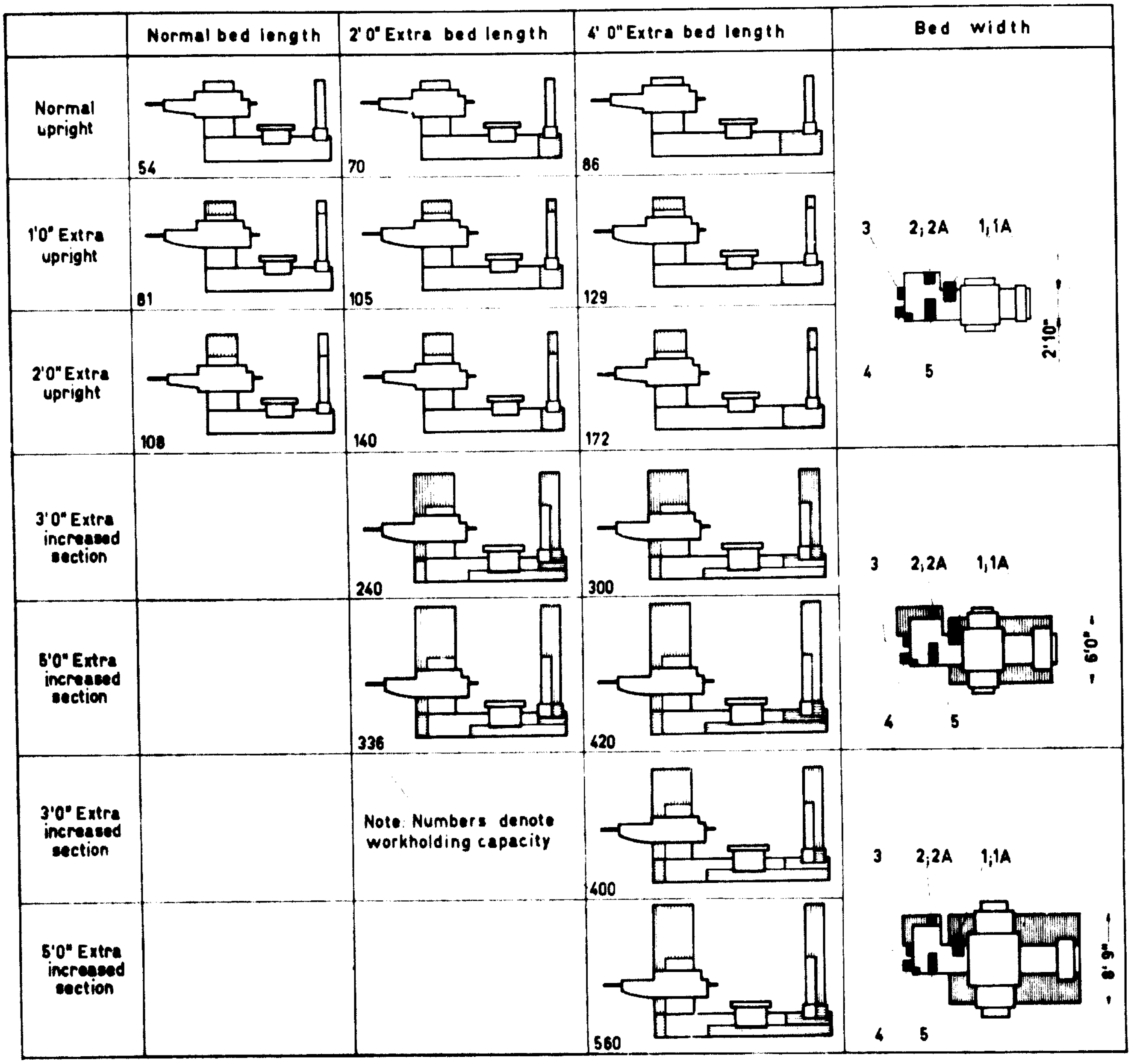



*Figure 24*

UNIT CONSTRUCTION DIAGRAM FOR 3.5-INCH AND 4-INCH SPINDLE MACHINE

extended a column giving an increase of over 70 per cent in vertical adjustment is available from the same pattern. This not only helps to reduce costs, but also minimizes the problem of pattern storage. Brief mention has been made of the treatment of castings upon arrival from outside suppliers. The full treatment, however, of these main units is extremely important and can, in fact, amount to approximately 5 per cent of the total manufacturing cost of the machine. Great care is therefore taken in the design stage to try to produce casting outlines which are easy to clean, fill and paint. A typical design of the type of casting which has been found satisfactory from this point of view is shown being sprayed in figure 26. Briefly, the treatment these major castings receive upon arriving at the works is as follows:

(*a*) Shot-blasting and trimming the casting;

(*b*) Spraying a coat of protective paint to form the seal;

(*c*) On completion of machining, components are returned to the paint shop and are completely cleaned;

(*d*) Finish trimming the casting;

(*e*) Filling applied by knife and component rubbed dry, mainly with mechanical devices;

(*f*) Brush priming-coat applied;

(*g*) Butts filed with sandpaper, applying large quantities of water;

(*h*) Clean machine faces;

(*i*) Paint by brushing;

(*j*) Machine completed and a finish coat of paint applied.

*Figure 25*

UPRIGHT PATTERN CONSTRUCTION

The insides of the majority of main gear-boxes are given a coat of hard-drying white enamel, which is naturally oil-resistant.

Returning to the manufacture of small components, including gears, shafts and similar items, these are, where suitable, produced on modern centre lathes or turret lathes. A general view of this section is shown in figure 27. In some cases, the traverse screws, all of which have 1-inch Acme thread, are dealt with on a thread-whirling machine, which is illustrated in figure 28. These screws are all manufactured from EN.9 steel, and the component shown is 6 feet 9 inches long and has a 2.5 inch diameter. The two t.p. thread is 5 feet long. The thread is cut in a plain bar, which has been groove-machined at each end for entry and exit of the cutters, the ends being finish-machined after the thread-whirling operation. Soluble oil mist is used as a coolant and the thread is cut with reference to a graticule in the built-in microscope of the machine. Screws ranging from 3 feet to 12 feet in length and from ⅞ inch to 3 inches in diameter are produced on this thread-whirling machine. Compared with normal centre-lathe screwing-cuttings, experience indicates that this method is approximately three times as rapid, with an excellent thread being produced, providing care is taken in maintaining good cutting tools and these are accurately set in the thread-whirling head. It is important to record that none of the screws are intended for measuring purposes, being merely for feeding the appropriate unit to which they belong. In order to improve the stiffness, in certain cases a special reduced depth of ½-inch pitch Acme thread is employed. The faster bronze nuts which are used with these screws are produced on a turret lathe by means of a ground thread tap having the forward cutting tools arranged to remove the metal alteratively from the top and shanks of the screw thread, with the final section of the tap with a full-section thread which produces the final shape.

In view of the comprehensive range of components with which these horizontal boring machines are expected to deal, it is regarded as essential that they should have a very wide range of speeds and a large number of speed changes within this range, in order to make them acceptable for the work and the materials of the components which they will have to machine. As mentioned previously, a special feature of the Kearns machines is the policy of incorporating a minimum number of gears and bearings in the headstock. To deal with the range of spindle speeds required, therefore, the main drive gear-box is usually mounted in the bed of the machine. Drive to this gear-box is from a constant-speed AC motor mounted at the back of the main bed through a toothed belt drive. The gear-box generally has nine changes obtained from nine gears, with drive from the output side of this gear-box to the main spindle being through a nylon/plastic belt operating at a high velocity. To assist handling and manufacture, the gear-box is produced in light alloy and manufactured on one of the company's own punch-card numerically controlled horizontal boring machines. These gear-boxes are expected to operate continually at high speed and with a minimum of vibration. The design is therefore arranged with large-diameter short shafts, and all gears are hardened and ground. The shafts are produced on a spline grinding machine in order to ensure concentricity of the ground gear on its shaft. The driving gears are manufactured from a 3 per cent nickel steel and are suitably heat-treated. The factory is equipped with two gear-grinding machines, one of which uses a formed wheel with an index plate for locating each tooth. In the case of wheels of up to 10 inches in diameter, these are produced on the latest type of gear grinder using a grinding-wheel in the form of a worm, with the component to be cut fixed to a vertical spindle and operating like a continuous generating machine. Ground gears produced by either of these methods allow a pitch-line velocity on the gears

*Figure 26*
CASTING DESIGNED FOR EASY PAINTING

*Figure 27*
CAPSTAN AND TURRET LATHE SECTION

*Figure 28*

THREAD-WHIRLING MACHINE

*Figure 29*

MAIN BED READY FOR ASSEMBLY LINE

of 1,000 feet per minute, to be accomplished with a minimum of noise, and the production of a toothed form which proves satisfactory when using the machine on milling operations where a minimum of backlash is essential. All gears are designed with a 20° pressure angle and the gear centres on which they operate are manufactured to 0 – 0.001 inch centres.

## 11. Final assembly and testing

The factory operates on the principle that the single components already described are sent to stock and are then recalled together with the appropriate purchased materials, i.e., ball races, screws and other items. These are then assembled into individual units. These units are built in batches of ten or more, depending upon the demand, while the individual components for these units are produced in quantities which give a certain stock value, rather than the actual number of items produced. This method of manufacture proves more efficient than attempting to balance the exact number of items required for each component, especially when these may consist of simple struts, flat plates or collars. From instructions issued by the Production Control Department, the various sections assembling the individual units draw their items from stock and proceed to manufacture a complete unit. As the actual specification for the machine to be built depends upon the customers' requirements, this information is prepared by the sales office, which issues an office order detailing the customers' exact requirements. From this, the planning office determines the types and specification of the individual units required in order to complete a single machine. As an illustration of the final assembly stages of these units into a completed machine, a model in the lower horsepower group has been selected. In accordance with the customers' requirements, a main bed of the appropriate length is provided from the unit stores and is received by the fitting bench in the condition shown in figure 29. From this illustration, it will be noted that the bed is completely machined, including the faces for the various units which must be inserted into this item. The rectangular end facing on this bed accommodates the main driving gear-box together with the change feed-box, both of which are shown in position in figure 30. The distribution or well box, a mechanical version of which is shown in figure 31, is then fitted during the final assembly stages into the main bed casting. Other units follow in a similar manner, including the saddle, main table and revolving table; finally, the vertical column and spindle slide are bolted into position, as is illustrated in figure 32. This illustration shows the spindle slide in position with the front cover removed so that during this final assembly stage the machine can be rotated and the automatic lubrication system can be fully inspected in operation.

During the final assembly stage of these machines, in addition to undergoing static testing, they also are required to complete a standard test piece which covers the majority of movements on the machine. This test piece being forwarded with each individual machine. The range of static tests is covered by diagrams of tests

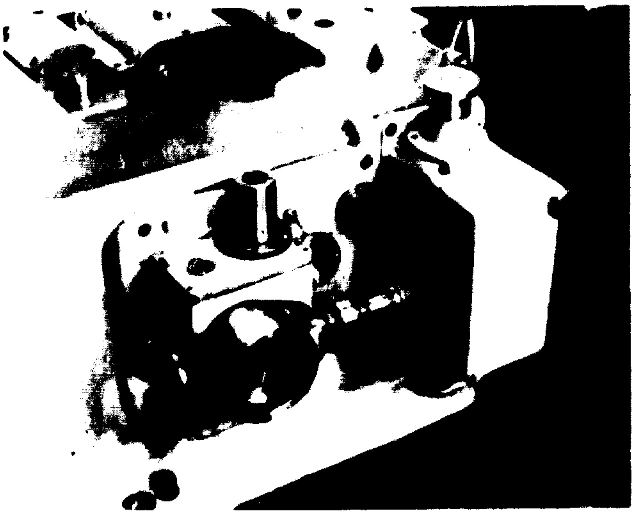


*Figure 30*

Drive and feed-box in position on main bed

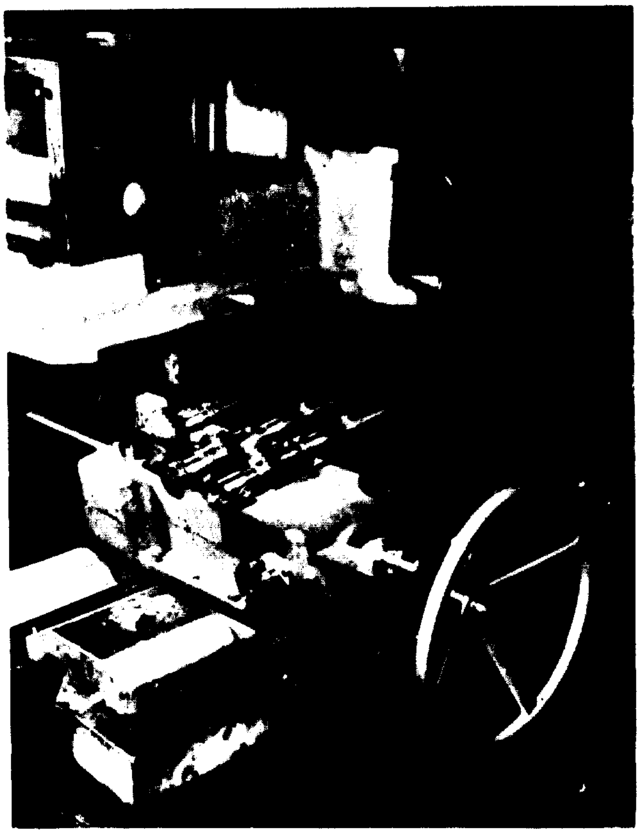


*Figure 31*

Fitting distribution-box in main bed

Nos. 1–16, shown in figures 33–36. As the majority of the machines are arranged with a built-in facing chuck combined with a travelling spindle, the series of tests have been devised in order to meet the exacting requirements of a machine of this type. Test No. 1 shows the levelling of the main bed. This test is designed to check the bed for levelling in both the longitudinal and transverse directions, and a permissible error of 0.001 inch in 48 inches is allowed. A problem of considerable import-

*Figure 32*

FINAL ASSEMBLY OF MACHINE

ance in the case of horizontal boring machines is the accuracy of the vertical column in relation to the main bed. This must be carefully checked and from the figures given in Test No. 2, it will be seen that the maximum permissible error is 0.001 inch in 24 inches. As this upright must be square, not only in the front but also in the end elevation, a further test, illustrated in Test No. 3, is required. Having produced the column at right angles to the main bed, it is now necessary to check the axis of the main spindle to the upright guide. This is shown in Test No. 4. During this test, it is important not to use a dial indicator which is fixed to the spindle and, therefore, changes its position as a result of reflection. During this inspection on the Kearns machines, a stiff bar is bolted to the facing chuck and a small block, complete with a dial indicator, is first used to check the top position between the side of this bar and the upright guiding edge. A similar test is then made in the bottom position. Using this method, it will be noted that the dial indicator is always used under similar conditions. Test No. 5 shows the setting of the axis of the spindle parallel with the guiding edge of the main bed. This is achieved by extending the spindle and then moving the tables longitudinally along the main bed, when a permissible error not exceeding 0.001 inch in 24 inches is allowed. Test No. 6 shows the allowable error when running the spindle in a 12-inch extended position; error must not exceed 0.0012 inch. A test for checking that the top of the main table is parallel with the top of the bed is shown in Test No. 7. In view of the importance of boring a component

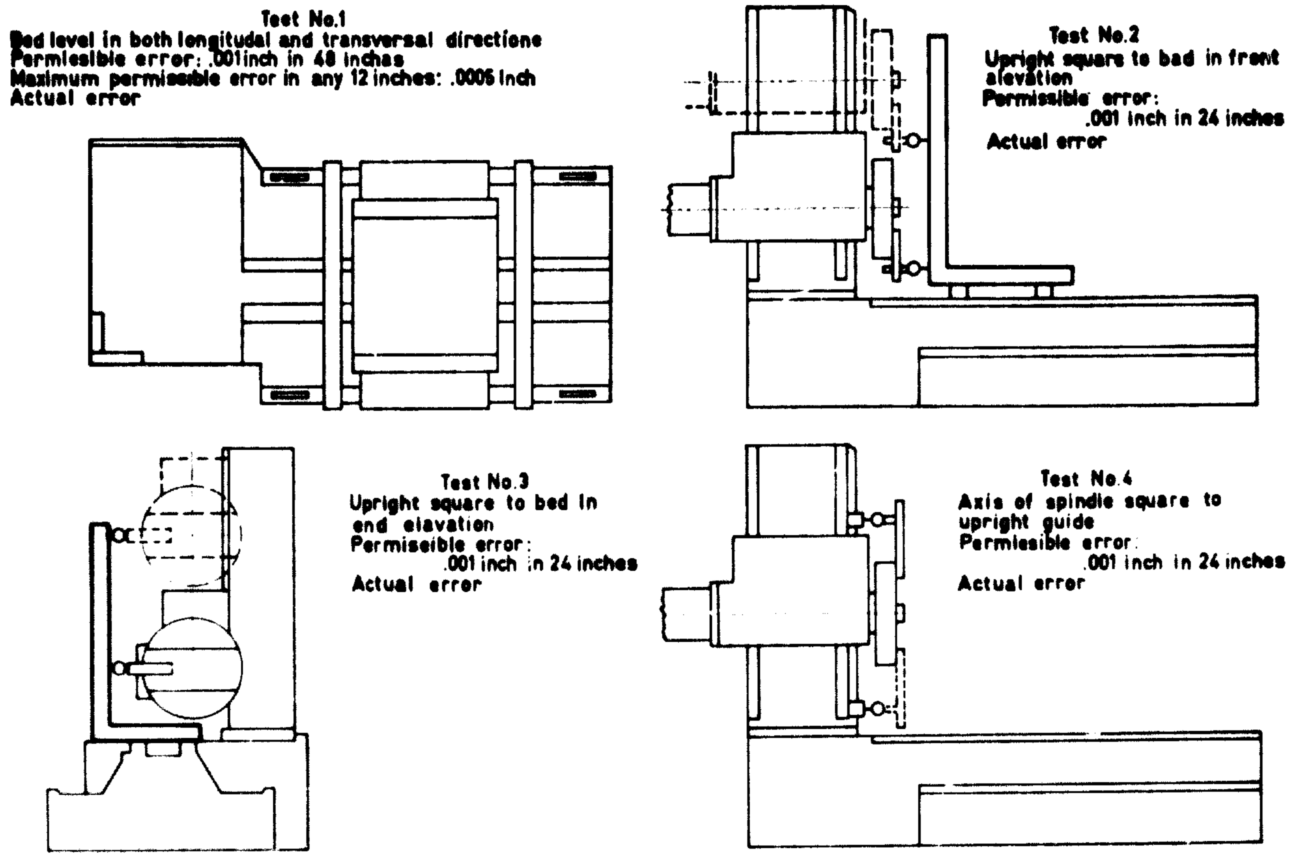



*Figure 33*

STANDARD TESTS FOR MACHINE: TESTS 1–4

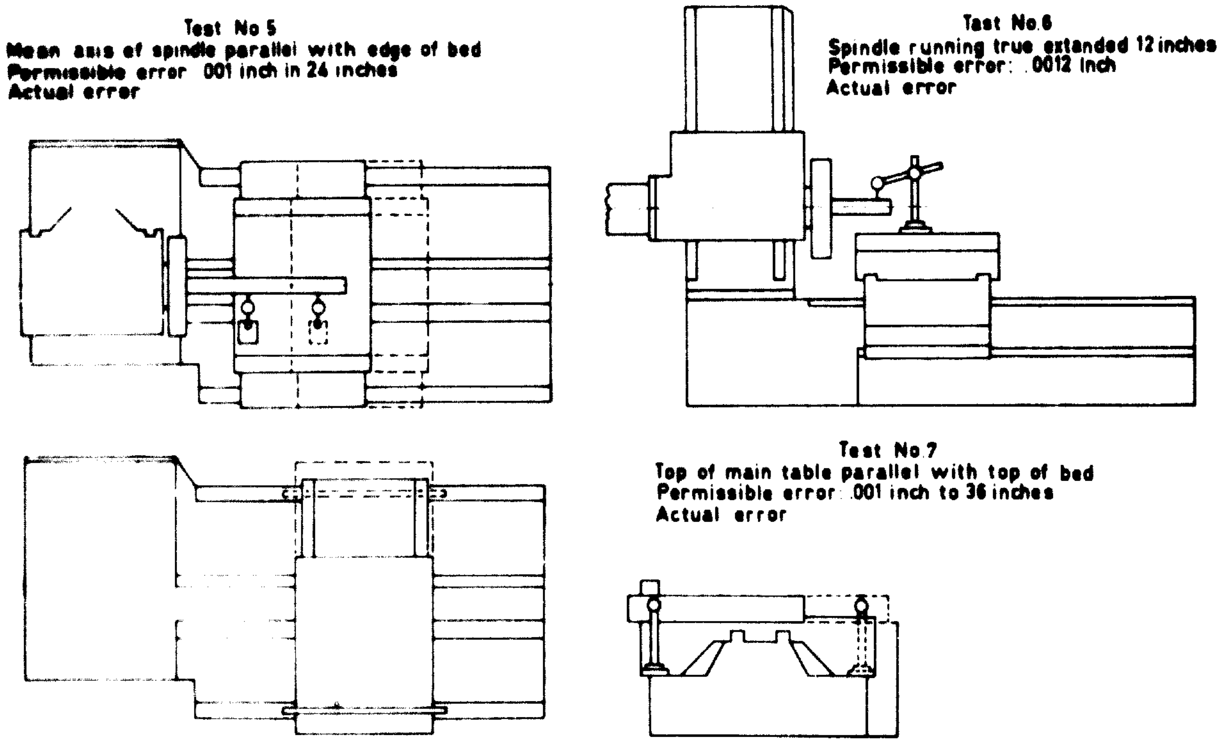



*Figure 34*

STANDARD TESTS FOR MACHINE: TESTS 5–7

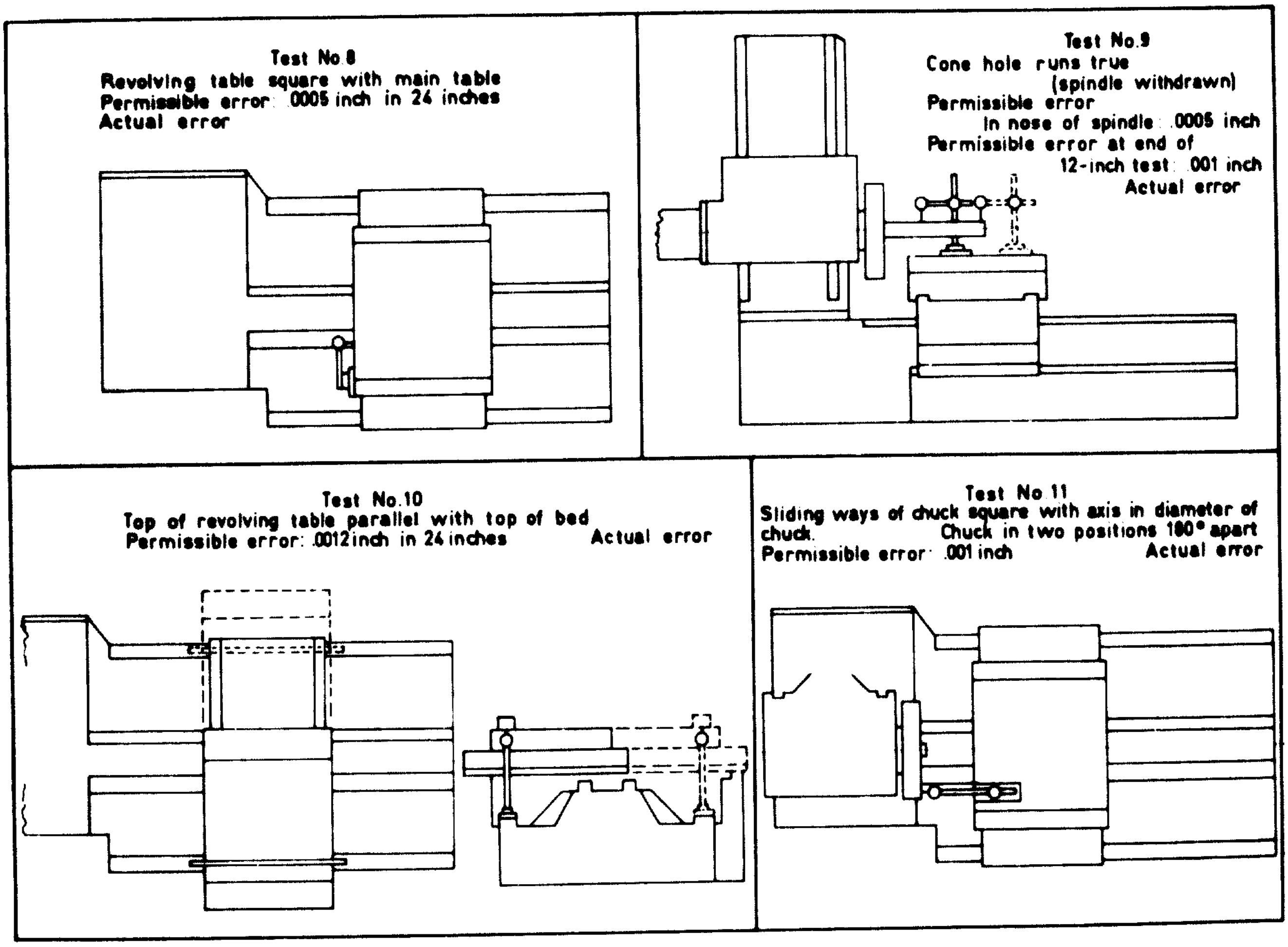



*Figure 35*

STANDARD TESTS FOR MACHINE: TESTS 8–11

first on one side and then rotating the table 180° and boring a second hole in line with the first, it is essential that the revolving table should have a high degree of accuracy when rotated. From Test No. 8, it will be seen that, in this case, the permissible error at the extreme end of the table should not exceed 0.0005 inch in 24 inches.

These and other tests, up to test No. 16, must be completed on every machine to the entire satisfaction of the chief inspector, his being the sole authority in determining when the machine is satisfactory. This policy of allowing a chief inspector the final decision in these matters is, in the case of H. W. Kearns, regarded as extremely important, as, although in the final result it means that the chief inspector is determining the output of the factory, he and he alone must ensure that the machines have reached a satisfactory level of accuracy before they leave the final assembly bays. Any interference with this authority would mean that the inspection staff would lose their authority and tend to turn to management for decisions which rightly should be theirs. As mentioned previously, in addition to undergoing these static tests, the machine performs a number of operations on a special test piece designed to cover the principal movements on the machine. For example, one of these test-pieces nearing these final stages is shown in figure 37.

Thus far, no reference has been made to the work on design and development which is undertaken on the machines before they are released to the factory for normal batch production. Over fifty years of specialization in the manufacture of horizontal boring machines has shown that the time required to develop and produce the first of a new range of machines is approximately three to five years. In view of this rather long and important phase, the company has decided to create the necessary departments to deal with this aspect of its business. The various departments involved in this exercise are placed under the control of the Technical Director. These include a future-design section, current-design office, development and experimental department, vibration- and model-testing section, production drawing office and a value engineering section.

Before a new model is produced, based on information received from the future-design section, the design office prepares drawings for a prototype machine to be built in the development and experimental department. A view of this section of the works, which occupies approximately 1,600 sq ft, is shown in figure 38. This department is equipped with a centre lathe, grinding and milling machine and drilling machine, as well as two horizontal borers. This equipment permits it to produce a large

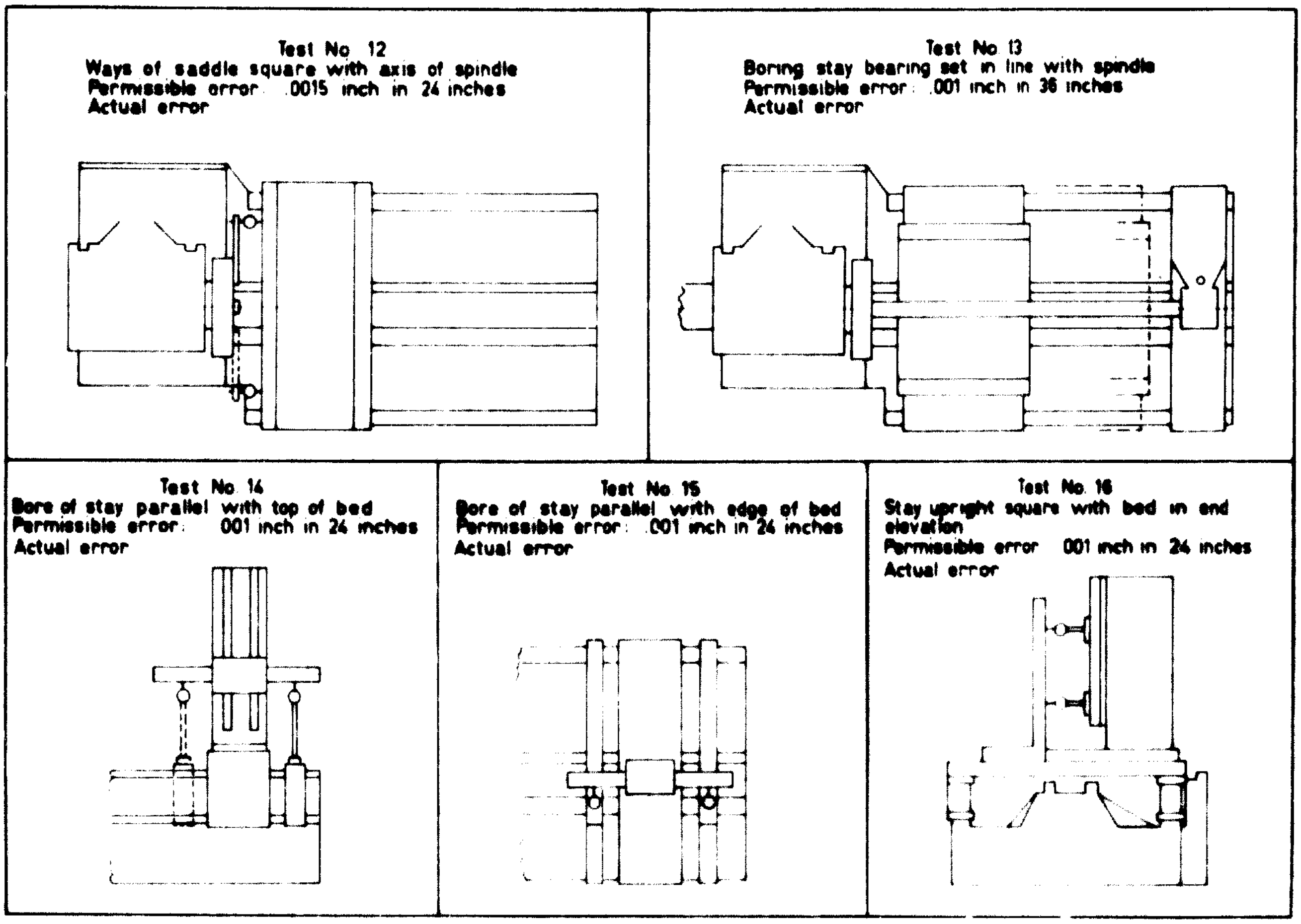



*Figure 36*

STANDARD TESTS FOR MACHINE: TESTS 12–16

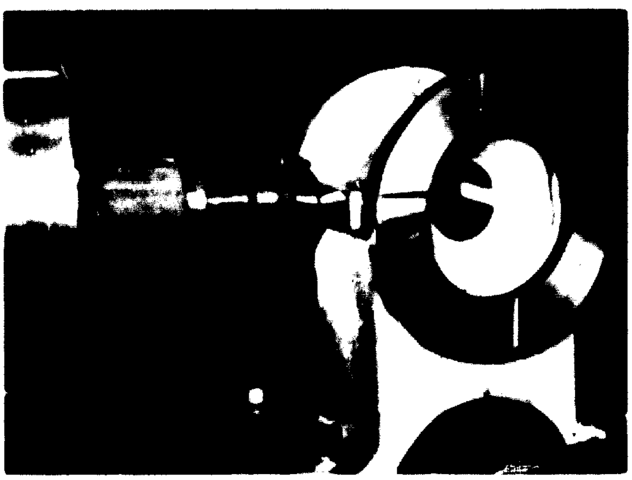


*Figure 37*

TEST PIECE BEING MACHINED

proportion of the new and experimental parts required without interfering with the main production shop. Regarded as equally important is the need to assemble new gear-boxes and attachments under conditions as free from foreign matter as possible, so that the greatest number of variables can be omitted from testing a new design. The department, therefore, includes a clean-air section; this is illustrated in figure 39. Also included in this development and experimental department is a section dealing with vibration and model studies. Figure 40 shows one of the machines which was recently developed undergoing a vibration study. This investigation is dealing with a machine fitted with a patented multiple-column support to the spindle slide. Figure 40 shows the vibration engineer with the oscillating equipment attached to the spindle nose and using a roving pick-up; tests are made over the structure in order to determine the phase and amplitude of the vibration. Work of this nature has proved invaluable in enabling the sales department to offer machines with a known cutting capability, while at the same time providing the factory with exact information on the degree of accuracy, material and often shape of the component which will permit the unit to fulfil its technical requirements at the minimum of manufacturing costs. This advanced work, together with a full and complete record of every one of the 6,000 horizontal boring machines the Company has produced, provides invaluable information, not only in producing and manufacturing existing models, but also in meeting what will obviously be more advanced machine tools in the future.

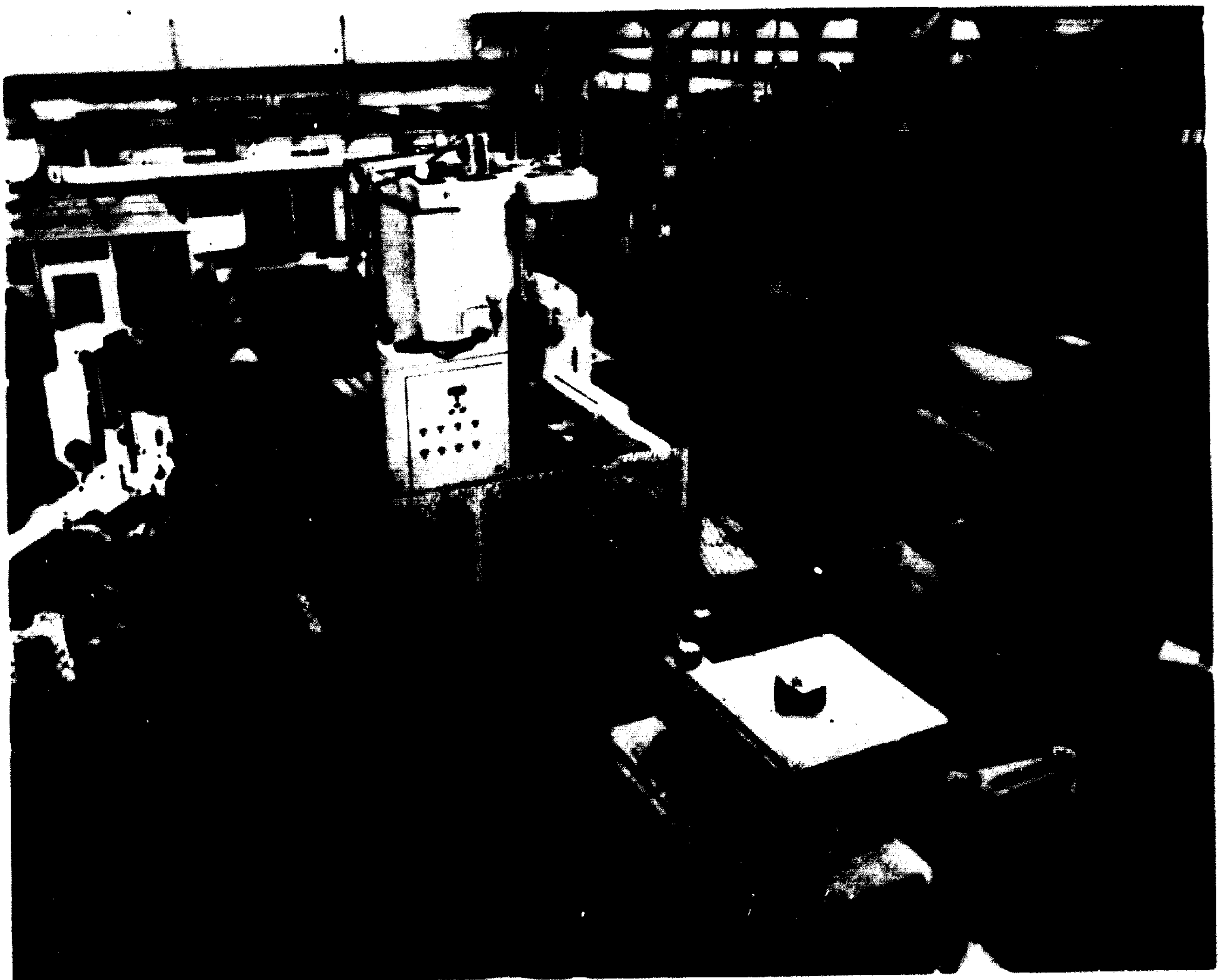


*Figure 38*

DESIGN AND DEVELOPMENT SECTION

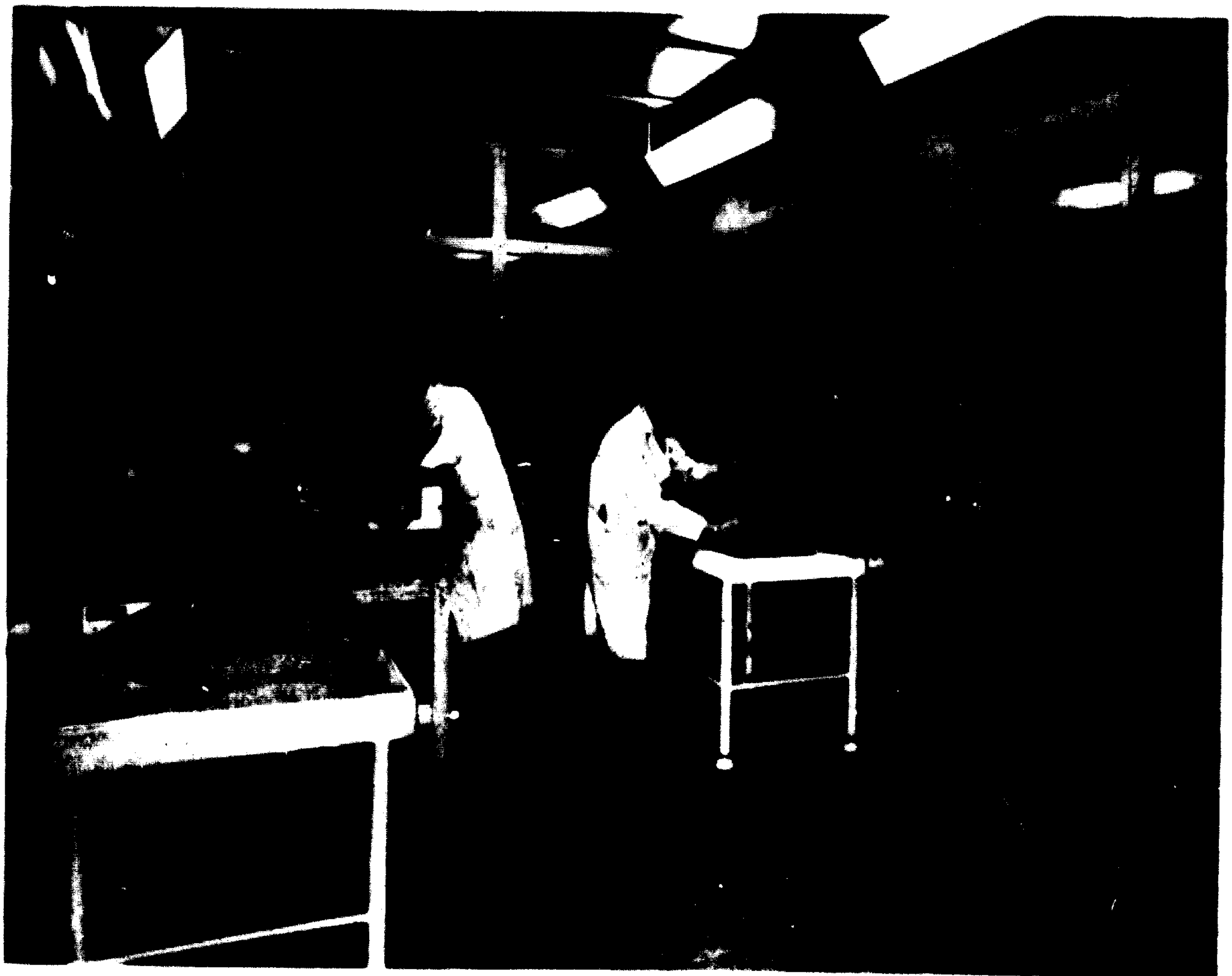


*Figure 39*

CLEAN-AIR SECTION, DEVELOPMENT AND EXPERIMENTAL DEPARTMENT

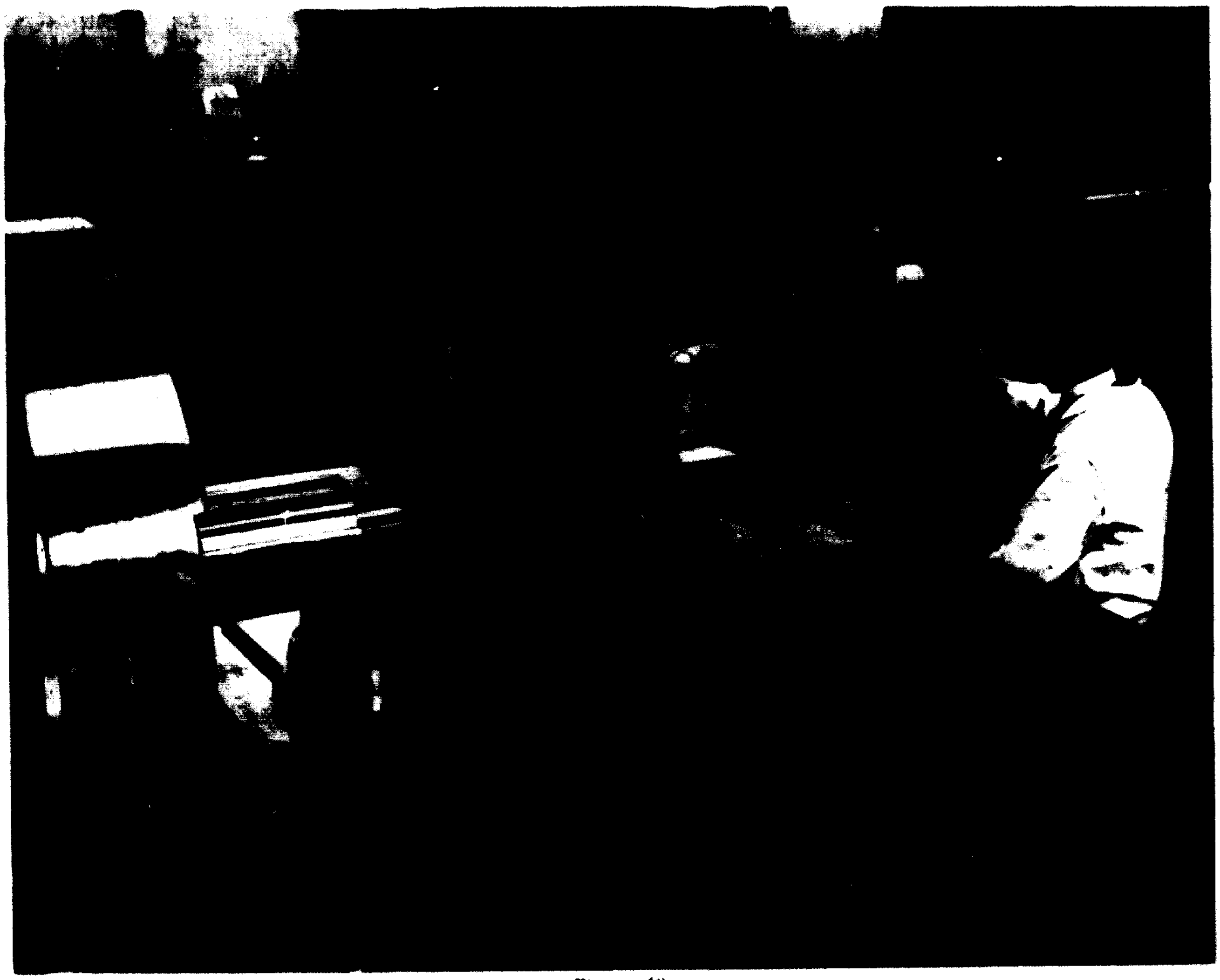


*Figure 40*

VIBRATION TESTS IN DEVELOPMENT AND EXPERIMENTAL DEPARTMENT

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