

[54] END MILL GRINDER

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Related U.S. Application Data

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[52] U.S. Cl. 51/94 CS, 51/95 WH, 51/97 R, 51/225

[51] Int. Cl. B24b 3/06

[58] Field of Search 51/97 R, 225, 74 R, 77 R, 51/94 R, 94 CS, 124 R, 219 R, 234, 237 R, 288

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[57]

ABSTRACT

A complete installation is provided for grinding cutters, especially and typically, end mills, by machine controlled operations. The installation has three separate stations which, when all are used, provide maximum flexibility in the shape imparted to the end mill, accuracy of grind, and the ability to repeat or duplicate a particular grind on a series of duplicate cutters. The only manual operations are loading and unloading the end mills at each of the stations; and consequently the grinding of the mill is accomplished rapidly and at low cost.

36 Claims, 33 Drawing Figures

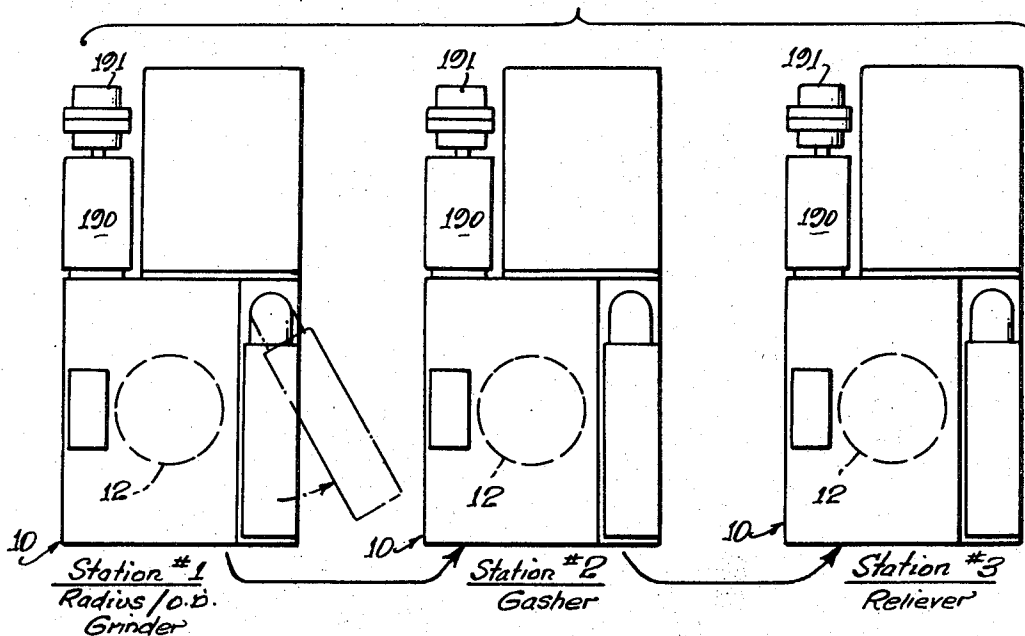


FIG. 1.

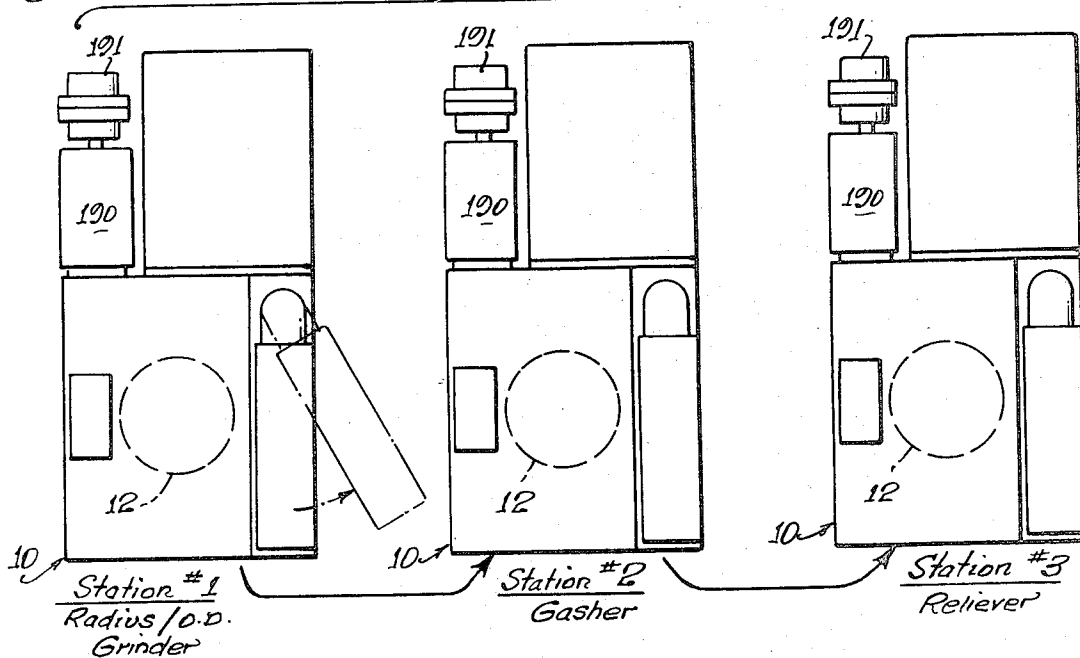
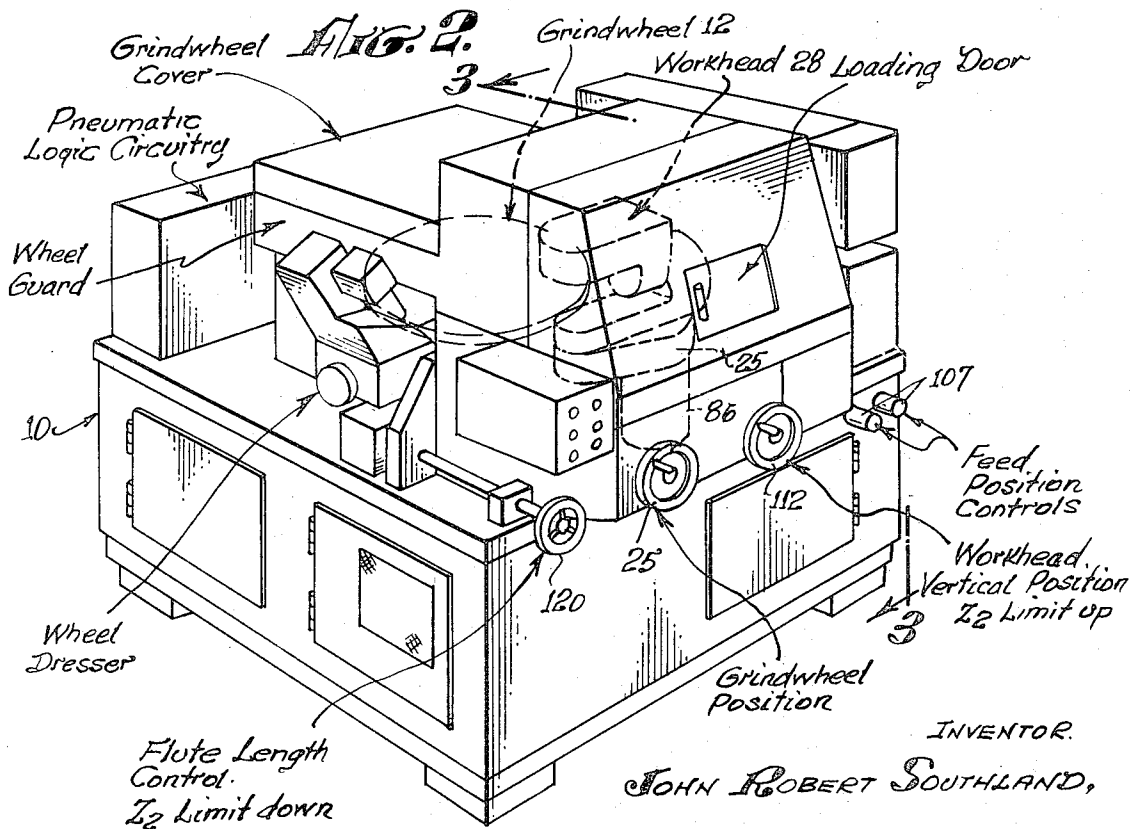


FIG. 2.

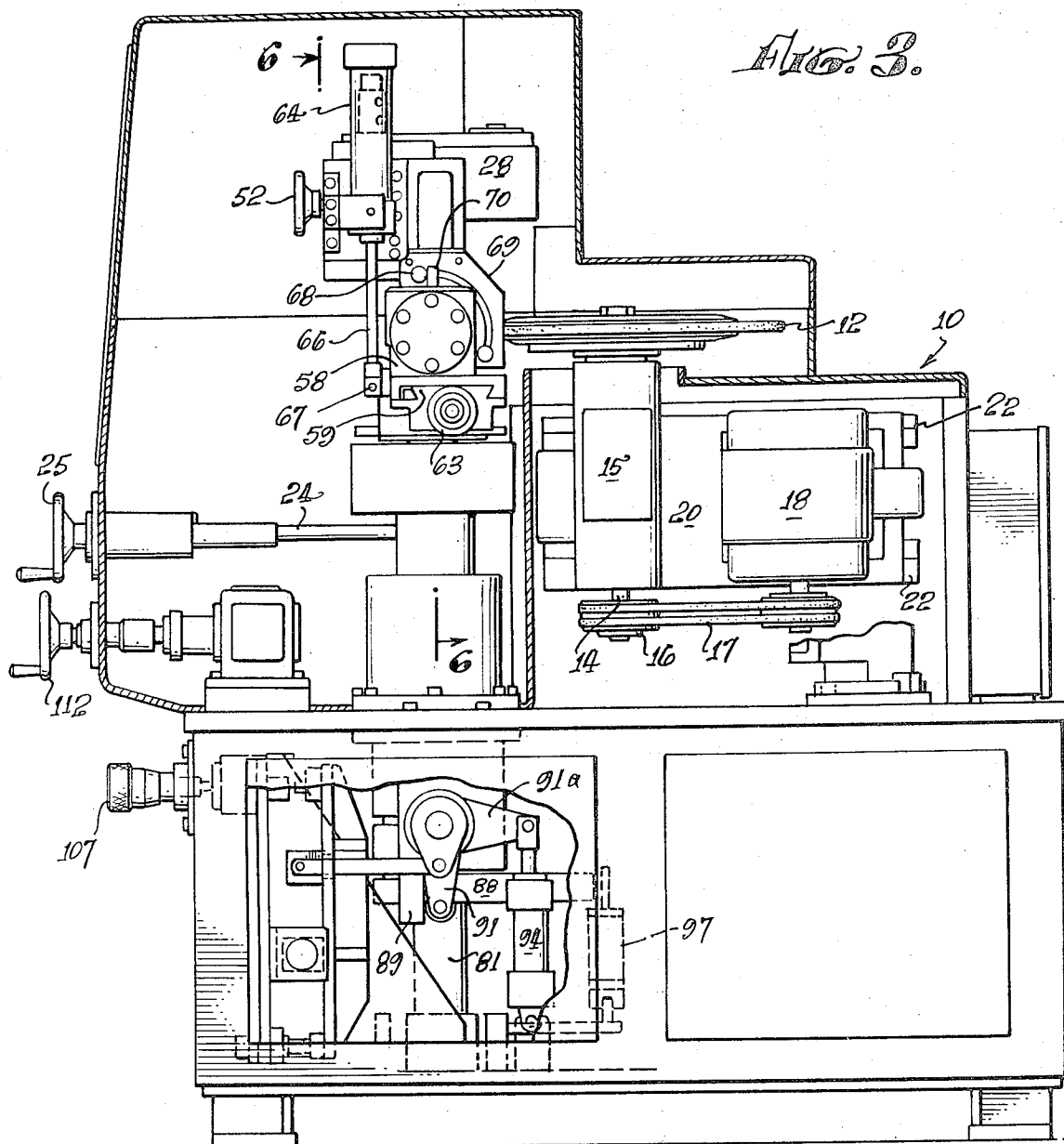
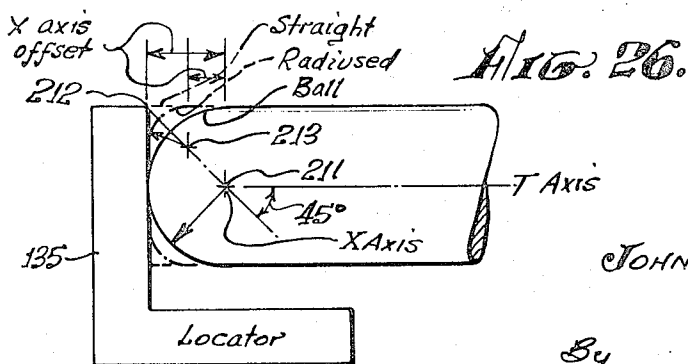


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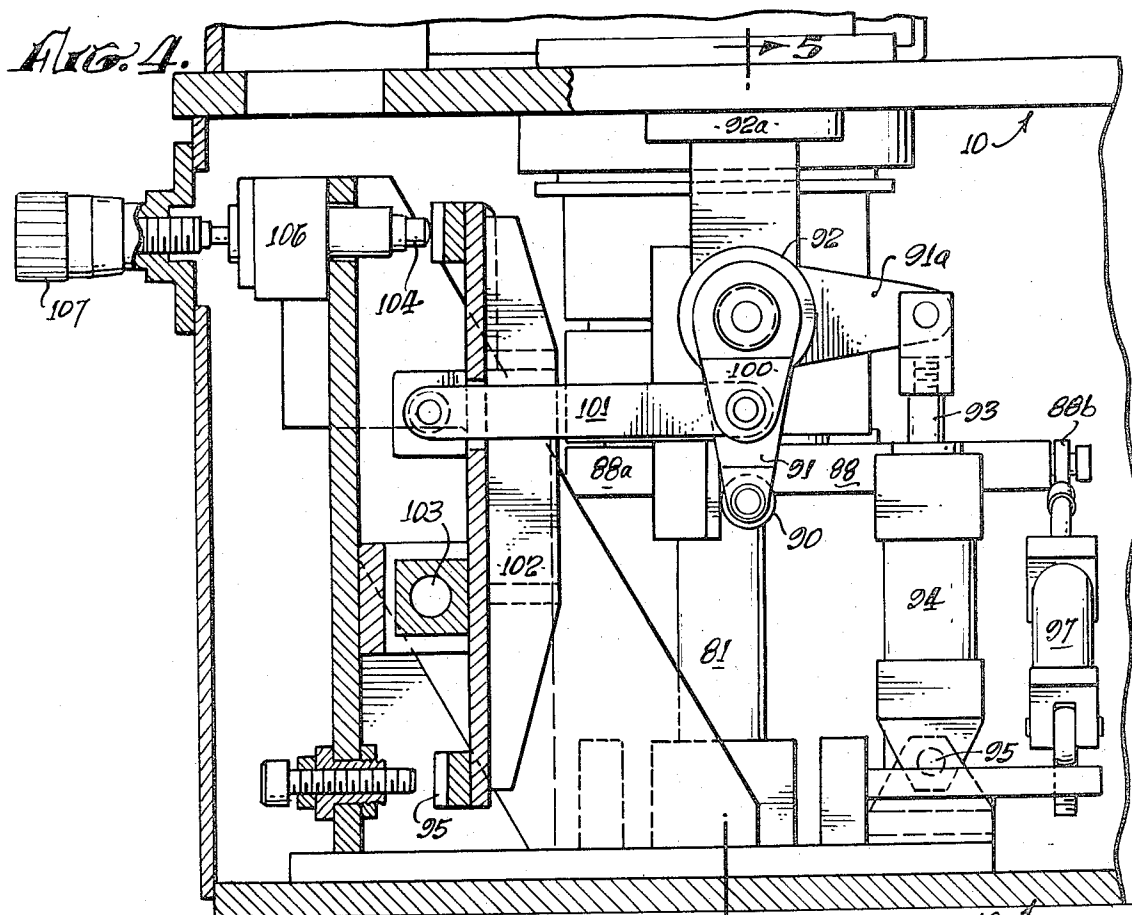
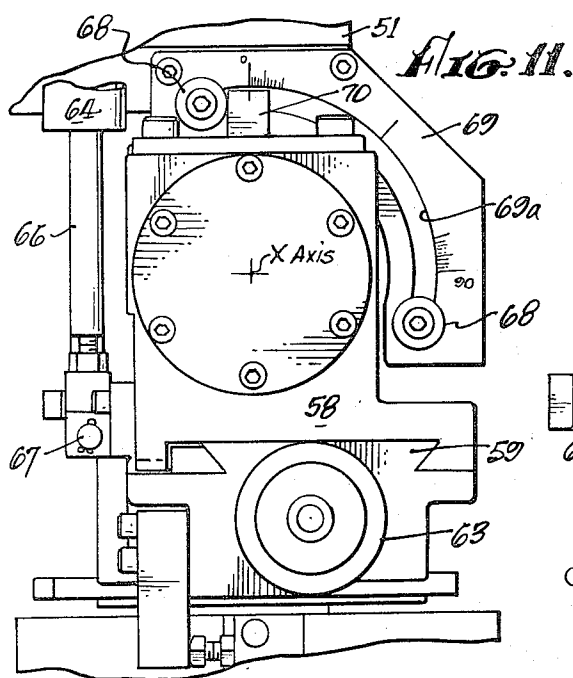
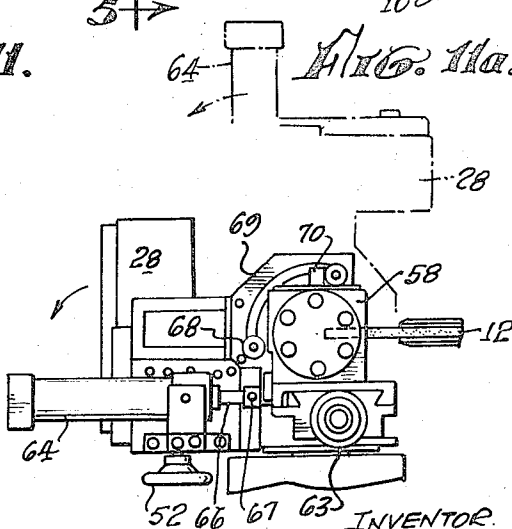
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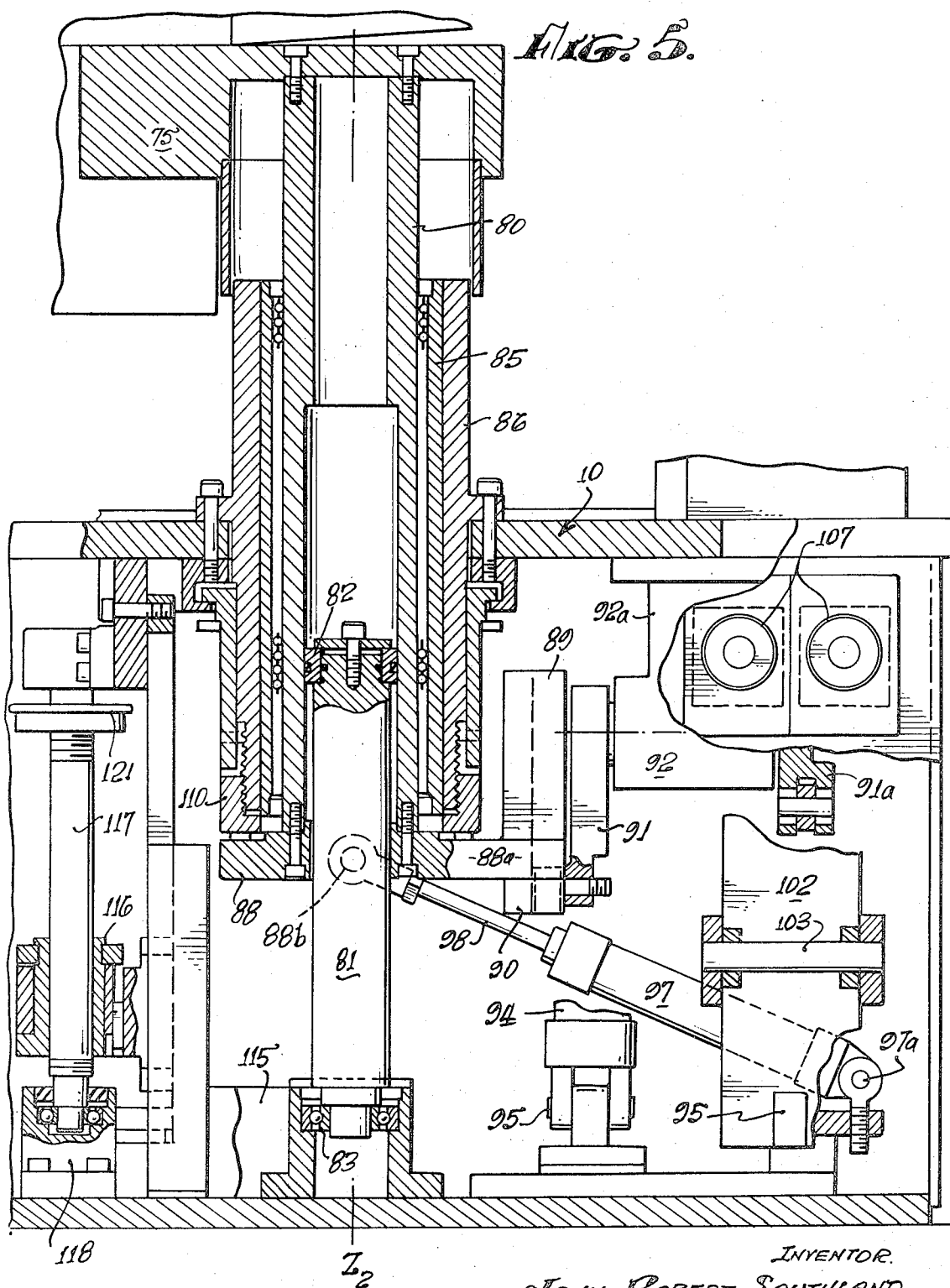
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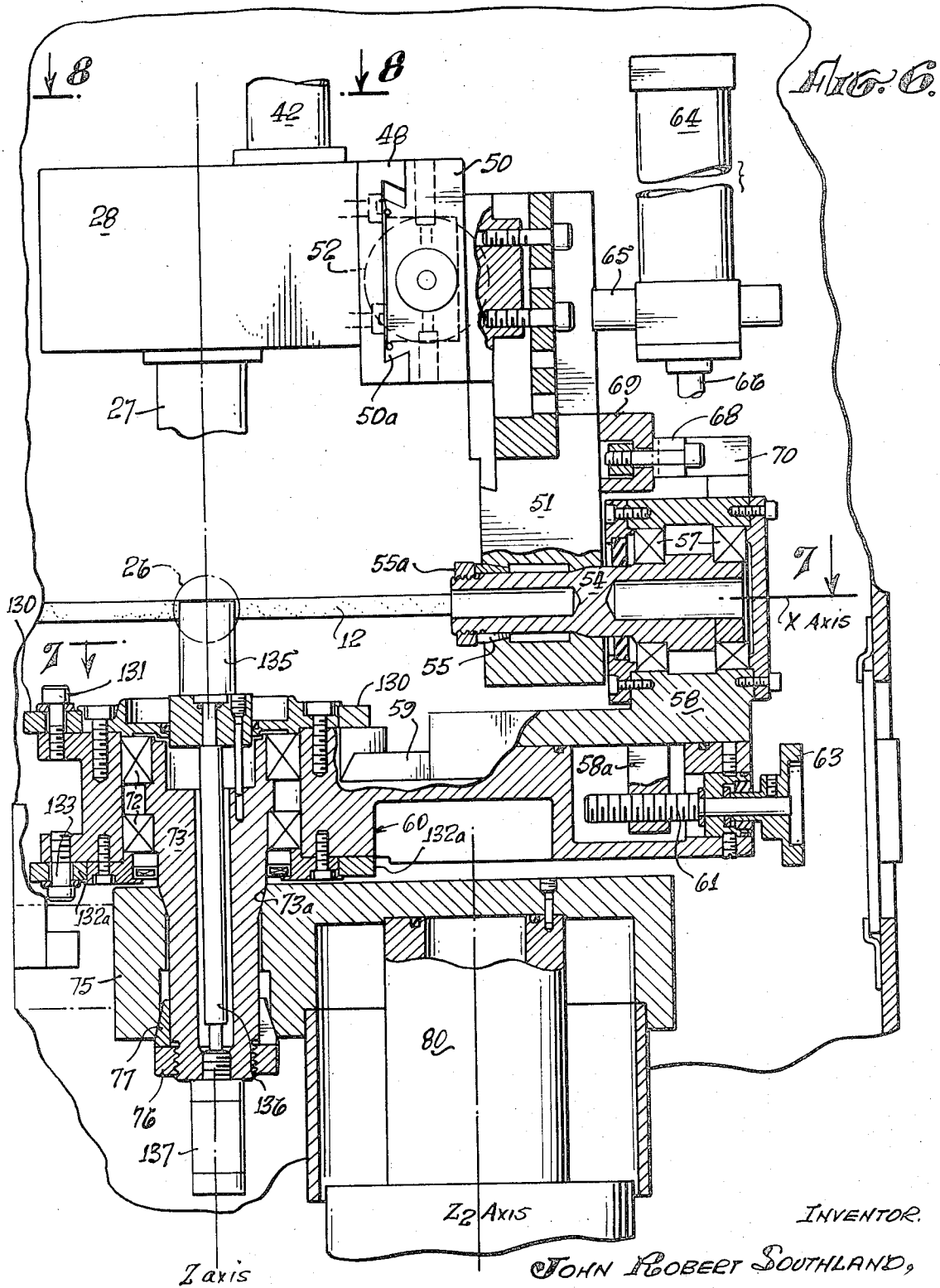


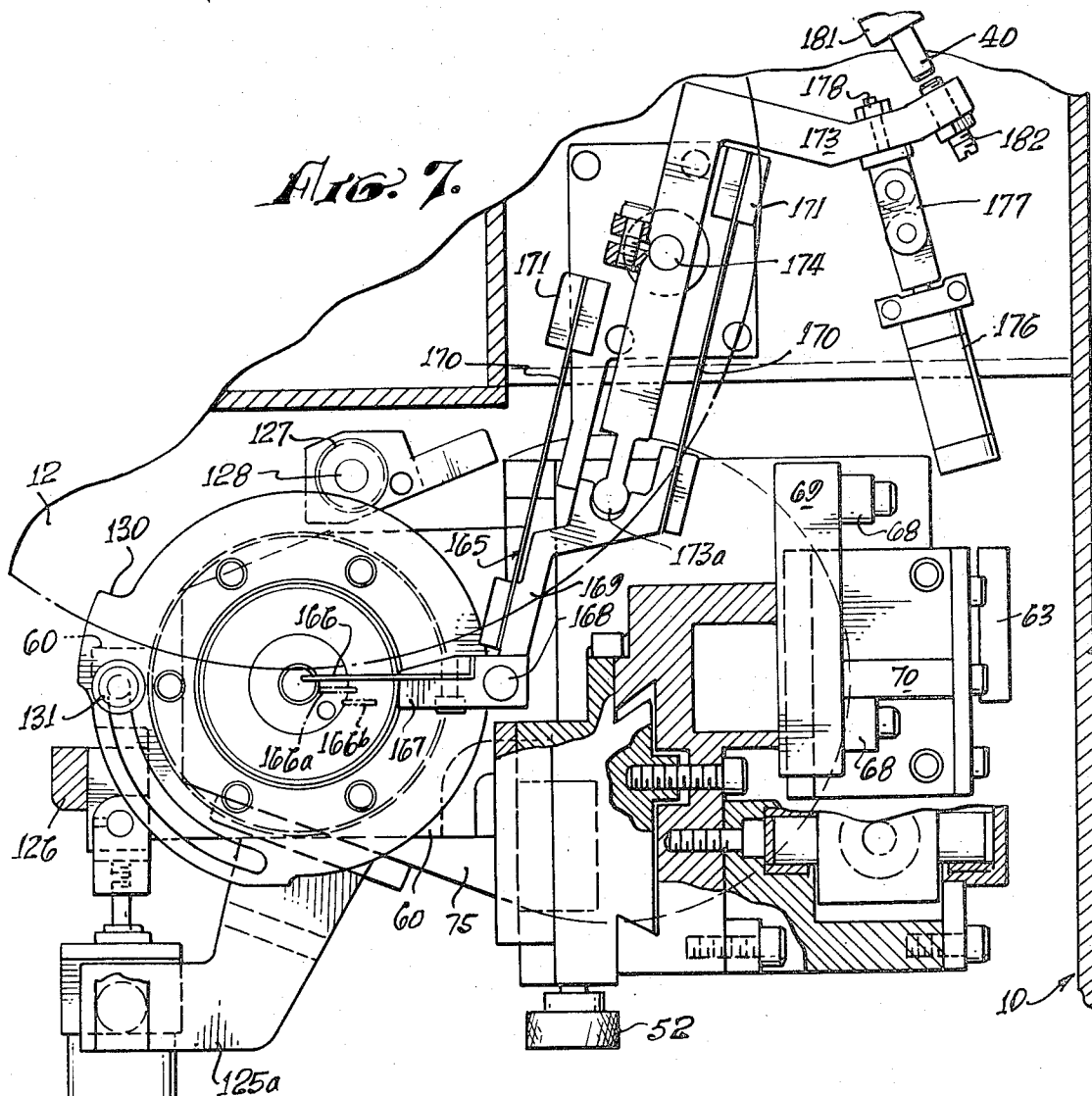
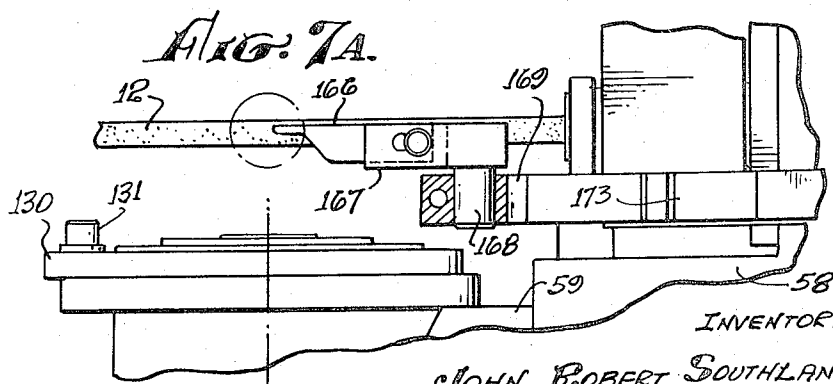
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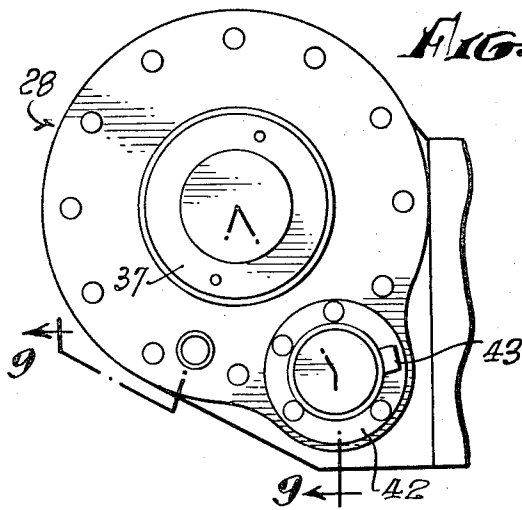
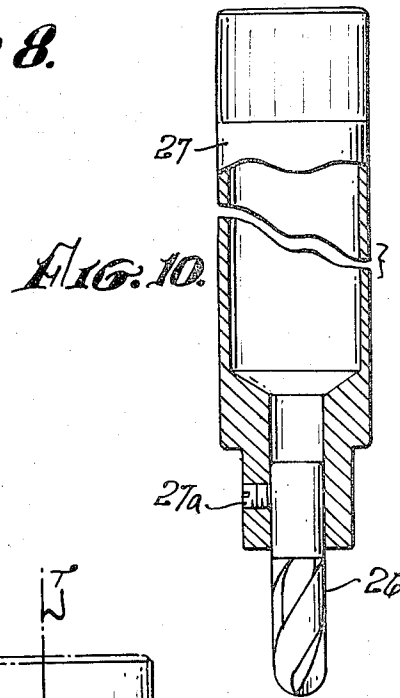
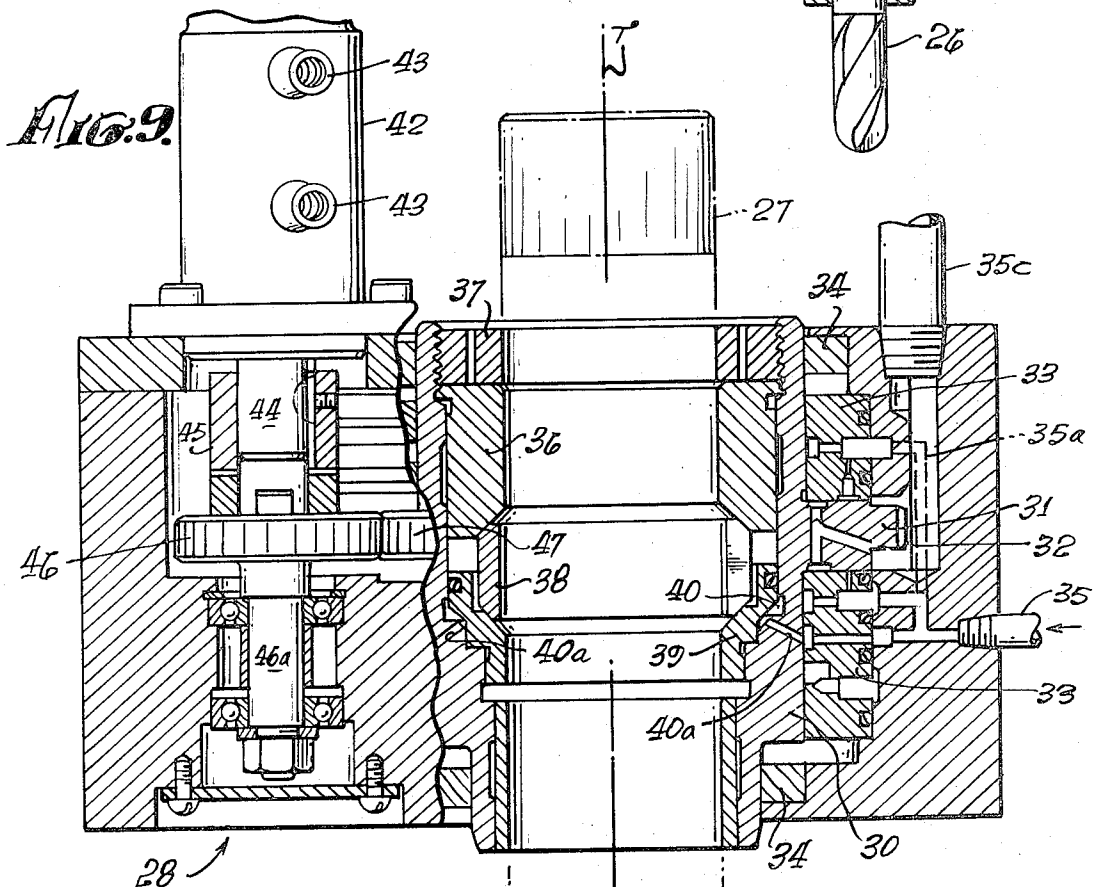
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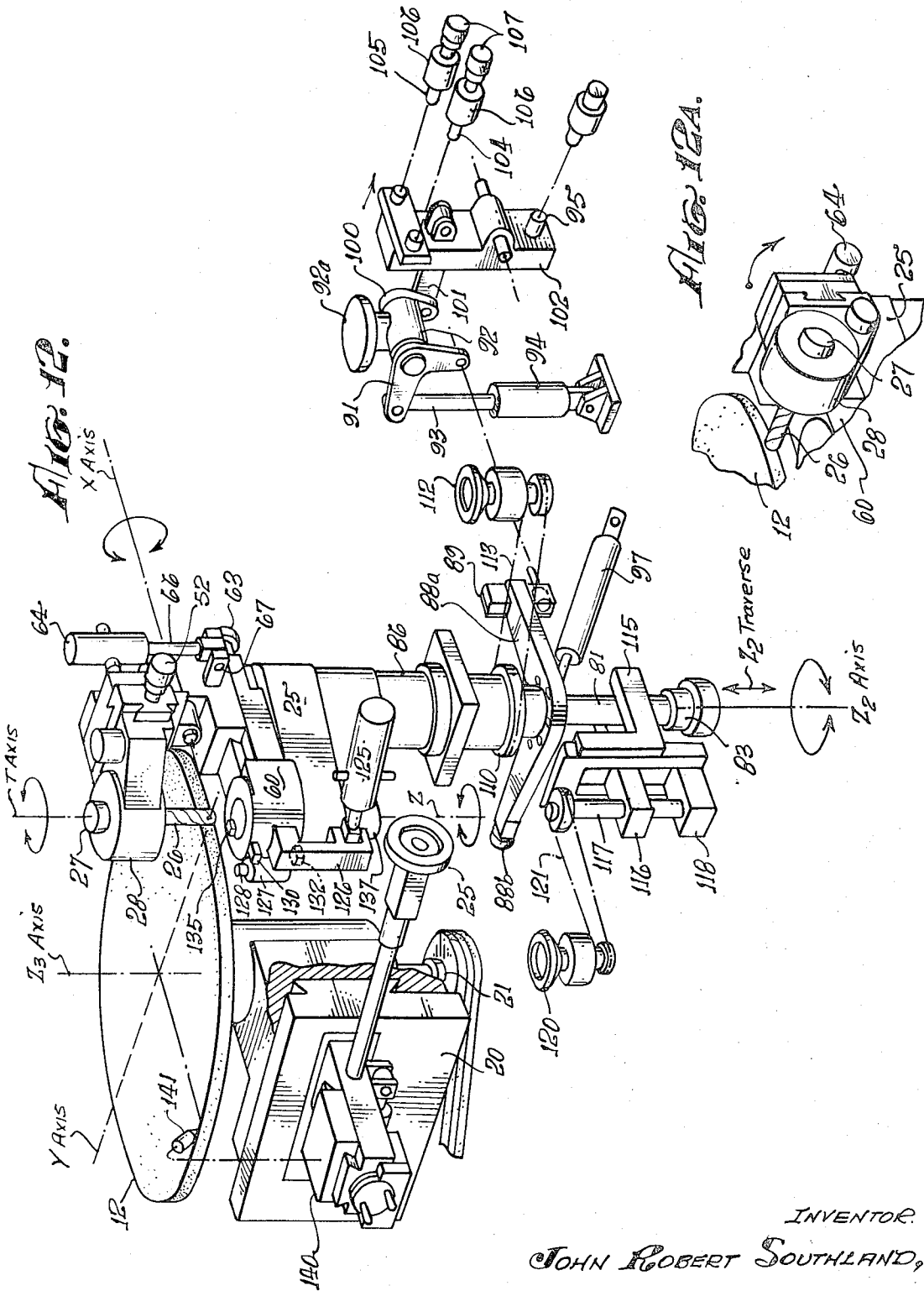
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FIG. 15.

BASIC AXIS RELATIONSHIPS.

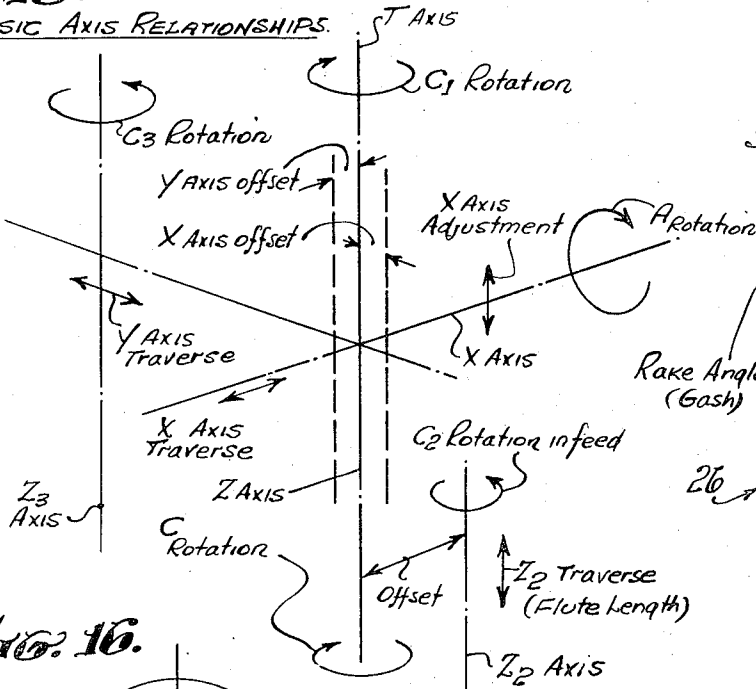


FIG. 13.

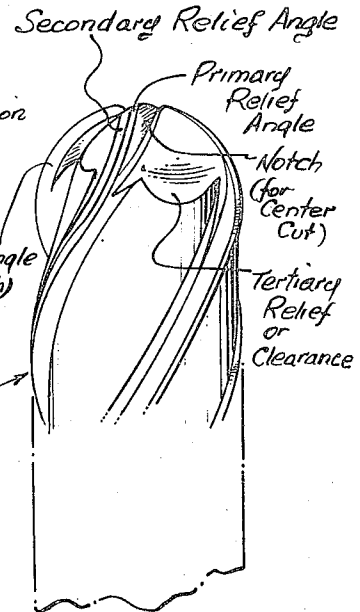


FIG. 16.

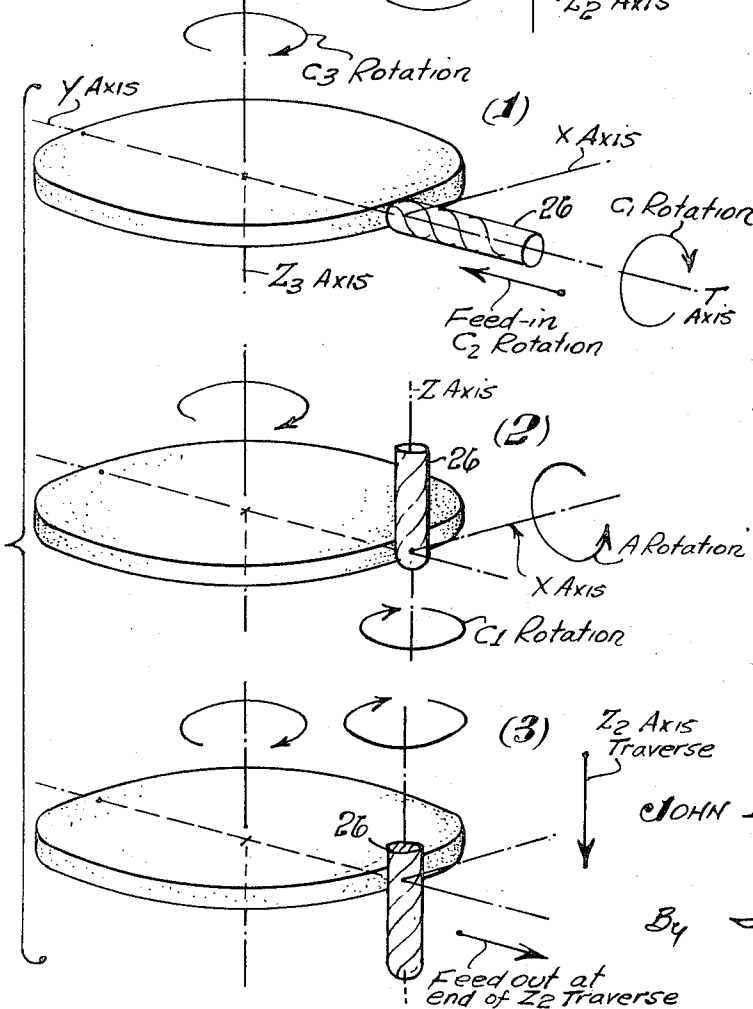
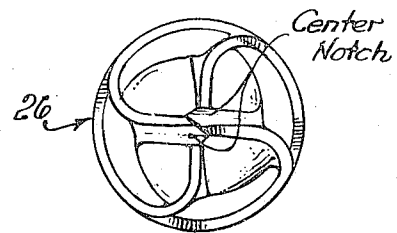


FIG. 14.



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FIG. 17.

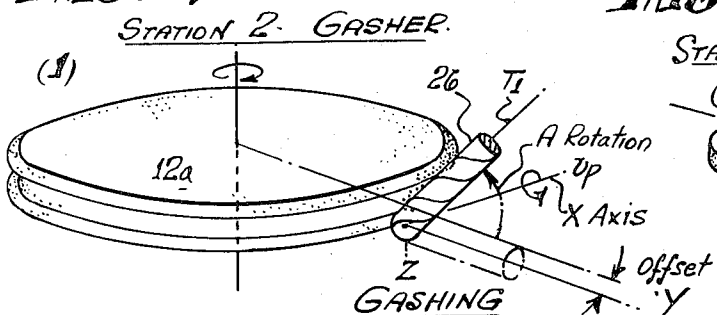
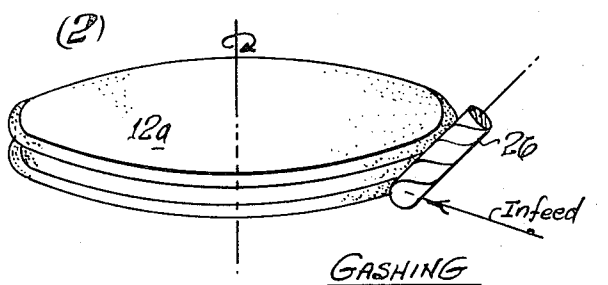
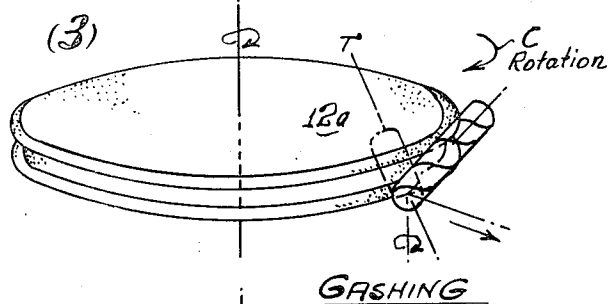
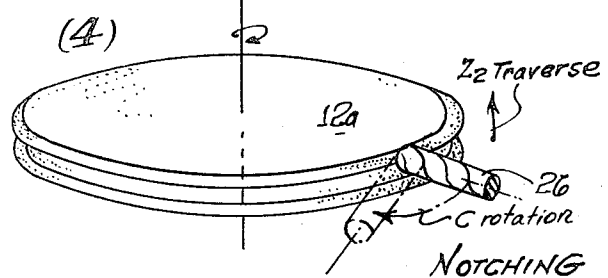


FIG. 18.

STATION 3- RELIEVER.

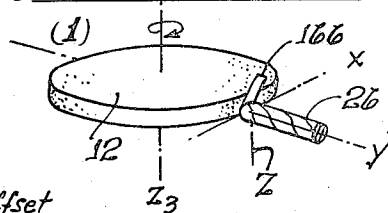
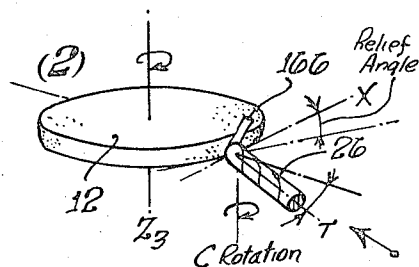
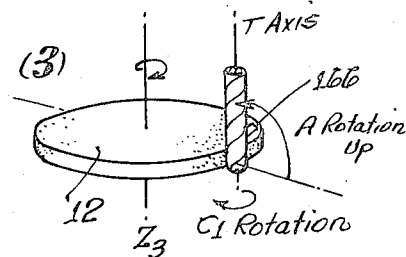
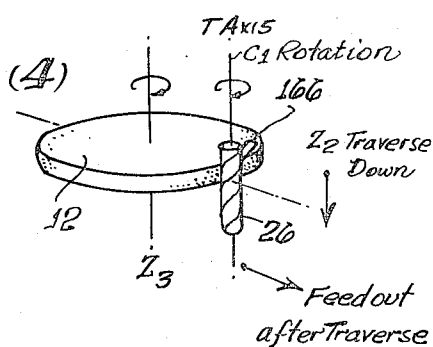
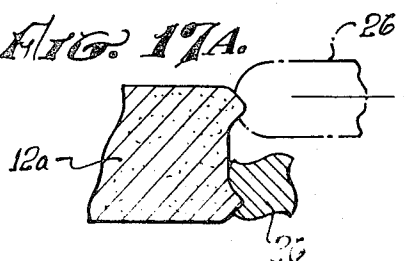


FIG. 17A.



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FIG. 19.

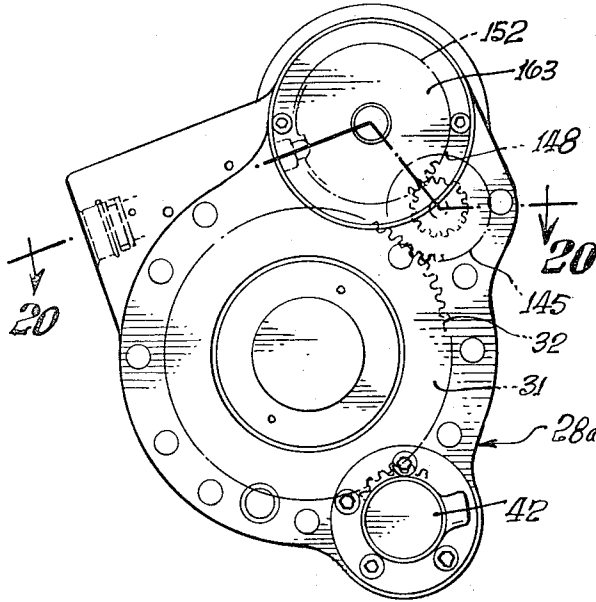


FIG. 21.

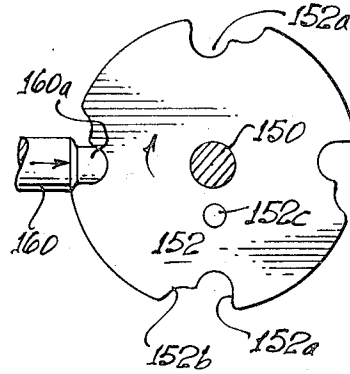


FIG. 20.

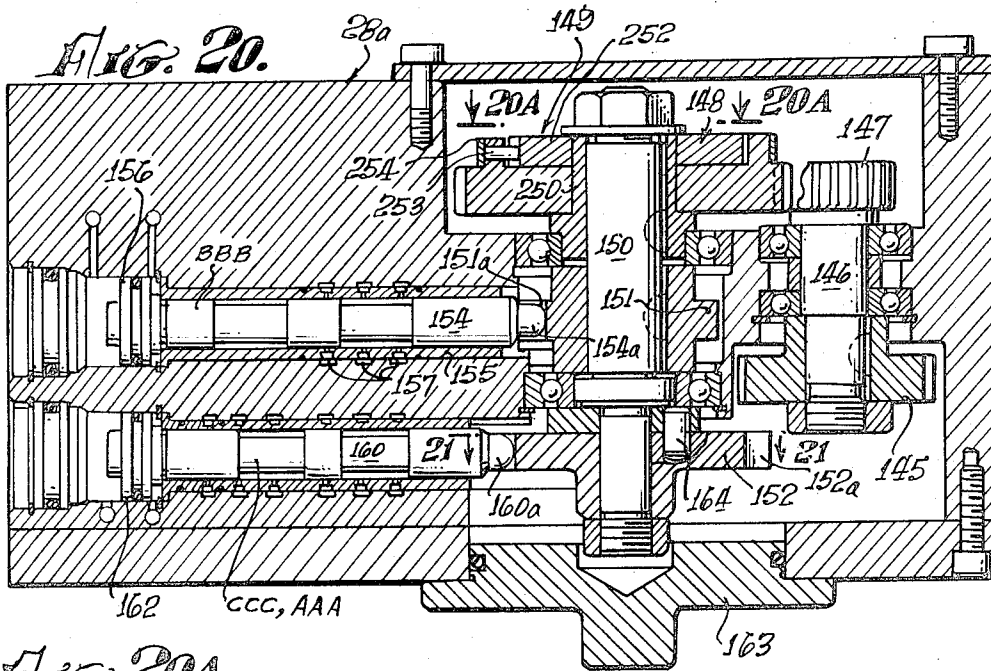
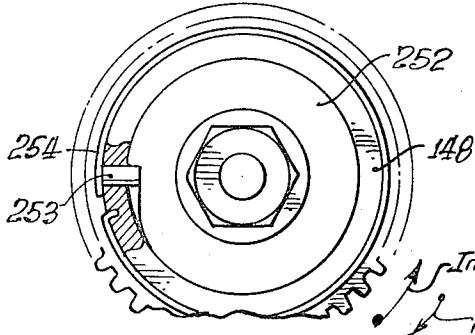


FIG. 20A.

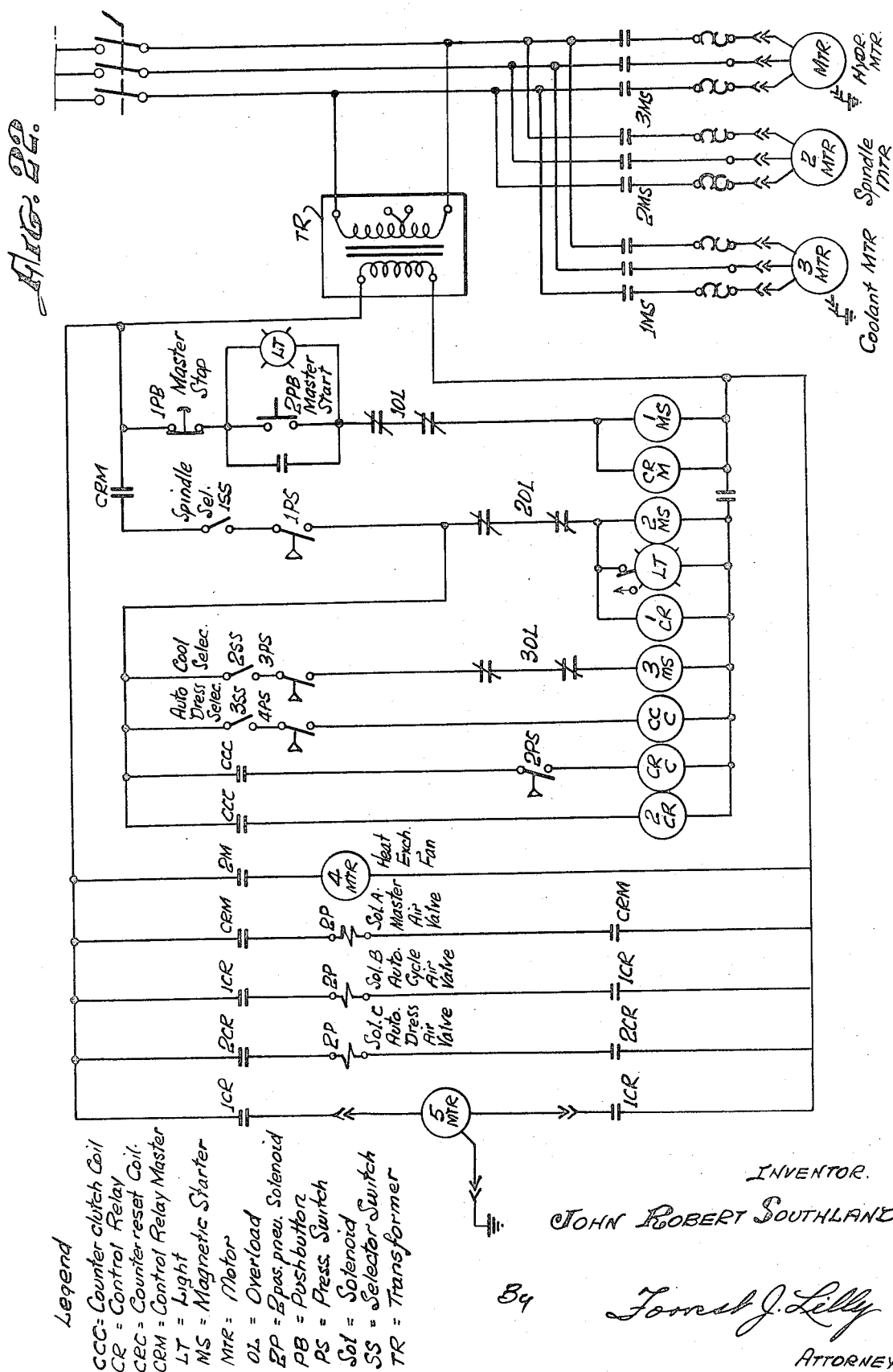


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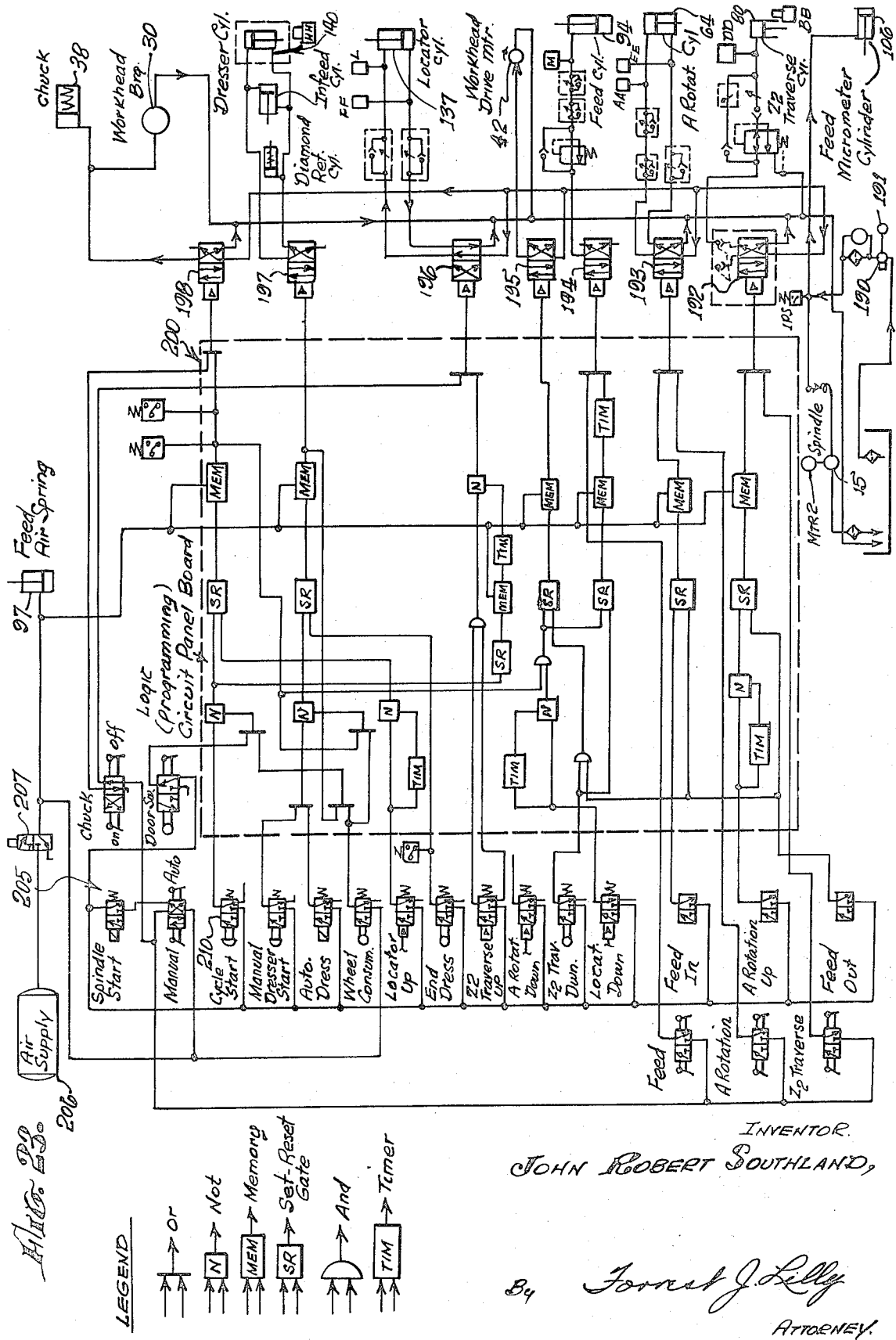


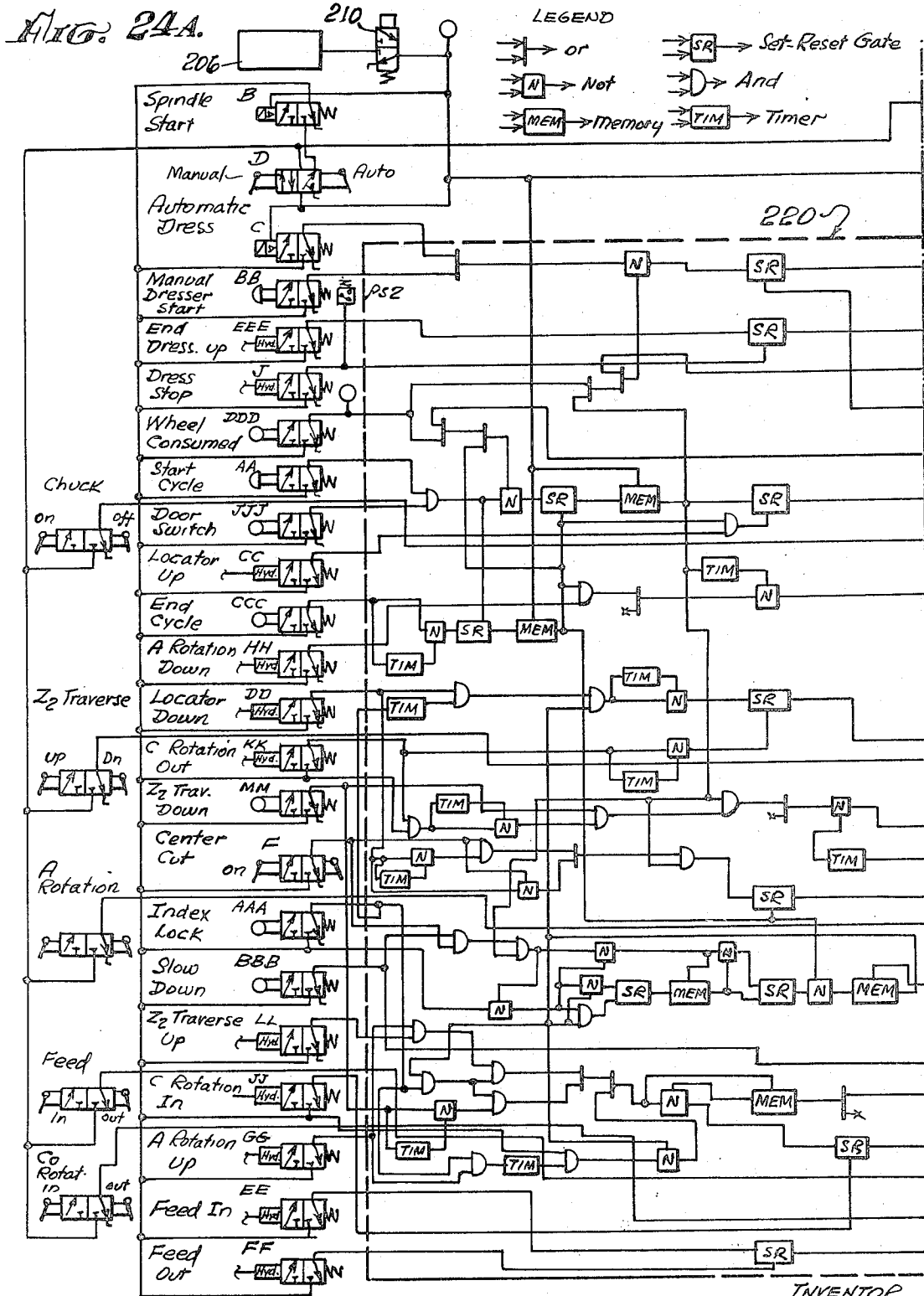
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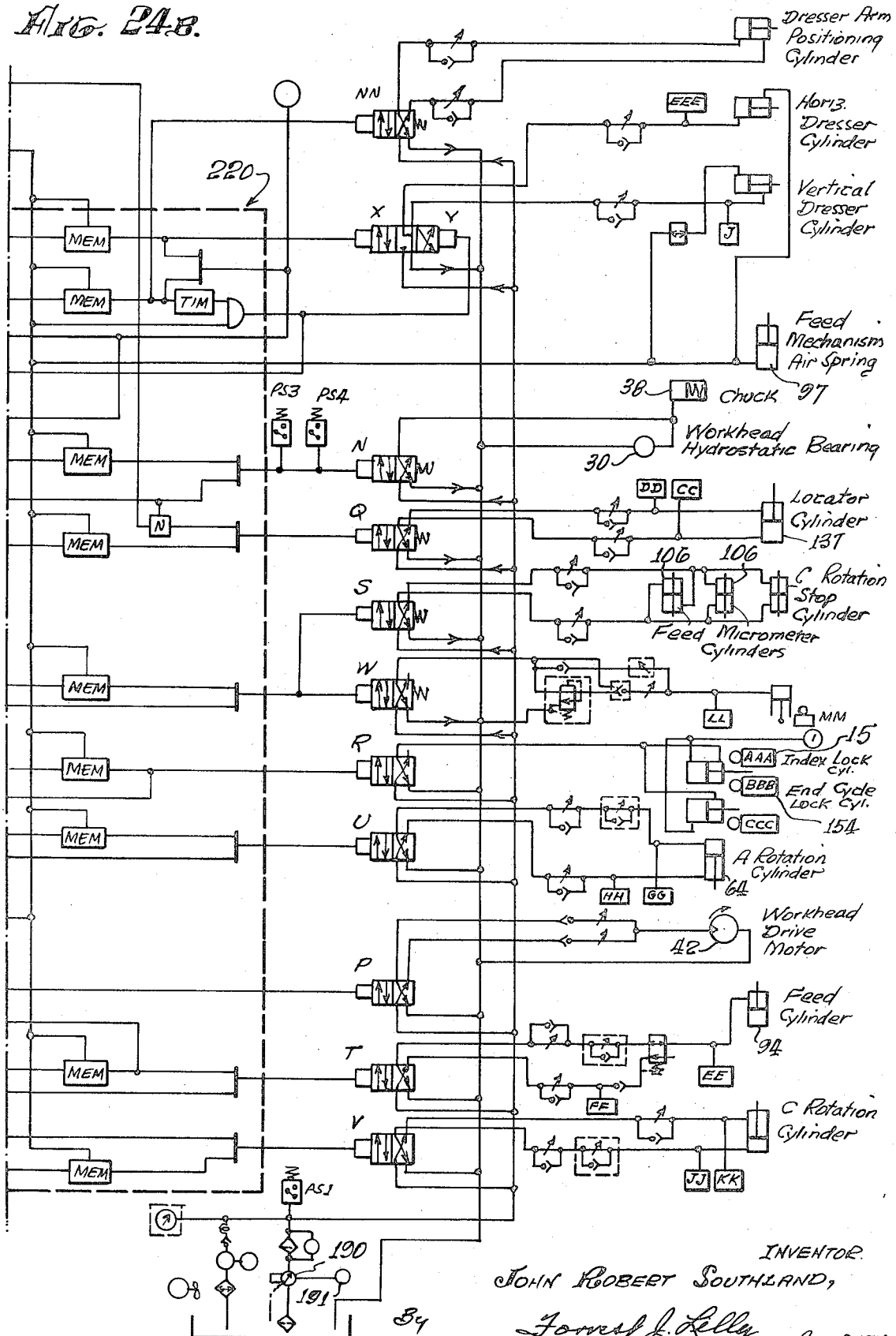




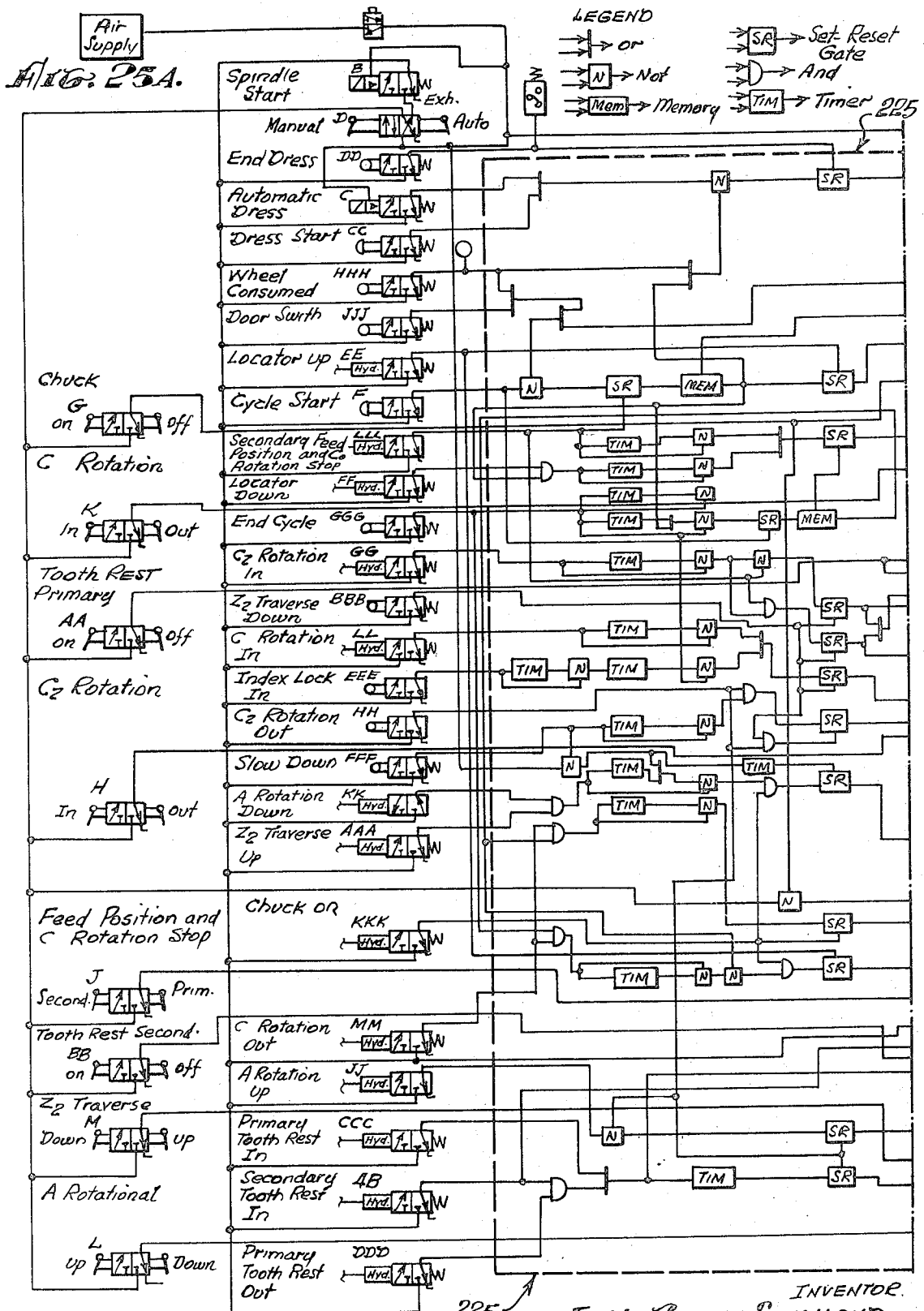
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FIG. 24-8.

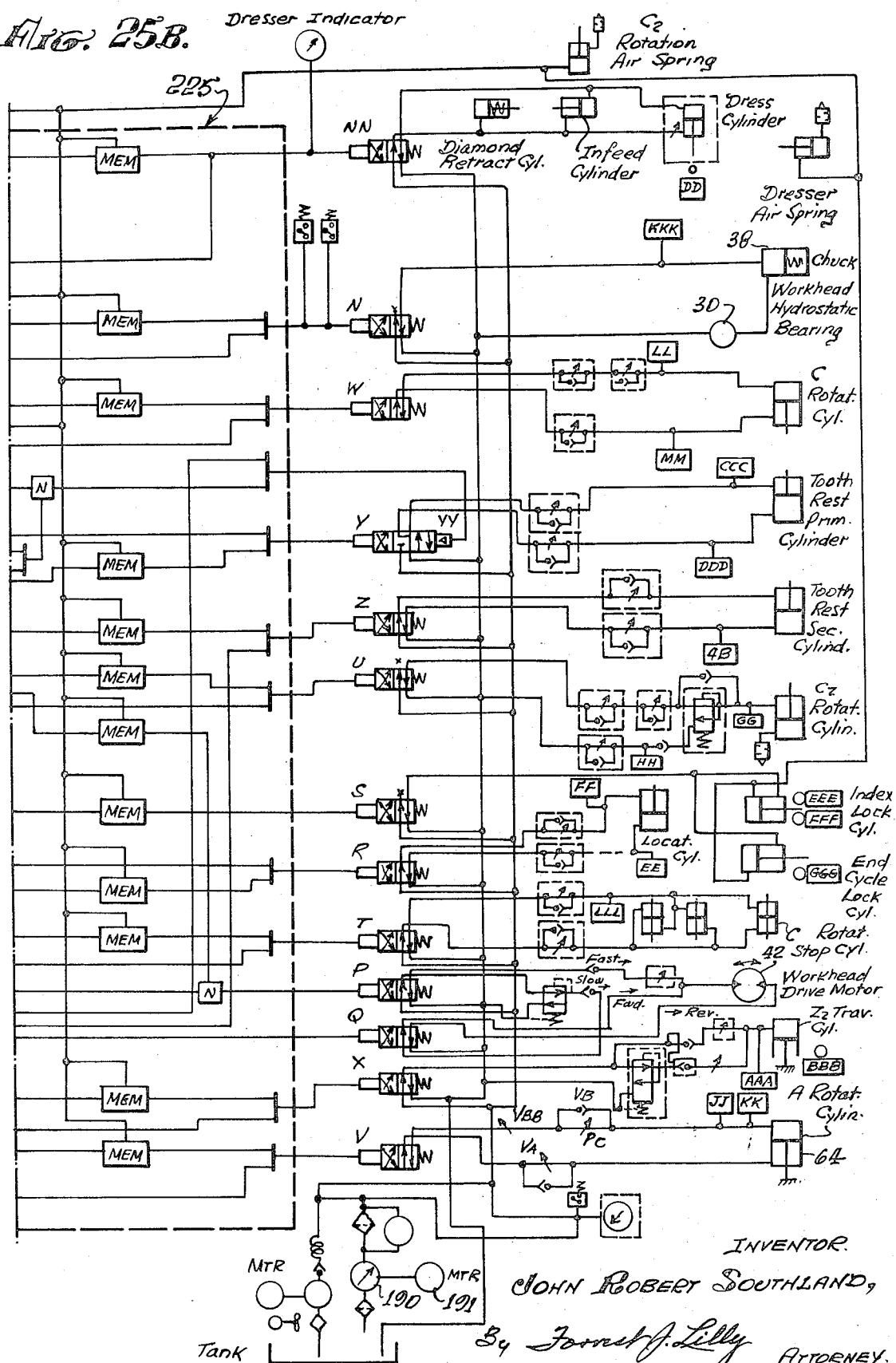


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Aug. 25B.



END MILL GRINDER

This is a continuation of application Ser. No. 836,467, filed June 25, 1969.

BACKGROUND OF THE INVENTION

The present invention relates generally to grinders for shaping or sharpening cutters for machine tools, and more especially to equipment of this type for grinding end mills, either sharpening old ones or grinding new ones from blanks.

Heretofore, grinding end mills in this way has been done by hand with the aid of jigs and fixtures. These mechanical aids steady the hand of the operator, but nevertheless known procedures depend largely upon the personal skill and experience of the particular operator. When the grinding is basically a manually controlled operation, the product of such known procedures suffers from unpredictable inaccuracies, and this in turn leads to a lack of uniformity in the product. As in most hand operations as compared with machine performed operations, the relative cost of sharpening a mill is greater when it is done by hand than by machine.

Modern mass production techniques have led to the widespread use of multiple-spindle machine tools of many varieties. A milling machine may have several spindles, for example three, each working on a separate part and all operating simultaneously so that three different work pieces are being machined at once. In other types of machine tools, a plurality of cutters are sequentially engaged with a work piece.

A further step in mass production technique has led to the operation of machine tools by numerical controls, typically a punched tape which feeds through a reader and causes the machine to perform all of the several cutting operations in the proper sequence without control by a machine operator. Multiple-spindle machine tools operated by numerical controls place a premium on having all cutting tools exact duplicates of one another so that they all operate exactly alike and, importantly, have the same useful cutting life.

By way of example, assume a milling machine having three cutters and it is known that a given number of work pieces can be milled before the cutters become dull and require replacement. In a numerically controlled machine, the tape is then punched to schedule a complete retooling of all spindles after a given number of pieces have passed through. However, if one cutter is not an exact duplicate of the others, then one or more adverse results are possible. Because of the different sizes or shapes of the cutters, all of the products are not precise duplicates of each other and therefore may not be interchangeable. This can lead to a large percentage of rejects with an obvious increase in cost of parts.

Another common result of this situation is that one cutter becomes dull before the other two. This results in the dull cutter breaking, causing a premature shutdown of the machine. In addition to the unnecessary and costly down time caused by an unscheduled tool change, the useful life of all the cutters in the machine is diminished since they must all be changed or replaced at the same time. Furthermore, an unscheduled stoppage of this character oftentimes results in much more time being required to place that particular ma-

chine back in operation than is true of stoppage at properly scheduled intervals.

Consequently, it becomes a general object of the present invention to provide an installation of novel construction for originally grinding or resharpening machine tool cutters, such as end mills, capable of producing cutters that are precise duplicates of one another.

It is also an object of the present invention to provide an installation for sharpening or initially grinding end mills which is capable of maximum flexibility in the sizes and shapes of end mills handled and the shapes of the cutting surfaces ground on the mills.

A further object of the present invention is to provide an installation capable of grinding cutters in which all operations are carried out by machine, and manual operations are limited to loading and unloading the grinding units, and in which grinding operations are performed more rapidly, more accurately, and with lower cost than has heretofore been possible.

SUMMARY OF THE INVENTION

The above and other objects and advantages of the present invention have been achieved in a cutter grinding installation comprising three separate but similar grinding stations, each station comprising a grinding wheel, a tool holder, and mounting means of novel construction for supporting and moving the tool holder and a cutter therein over a predetermined path with respect to the grindwheel to perform certain grinding operations at each station. The first and third stations are provided with grindwheels having a cylindrical grinding surface while the second station differs in having the grindwheel with at least one and preferably two circumferential ridges. All three stations are very similar in appearance since many common parts are used in the basic structures, although each station has certain unique features. In order to make maximum use of common parts, some movements or parts at any of the stations may be superfluous; but the presence or absence of such parts is normally a matter of choice.

The first station is a radius and outside diameter grinder adjustable to grind any desired cutting surface on an end mill from a ball grind to a straight grind with a flat end surface on the cutter or with any desired degree of radius in between. In the first station, the tool holder is mounted in a work head which includes a motor for continuously rotating the tool holder while the cutter is in contact with the grindwheel.

At the second station, a gash is cut at the base of each land of a radiused or ball end mill. For this purpose the work head is also provided with an indexing mechanism to index the drill by rotating the drill about its axis in increments determined by the number of flutes on the cutter and means to lock the cutter in each grinding position.

At the third station, the primary and secondary relief angles are ground on each land. Consequently, the work head is here also provided with indexing and lock mechanism similar to that at the second station. Means for setting the desired angles are provided. The cutter in the work head then turns about its own axis in contact with a tooth rest to grind the desired relief angle on each land in proper sequence.

In general, each station is constructed with reference to X, Y, and Z principal geometric axes that, generally speaking, lie respectively in one of three mutually per-

pendicular planes. When in position for initiating the grinding operation, these three axes intersect at a common point; and in some operations the three axes are mutually perpendicular, while for other grinding operations certain of the machine elements initially corresponding with said geometric axes may be moved into oblique positions.

The vertical Z axis and the horizontal X axis are established by major machine elements, but these machine elements are each independently movable to obtain the necessary flexibility of three-dimensional movement required for proper grinding of the cutters. Means are provided for feeding the cutter toward and away from the grindwheel by swinging the Z axis in a short horizontal arc about a second vertical axis identified as Z₂. The machine parts whose axis initially defines the X axis may be perpendicular to the Y axis in any station; but means may be provided to enable these X axis part to be swung in a horizontal arc about the Z axis to a position other than perpendicular to the Y axis for some types of grinds. The Y axis is not represented by a tangible machine element and so may be regarded as being horizontal and movable vertically with the X axis to intersect the X axis at all times.

The nose of a ball end mill has the rake angle provided by grinding the side face of a land at the second station. The movement of the cutter is carefully controlled to grind a smooth surface on the nose of the cutter that blends without interruption into the relatively tangential face of the land along the side of the cutter. This side face of the land is then used as a guide or template which is engaged and followed by a tooth rest at the third station as the primary and secondary relief angles are ground on the land.

The grindwheel is rotatably mounted to revolve about a vertical axis parallel to and spaced along the Y axis from the Z axis. The axis of the grindwheel is fixed during grinding operations but is adjustable to compensate for wear of the grindwheel.

The cutter is mounted in a tool holder which, in turn, is mounted in a work head adapted to position the tool holder initially with the longitudinal axis of the cutter horizontal and in the Y-Z plane, or parallel thereto. Means are provided for swinging the tool holder and cutter about the X axis as necessary for various grinds. When the X axis is perpendicular to the Y axis, as at the first station, the cutter axis then moves in the Y-Z plane. Means are provided for turning the tool holder and cutter therein about the axis of the cutter, this means differing from station to station according to the function to be performed. At the first station, rotation of the tool is continuous during grinding; but at the other two stations this angular movement of the tool may be regarded as intermittent. Both the second and third stations have in common the indexing movement of the tool by the work head to advance the lands in succession into grinding position.

BRIEF DESCRIPTION OF THE DRAWINGS

How the above objects and advantages, as well as others not specifically mentioned, are achieved will be better understood by reference to the following description and to the annexed drawings, in which:

FIG. 1 is a diagrammatic plan view showing the grinding system comprising three separate stations;

FIG. 2 is a front and side perspective of the grinder at station No. 1, the grinders at stations No. 2 and No. 3 being substantially the same;

FIG. 3 is a side elevation of the machine of FIG. 2 with the upper portion of the housing broken away;

FIG. 4 is an enlarged view, taken from FIG. 3, of a part of the mechanism for imparting motion to the work head and the support column therefor;

FIG. 5 is a vertical section through the column supporting the work head taken on line 5—5 of FIG. 4;

FIG. 6 is a fragmentary vertical section showing the work head and the upper portion of the column supporting the work head, taken on line 6—6 of FIG. 3;

FIG. 7 is a combined plan view and section of the work head support at station No. 2 or No. 3 as if taken partially on line 7—7 of FIG. 6;

FIG. 7a is a fragmentary elevation similar to FIG. 6 showing the tooth rest employed at stations No. 2 and No. 3;

FIG. 8 is a plan view of the work head and motor at station No. 1, taken on line 8—8 of FIG. 6;

FIG. 9 is a vertical section through the work head and the tool holder taken on line 9—9 of FIG. 8;

FIG. 10 is a combined elevation and median section through the tool holder with a cutter in place in the tool holder;

FIG. 11 is an enlarged fragmentary side elevation, viewed as in FIG. 3, of the mechanism for pivoting the work head (A rotation) about a horizontal axis;

FIG. 11a is a fragmentary side elevation similar to FIG. 11 at reduced scale showing the work head tilted forward to the initial or loading position;

FIG. 12 is a schematic view in perspective of the grindwheel, the work head, and the column on which the work head is mounted, together with the mechanism for producing the desired movements of the work head relative to the grindwheel, characteristic of all three stations;

FIG. 12a is a fragmentary perspective, similar to a portion of FIG. 12, showing the work head tilted forward into the initial or loading position;

FIG. 13 is a fragmentary side elevation of the end of a ball end mill;

FIG. 14 is an end or top plan view of the ball end mill of FIG. 13;

FIG. 15 is a diagram showing the geometric relationships of the several design axes and the directions of offset and movements of the cutter relative to the axes;

FIG. 16 is a series of three schematic views showing successive positions of an end mill while undergoing a radius and outside diameter grind at station No. 1;

FIG. 17 is a series of schematic views showing four successive positions of an end mill while undergoing gashing at station No. 2;

FIG. 17A is a fragmentary median section at the periphery of the grindwheel at station No. 2;

FIG. 18 is a series of schematic views showing four successive positions of an end mill while grinding relief angles at station No. 3;

FIG. 19 is a front elevation of the indexing type of work head at stations No. 2 and No. 3 tilted to initial or loading position;

FIG. 20 is a horizontal section through the indexing work head on line 20—20 of FIG. 19;

FIG. 20A is a plan view of an over-running clutch in the indexing work head viewed on line 20A—20A of FIG. 20;

FIG. 21 is a plan view of the indexing lock disc in the work head of FIG. 20 viewed on line 21—21 therein;

FIG. 22 is a schematic view of the basic electrical circuit at each station;

FIG. 23 is a diagram of the automatic control system, including the logic circuit, showing the air and hydraulic elements controlling the sequence of operations of the grinder at station No. 1;

FIGS. 24A and 24B combined are a diagram of the automatic control system, including the logic circuit, showing the air and hydraulic elements controlling the sequence of operations of the grinder at station No. 2;

FIGS. 25A and 25B combined are a diagram of the automatic control system, including the logic circuit, showing the air and hydraulic elements controlling the sequence of operations of the grinder at station No. 3; and

FIG. 26 is a diagram showing the X axis offset and the relative shift in the axis for A rotation at station No. 1 for different types or profiles of end mills.

DESCRIPTION OF A PREFERRED EMBODIMENT

General

The detailed construction and operation of the cutter grinder can be more easily understood from a preliminary discussion of the concepts and general principles followed in its design and construction.

One of the first features obvious from inspection of FIG. 1 is that the entire installation involves three separate stations. These stations use as far as possible common parts, and therefore the stations have an over-all similarity in appearance, although they each perform separate and independent functions and consequently have different control systems.

Each station is based on the same common design features or concept, but modified to the extent necessary to perform the particular grinding operations of that individual station.

While it would be possible to incorporate all functions into a lesser number of stations, a division of the total number of operations into three stations is preferred, because different shapes of grinding wheels can be used without replacing the wheels at a given station; the production rate is increased since different functions can be performed simultaneously; accessibility of the machines for maintenance and service is improved; and the layout of the entire installation is more flexible. Another reason is that a particular plant or factory may not require all three stations, making it more economical to buy only the stations required.

The cutter grinder at each of the three stations is designed and built with reference to three geometric axes that lie respectively in three mutually perpendicular and intersecting planes. In accord with common practice these axes are designated as the X, Y, and Z axes. The X and Y axes are horizontal and extend respectively from left to right of an observer standing at the front of the machine and toward and away from the observer at the same point. The Z axis is vertical, passing through the intersection of the X and Y axes. This geometric relationship of the three principal axes is shown

in FIG. 15. Other axes are designated by the same reference letter as the parallel principal axis with the addition of a subscript. Also in accord with common usage, rotation about one of the principal axes, as indicated diagrammatically in FIG. 15, is designated A, B, or C rotation when about the X, Y, or Z axis, respectively. The X axis, initially established by a major machine element in one position thereof is always horizontal, but the machine element, as will become apparent, can be raised and lowered, or swung about the Z axis.

Using this same design concept, all three stations can utilize to a large extent common parts. Commonality of parts is utilized to the maximum in the preferred embodiment illustrated. Consequently the illustration and following description refers at first to a type or composite grinder performing operations conducted at station No. 1 and including a description of some additions or modifications required for stations No. 2 and No. 3 but not inconsistent with operations at station No. 1. This design rationale results in some instances in a particular station having movement capabilities that are superfluous and therefore not used; but the reason for this situation being understood, it will likewise be understood that these design features in the illustrated preferred type embodiment are not necessarily limitative upon the invention in its broader aspects.

Referring now to FIG. 1, there is illustrated therein the three stations of a complete installation, it being realized that the stations may be installed contiguous to one another or separated as desired. Cutters are manually loaded and unloaded at each of the three stations and transferred from one station to another as required, so that no fixed spatial relationship between the stations is necessary.

Still referring to FIG. 1, station No. 1 is a radius and outside diameter grinder. This machine performs a nose or end rough grind followed by a continuous grind around the periphery of the cutter to establish the outside diameter. This operation may be applied to a blank or to a dull or damaged end mill in preparation for the finish grinding operation at subsequent stations, so that a minimum amount of material is removed from the cutter during the finish grinds.

Station No. 2 is designated as a gasher and performs the axial and rake angle grinds, a flute blend grind, and center notching at selected lands.

Station No. 3 is termed a reliever and performs primary and secondary relief angle grinds, starting at the nose center line and progressing around the nose periphery to grind continuously the full length of the flutes. From rough blank to finished cutter, requires operations performed at all three stations. For resharp- ening a cutter, only stations No. 2 and No. 3 are normally required. Hence the advantage of separate stations, each with its own sequence of operations.

It should be pointed out in advance that the motion required of the cutter for grinding at any of these stations is determined by the type or style of cutter. As will become apparent from subsequent description, the stations have sufficient flexibility in movement of the cutter to grind accurately a straight or flat end mill, a ball end mill, or one of intervening intermediate shape generally referred to as a radiused end mill.

TYPE GRINDER

In FIG. 2 the grinder at station No. 1 is shown in diagrammatic perspective. Except for changes in the con-

trol circuit and in the grindwheel and work head as will be particularly noted, this is typical of the installation at all three stations. The unit herein described as a preferred embodiment is perhaps more accurately defined as a type grinder since it includes certain parts that are not necessary at station No. 1 but not inconsistent with the station and so are redundant or superfluous there but are used at station No. 2 or station No. 3.

Each grinder comprises a frame which is indicated generally at 10 and which may be of any suitable design and construction, preferably being duplicated at each of the three stations. A protective enclosure or housing is mounted upon the frame as shown in FIG. 2 to enclose the moving parts, both for safety and to confine splatter of coolant and debris produced in the grinding operation. The housing may be of any suitable shape and size. The grinder includes panels on which are mounted external controls.

One of the major elements of the machine is the grindwheel assembly shown in side elevation in FIG. 3 and diagrammatically in FIG. 12 in its relation to other elements of the grinder. This assembly comprises grindwheel 12 attached on the upper end of spindle 14 rotatably mounted in hydrostatic bearing 15. On the lower end of spindle 14 is carried a pulley 16 over which passes one or more belts 17. These belts also pass over a pulley on the output shaft of electric motor 18 (or 2MTR of FIG. 22), of any suitable type. Spindle bearing 15 and motor 18 are mounted on slide 20. As shown in FIG. 12, slide 20 is provided on one side with dovetail 21 which moves relative to frame 10 on and between a pair of rails 22 mounted on the frame. While means are also provided for moving the grindwheel automatically to a desired position, this arrangement also permits the grindwheel to be moved toward and away from the tool, by manually operated lead screw 24 passing through a fixed nut, not shown, on the slide. The lead screw extends forwardly of the grinder and is provided at one end outside of the housing with hand wheel 25 by means of which the lead screw may be rotated.

The axis of revolution of grindwheel 12 is a vertical axis designated as Z_3 which is parallel to and spaced from principal axis Z. The movement of the grindwheel assembly produced by hand wheel 25 and lead screw 24 is toward and away from Z axis along the Y axis.

Means are provided for holding a cutter to be ground and for moving the cutter over a predetermined path relative to grindwheel 12, such means being shown in detail in FIGS. 3-6 and 9. The assembly of these parts is shown in a diagrammatic perspective in FIG. 12.

A cutter 26 to be ground is illustrated in FIGS. 9, 10 and 12 as being mounted in work holder 27 which in turn is mounted in work head 28. Work holder 27 is essentially a sleeve having at one end a central bore of a reduced diameter to receive the cutter shank. A plurality of such holders are provided at each station, each holder having a bore of selected size in order to receive the shank of a particular size of cutter 26. The outside diameters of all holders are the same to fit into work head 28 as in FIG. 9 so that the holders are in effect adapters which enable work head 28 to receive cutters of different diameters and lengths and hold them for proper grinding engagement with grindwheel 12.

Details of work head 28 are shown in FIG. 9 wherein it will be seen that rotor 30 is mounted to turn within the fixed body of work head 28. The rotor has a sleeve-

like configuration with an annular gear body 31 extending around the periphery of the rotor. Gear body 31 carries gear teeth 32 by which the rotor is driven. The opposed radial faces of gear 31 serve as axial thrust bearings and ride in contact with bearing blocks 33 at opposite sides of the gear. The cylindrical surface of sleeve 30 at either side of gear 31 is a radial bearing and is in contact with a bearing block 33. Lubrication for these bearing surfaces is provided by hydraulic line 35 connected to the work head and supplying lubricating fluid under pressure to a network of distribution passages 35a, as shown in FIG. 9. A dynamic oil seal 34 is held in the work head at each end of rotor 33, and rotor 30 is provided with a hydrostatic type of bearing. A fluid return line is shown at 35c.

Inside rotor 30 is abutment ring 36 which is slidably received within the rotor and held in place by lock ring 37 which is externally threaded and screwed into the end of rotor 30 to hold abutment ring 36 in place. At the inner end of the abutment ring is a contractable annular chuck 38 which is held between abutment ring 36 and annular piston 39. When operating fluid under pressure is introduced from line 35 through passages 40a to annular space 40 around the piston, piston 39 is forced upwardly in FIG. 9 against chuck 38. The inclined surfaces on the opposite ends of chuck 38 engaging abutment 36 and piston 39 cause the chuck to contract and grip tool holder 27 as the piston moves up. When fluid pressure in annular passage 40 is released, the resilience of the parts causes the chuck to expand and release the tool holder.

Rotor 30 rotates about its longitudinal axis which is coincident with and establishes cutter axis T. Since this axis is often vertical during grinding, it is often referred to as the Z_1 axis, but is identified herein as the T axis. The rotor is driven by hydraulic motor 42 mounted on work head 28, hydraulic fluid under pressure being circulated to and through the motor by the hydraulic lines (not shown) connected to the motor at ports 43. The output shaft 44 of motor 42 is connected by coupling 45 to gear 46 on shaft 46a which is rotatably mounted in the work head by suitable radial and thrust bearings, as shown in FIG. 9. Gear 46 meshes with and drives gear 32 on rotor 30.

Means are provided for supporting and moving work head 28 in three dimensions in order to provide the necessary movement of tool 26 held by the work head to attain the desired grinding by the grindwheel. As a part of this supporting means for the work head, the work head is provided on one side with guide block 48 (see FIG. 6) which has in one face a groove adapted to receive slidably dovetail 50a on mating block 50. This structure permits relative sliding movement in a straight line between block 50, which as will be seen may be considered as relatively stationary, and work head 28. This slide is designated as the X-axis offset because when the work head is in the grinding position shown in FIGS. 6 and 12, the motion at the sliding connection between blocks 48 and 50 is horizontal and parallel to the Y axis whereby the cutter axis can be traversed along the Y axis and also offset horizontally from the Z axis for grinding.

Sliding movement of block 48 with respect to block 50 is controlled by a lead screw, not shown in detail in the drawing, but which is threaded into a traveling nut secured to block 48 and which is manually rotated by knob 52. By rotation of knob 52 in one direction or the

other, cutter 26 can be accurately moved along the Y axis and positioned as desired.

Block 50 is joined to support leg 51 by a second similar dovetail connection at 53 perpendicular to the slide between blocks 48 and 50. When in the position shown in FIG. 6, block 50 can be adjusted vertically with respect to leg 51 to accommodate different sizes of cutters. This sliding connection is non-functional from the standpoint of moving and shaping the cutter during grinding operations and is provided essentially as a means for achieving a desired dimensional relationship between the work head and the X axis or between the cutter and the grindwheel.

Work head 28 is supported by leg 51 for angular movement about the horizontal x axis, referred to as A rotation. For this purpose, the lower end of leg 51 is bored, as shown in FIG. 6, to receive pin 54. The pin has a tapered shoulder which in cooperation with an opposite taper on washer 55 adjoining clamp nut 55a connects the pin nonrotatably to leg 51. Pin 54 projects beyond leg 51 where it is received in bearings 57 which establish rotation of pivot pin 54 and the parts mounted thereon about the horizontal X axis.

Bearings 57 are carried in the upwardly extending leg of an L-shaped bracket 58. The lower leg of bracket 58 extends horizontally and has in its undersurface a recess with converging side walls that cooperate with dovetail 59 to provide a sliding connection between the bracket and arm 60 of which dovetail 59 is an integral part. Movement of bracket 58 and parts supported thereby is rectilinear and horizontal, and is controlled by lead screw 61 having a threaded connection at lug 58a to bracket 58 and rotatably mounted in arm 60, the lead screw being manually rotated by thumb screw 63.

The sliding connection between bracket 58 and arm 60 provided by dovetail 59 is the second of two slides primarily affording controlled rectilinear movement of work head 28. Movement produced at this slide is along the X axis whereby tool 26 can be traversed along the X axis to accurately position the tool for grinding operations. This is the movement designated "Y axis offset" in FIG. 15.

During any such traversing movement, work head 28 and elements 48, 50, and 51 supporting it on angle bracket 58, move horizontally as a unit. Angular movement of the work head about the X axis relative to bracket 58 and arm 60 is effected by double-acting hydraulic cylinder 64 which is pivotally connected at 65 to leg 51. A piston in cylinder 64 may be moved in either direction within the cylinder by admitting hydraulic fluid under pressure into a selected end of the cylinder. Attached to the piston, not shown in the drawings, is piston rod 66, the outer end of which is pivotally connected at 67, as shown in FIG. 3, to a fixed lug on the face of bracket 58. Since the lower end of the piston rod 66 is fixed at 67, fluid admitted into the lower end of cylinder 64 moves the cylinder downwardly with respect to the piston and rocks the work head counter-clockwise as viewed in FIG. 3 from the upright position shown in FIGS. 3 and 12. This movement is the A rotation about the X axis and brings the longitudinal axis T of cutter 26 into a horizontal position and, often, into coincidence with the Y axis. The longitudinal axis of cutter 26 is horizontal at the initial or starting position of the various grinding cycles, as shown in FIGS. 11a and 12a.

Angular movement of the work head and cutter away from this initial position in a clockwise direction, when viewed as in FIG. 3, is typically 90° but may be less than 90°. In order to control the angular movement of leg 51 and the cutter mounted in the work head, leg 51 is provided with a pair of adjustable stops 68, shown in FIG. 11. These stops are movable within an arcuate slot 69a in quadrant plate 69 which is attached to and movable with leg 51. The adjustable stops may be clamped in the slot in selected positions to engage a fixed stop 70 mounted on the upper surface of bracket 58, as shown in FIG. 11. Stop 70 carries an index which cooperates with calibrations along the slot in quadrant plate 69 to indicate the angular swing of the work head about the X axis. In other words, the amount of A rotation can be read directly at the index on fixed stop 70.

Horizontally extending arm 60 of the work head support carries at one end a spaced pair of radial bearings 72 (FIG. 6) by which the arm is rotatably mounted upon fixed pivot pin 73. The lower end of pivot pin 73 is clamped in a horizontally projecting portion of platform 75. Pin 73 has a taper 73a; and clamp nut 76 bears against collar 77 having an opposite taper to that on the pin whereby tightening nut 76 clamps arm 75 to pivot 73. The axis established by pivot pin 73 is a vertical axis and becomes the Z axis of the grinder. Arm 60 swings about this axis; and the longitudinal axis T of cutter 26 when vertical, can be brought into coincidence with the Z axis, or offset therefrom, by turning hand wheel 52 or 63 to effect movement of work head 28 at slide 48 or slide 59, respectively, as required.

Platform 75 is mounted on the upper end of post 80, as shown particularly in FIG. 6, for either or both swinging movement about the vertical axis of post 80, which axis is designated as the Z₂ axis, and vertical movement along this Z₂ axis. Platform 75 moves with it all of the structure mounting work head 28 on the platform.

Means for effecting these last two movements are shown in FIGS. 4 and 5, particularly, while reference to FIG. 12 further illustrates the relationship of certain of the parts.

Considering first the vertical movement effecting a traverse along axis Z or Z₂, it will be seen from FIGS. 5 and 6 that post 80 is hollow and closed at the upper end by platform 75. Entering the central bore of post 80 from the lower end, is piston 81 which is provided at its upper end with suitable sealing means indicated generally at 82. The lower end of piston 81 is mounted in a thrust bearing 83 supported in a pedestal structure on frame 10. The introduction of hydraulic fluid under pressure into the interior of post 80 above fixed piston 82 causes the cylinder space to expand, raising post 80, platform 75, and the parts supported thereon.

Post 80 is mounted in a manner to provide for both axial and angular movement. The post is supported laterally and guided in a vertical direction by a linear ball bearing structure 85 comprising a fixed sleeve holding a plurality of ball bearings which engage the outside surface of post 80 to permit both types of motion relative to sleeve 85. Bearing sleeve 85 is contained within structural housing sleeve 86 which, as shown by FIG. 5, is supported upon a portion of frame 10.

Angular movement of post 80 about the axis Z₂ of piston 81 is imparted to it through bell crank 88 which is nonrotatably connected to post 80 at the lower end thereon. One arm 88a of the bell crank carries a pres-

sure pad 89 having a vertically extending face along which rides roller 90. Roller 90 is pivotally mounted on one arm of bell crank 91 which is pivotally mounted in bearing 92 to swing about a horizontal axis. Bearing 92 is a journal bearing attached to frame 10 by a depending bracket 92a.

The other arm of bell crank 91 is pivotally connected to piston rod 93 connected to a piston movable within feed cylinder 94. The lower end of feed cylinder 94 is pin-connected at 95 to a bracket connecting the cylinder to frame 10.

Referring to FIG. 12, it will be apparent that when hydraulic fluid under pressure is introduced into the upper end of feed cylinder 94, the piston therein is moved downwardly in a direction to move connecting rod 93 downwardly and rotate bell crank 91 in a counterclockwise direction as viewed in FIG. 12. This movement of the bell crank is transmitted through roller 90 to pressure pad 89 on arm 88a of bell crank 88. The result is to rotate the latter bell crank and the attached post 80 in a clockwise direction about axis Z_2 , viewed from above. This motion is termed a "feed motion" because, as will become apparent later, it feeds the cutter into grinding engagement with the grindwheel; and when reversed, feeds the cutter away from the grindwheel after a grind cycle is completed.

This reverse movement or outfeed is produced by an air spring which consists of cylinder 97 having a piston therein connected by rod 98 to bell crank 88 at the end of arm 88b. One end of cylinder 97 is pin-connected to the frame at 97a in any suitable manner. The action of the air spring provided by cylinder 97 and the piston therein is such as to bias the work head away from the grindwheel at all times except when feed cylinder 94 is supplied with fluid which positively produces an infeed movement. The amount of infeed movement imparted to the cutter is adjustable. It is controlled by a linkage comprising arm 100 which is secured to the rock shaft in bearing 92 carrying bell crank 91 so that the angular movement of arm 100 is equal and simultaneous with that of crank 91. Link 101 connects arm 100 to rocker block 102, the rocker block being pivotally mounted at 103 on the frame.

From FIG. 4 it will be seen that downward movement of connecting rod 93 in a direction to cause infeed movement of the cutter, rotates bell crank 91 and arm 100 in a clockwise direction, as viewed in that figure. This rocks block 102 around pivot 103 in a counterclockwise direction, and the angular movement of the rocker block is limited by its engagement with hydraulically controlled stop 104. In the type machine, there are two similar stops 104 and 105 (FIG. 12) which can selectively be brought into position to engage rocker arm 102 by pressurizing an associated hydraulic cylinder 106, there being one cylinder connected to each of the stops 104 and 105. When hydraulic fluid under pressure is introduced into a cylinder 106, the associated stop is fully extended; and the position of the stop when fully extended is regulated by a micrometer-type lead screw 107 having a thimble located on the control panel of the machine where the operator can rotate the thimble of the micrometer to adjust the range of infeed movement. Stops 104 and 105 are alike and limit the extent of infeed of the cutter, and either one may be adjusted to a lesser or greater amount of infeed travel.

Although the type machine illustrated has two stops 104 and 105 which can be selectively actuated, as will be further explained, the two stops are used only at stations No. 2 and No. 3. The grinder at station No. 1 requires only a single stop; and the other stop may be omitted at station No. 1 as it is superfluous and becomes nonfunctional there.

Vertical movement of the work head and all the elements mounting the work head for necessary movement may be regarded as a traverse along either the Z or Z_2 axis. The range of such traverse in a vertical direction is variable and adjustable stops are provided to determine the upper and lower limits. As already mentioned, hydraulic fluid under pressure is introduced into the cylinder space provided within post 80 to lift the work head and its supporting structure. Upward movement of these parts ceases when bell crank 88 comes into contact with collar 110 threaded onto the lower end of stationary sleeve 86 which is fastened to frame 10. The level of contact between these two elements can be varied by rotational movement of collar 110, shown in FIG. 5. Because of the screw thread mounting, rotation of the collar shifts the collar vertically with respect to stationary sleeve 86 and thus changes the elevation of the under face of the collar at engagement by the upwardly moving bell crank 88. Hard metal wear pads 111 are placed on bell crank 88 to maintain accuracy.

Collar 110 is rotated by means of hand wheel 112 at the front of the machine and which is connected to the collar by any suitable mechanism, not shown in the drawings, but indicated diagrammatically at 113 in FIG. 12. This vertical movement of the column supporting the work head is utilized, as will become further apparent, to locate the cutter vertically with respect to the grindwheel at the starting position of the grind cycle. The required range of adjustment provided by collar 110 is relatively narrow.

A much wider range of adjustment is provided in the stop which determines the lower limit of the Z_2 traverse movement downwardly. This latter stop comprises a pair of L-shaped brackets 115 which straddle stationary piston 81 in a position to engage with their upper faces the lower face of bell crank 88 when the work head and its supporting column descend along axis Z_2 .

The two brackets comprising stop 115 are connected to traveling nut 116 which is threaded onto lead screw 117 seated in a radial and thrust bearing 118. Accordingly, rotation of lead screw 117 causes nut 116 and the attached limit stops 115 to move up or down, stop 115 being shown at the lowermost position in FIG. 5. Lead screw 117 is rotated by hand wheel 120 at the side of the machine. The shaft carrying hand wheel 120 is connected to shaft 117 by a sprocket and chain drive indicated diagrammatically at 121 in FIG. 12.

The extent of downward movement of the work head and cutter from their initial position is determined by the length of the flute to be ground. Accordingly, the hand wheel 120 is referred to as the flute length control, as it determines the length of the flute ground or the length of the cutter that is finished to a given outside diameter. The range of movement of stop 115 is determined by dimensions of the cutters to be handled and is of greater range than the movement of upper limit stop 110.

The type machine illustrated herein also includes means for producing an angular swinging movement (C rotation) of arm 60 and the parts supported thereby, including the work head and the cutter, about the Z axis relative to platform base 75. This means (FIG. 7) comprises hydraulic cylinder 125 which is pivotally supported by bracket 125a attached to platform 75. The piston rod extending from the cylinder is pin-connected to bracket 126 rigidly attached to arm 60 so that motion of the piston rod relative to cylinder 125 causes relative angular movement of platform 75 and arm 60 about the Z axis.

Stop means are provided for limiting rotation about the Z axis, herein referred to as C rotation, from the initial or starting position. This stop means comprises hydraulic cylinder 127 having a normally lowered plunger 128 that extends from opposite ends of the cylinder. When the plunger is extended upwardly, as shown in FIG. 12, as a consequence of introducing hydraulic fluid under pressure into cylinder 127, plunger 128 is placed in the path of stop 130 mounted on arm 60. Contact of the stop with the plunger limits angular movement of arm 60. Stop 130 is a projection on stop ring 130a which is adjustably mounted on arm 60 to turn about the Z axis. Stop ring 130a has an arcuate slot through which passes lock screw 131, which arrangement, as shown in FIG. 6, allows the stop to be clamped to the arm in selected adjusted positions.

When plunger 128 is lowered, a different limit to angular movement of arm 60 is established, angular movement then being limited by engagement of lower stop 132 with the lowered plunger 128 projecting below cylinder 127. Stop 132 is a projection on stop ring 132a mounted on arm 60. Stop ring 132a (FIG. 6) is a duplicate of stop ring 130a but mounted at a lower position on arm 60. It likewise is angularly adjustable on arm 60 about the Z axis, being held in any adjusted position by means of clamping screw 133.

Cylinder 127 and stops 130 and 132 are shown in the type grinder. However, these stops are not used at station No. 1. Therefore the two stops as well as cylinder 125 may be omitted at station No. 1, in which case arm 60 and platform 75 are locked together by bolts or the like. However, these stops and cylinder 125 are used at both stations 2 and 3 to limit movements of the cutter as will be later described.

As an element of the means for accurately locating the cutter at the beginning of a grind cycle, there is provided locator 135, shown in FIG. 6. Cutter locator 135 is attached to the upper end of rod 136 which moves vertically along the Z axis, movement of the rod and locator being effected by introduction of fluid under pressure into double-acting hydraulic cylinder 137. The locator and its actuator 137 are mounted within and coaxially of pivot 73.

In FIG. 6 the locator is shown in lowered position where it does not interfere with advancing the cutter into grinding engagement of the cutter with the grindwheel; but the actuator 137 raises the locator into position to engage the end of the cutter for properly locating the cutter at the beginning of a grind cycle.

In order to keep grindwheel 12 accurately shaped, each station is provided with suitable means for dressing the grindwheel. Since the wheel dressing means are not novel and constitute no essential part of the present invention, such means are shown only diagrammatically in FIGS. 2 and 12. Briefly, dressing means com-

prise adjustable slide 140 on which is mounted the dressing tool 141 as is diagrammatically indicated in FIG. 12. The wheel dresser may be of any suitable known design and performs the normal function of periodically dressing the grindwheel to the desired size or shape after a given number of tools are ground. This wheel dressing means is mounted upon the grindwheel supporting slide 20 to move therewith. Since the grindwheel at station No. 2 is a shaped wheel, the dresser assembly at that station includes a cam (not shown) controlling movement of the dresser diamond to obtain the desired wheel shape. The wheel may be dressed at any time by operating manual controls; but periodic automatic dressing of the grindwheel is provided for in the control system, as will be seen by reference to the control circuits in FIGS. 23-25 and the sequence charts in FIGS. 26-28.

GRINDER UNIT AT STATION No. 2

The type grinder so far described is suitable as illustrated for operations performed at station No. 1, even though the type grinder has excess parts that may be omitted since they are nonfunctional at station No. 1. However, these excess parts are utilized at stations No. 2 and No. 3, as has already been pointed out or will become apparent from the description of the operations performed at these two stations.

The grinder at station 2 is modified, as will now be described, from the type unit. The first and most obvious change in the grinder is in the grindwheel itself. As may be seen in FIG. 17 or 17a, the grindwheel 12a is thicker than wheel 12 at station No. 1 and is provided with at least one, and preferably two, circumferential ridges. A shaped wheel of this character is desired in order to provide the gashes required at the base of the lands on the cutter. The mounting of grindwheel 12a conforms in all respects to the mounting already described.

The other principal modification of the grinder at station No. 2 is a change in the construction of the work head. Work head 28a, illustrated in FIGS. 19, 20 and 21, differs from the previously described work head 28 by the addition thereto of cutter indexing means. The purpose of this indexing means is twofold. In the first place, the indexing mechanism causes the tool to be rotated forward periodically through an angle equal to the angle between successive lands or flutes on the cutter in order to orient the cutter with respect to the grindwheel for grinding successive lands. In the second place, in conjunction with a tooth rest during a grinding operation it may permit reverse rotation of the cutter being ground so that the grindwheel follows a helical path on the cutter during Z traverse down, thus causing the contact between the grindwheel and the cutter to travel along a flute or a land of the cutter.

This indexing mechanism shown in FIGS. 19 and 20 comprises an idler gear 145 which meshes with teeth 32 on body gear 31 of the rotor which turns the cutter. Idler 145 is keyed or otherwise mounted upon shaft 146 which is mounted in suitable bearings in the work head. Also carried on shaft 146 is a second idler gear 147 which meshes with gear 148, as shown in FIG. 20. Gear 148 is mounted on shaft 150 to which the gear is drivingly connected through a one-way or overrunning clutch indicated generally at 149. Clutch 149 may be of any suitable type that drives forwardly only from a single position. As an example of such a clutch, the one

15

illustrated comprises a bearing sleeve 250 keyed or otherwise nonrotatably secured to shaft 150. On this sleeve gear 148 is journaled. Disc 252 is nonrotatably secured to sleeve 250. A single drive pin 253 is slidably mounted in a lug on gear 148 and is urged by leaf spring 254 against disc 252. The disc has a single shoulder that engages the pin to transmit power from the gear to the shaft in one direction; but when the gear is rotated reversely by motor 42, the pin is cammed outwardly by disc 252 against spring 254 which yields and allows the gear to turn without turning the disc and the shaft. This permits the motor to turn the cutter for indexing between grinds as well as turning it when grinding to follow a land.

Shaft 150 is mounted in suitable bearings in the work head and has keyed to it, or otherwise attached in a nonrotatable manner, a pair of motor lock discs 151 and 152. Cam 151 has a cylindrical peripheral surface in which there is a single recess 151a. Cooperating with this disc is plunger 154, the body of which is also a spool valve that reciprocates radially of the cam in a ported sleeve 155. The outer end of plunger 154 is connected to piston 156 reciprocating in a bore in the body of work head 28a and serving as a double-acting hydraulic valve actuator. Hydraulic fluid under pressure at one side of piston 156 exerts a force on piston 156 which urges plunger 154 inwardly against cam 151; fluid pressure at the other side of the piston retracts the plunger. This first force causes the nose 154a of the plunger to enter recess 151a when the recess is aligned with the end of the spool to lock disc 151 against rotation. The hydraulic motor and the tool holder are also locked in place when the plunger is advanced. A change in spool position by hydraulic pressure in piston 156 effects a change in connections between sleeve ports 157 which are in the control system including an air logic circuit, described later.

The gear ratio between rotor gear 31 and shaft 150 is such that disc 151 makes one revolution for each revolution of the tool holder and the cutter therein. Thus, when plunger 154 is in the advanced position shown in FIG. 20, the spool valve position generates a signal to the logic circuit which indicates that a full grind cycle has been completed. Also, the motor and tool holder are locked in position against rotation.

Disc 152 is a similar disc but it has a plurality of recesses 152a, as may be seen in FIG. 1. The number of recesses in the cam is equal to the number of flutes on the cutter being ground. Disc 152 cooperates in a manner similar to that just described with plunger 160 which likewise has a body acting as a spool valve that reciprocates in a ported sleeve 161, the ports therein being connected to the air side of the logic circuit. The combined index lock plunger and valve is operated by a double-acting hydraulic actuator provided by piston 162 on the end of the plunger and reciprocating in a bore in the body of work head 28a. Plunger 160 is urged, by hydraulic pressure applied to one face of piston 162 toward disc 152 and is retracted by pressure applied to the opposite face. As will be apparent from later description, entry of the nose 160a of spool 160 into a disc recess 152a, as shown, shifts the spool valve from its alternate position and generates a signal indicating that grinding at one flute has been completed and the next flute should be rotated into grinding position while at the same time locking disc 152 and shaft 150 against rotation.

16

It will be noted in FIG. 21 that each recess 152 has a preliminary step 152b at which plunger 160 advances to an intermediate position before fully advancing into a recess. When at this step 152b, spool 160 generates a signal to the logic system that slows down hydraulic motor 42 in approach to the end of its indexing motion and preparatory to entry of nose 160a into the deeper portion of the recess 152a at which time indexing motion of the tool holder and cutter ceases.

The number of recesses 152a in cam disc 152 equals the number of lands on a cutter and the angular spacing of the recesses corresponds to the angular spacing between successive cutter lands. It thus becomes necessary to supply a different lock disc 152 for each different number of flutes on the cutters being ground. In FIG. 21, the disc is suitable for grinding an end mill or other cutter having four flutes or lands. For a cutter having six lands the disc will have six recesses 152a. In order to provide ready access to the interior of work head 28a for changing discs 152, a removable cover is placed over an opening in the housing opposite the end of shaft 150, as shown in FIG. 20. The discs are properly oriented on shaft 150 by index pin 164 carried by a disc fastened on shaft 150 and which fits into a recess 152c in the face of the disc.

Grinder at Station 3

The grinder unit at station No. 3 is designed for grinding primary and secondary relief angles along the lands of the cutter. This is accomplished with a grindwheel having a cylindrical surface duplicating the grindwheel 12 at station No. 1.

In addition to the structure already described in connection with the type grinder for station No. 1, there is added a tooth rest assembly indicated generally in FIG. 7 at 165. This tooth rest assembly comprises a blade 166 having a pointed end which engages the side face of a land on the cutter and against which the cutter presses in order to present a desired portion of the land to grindwheel 12. Blade 166 is clamped in a holder 167 mounted on post 168. The post in turn is clamped in a split collar structure 169a on one end of arm 169.

As may be seen clearly in FIG. 7, the arm 169 is supported on the ends of two parallel leaf springs 170 which are each rigidly mounted on frame 10 at the other end of the spring by attachment to a post 171. The two posts 171 provide two locations about which arm 169 and blade 166 can swing with respect to the frame. The result is a parallelogram type of linkage, often referred to as a four-bar linkage. This controls the path of the tip of blade 166 moving away from engagement with a cutter when it becomes necessary to retract the blade to permit indexing or other movement of the cutter.

The tooth rest assembly also includes angular operating arm 173 which is pivotally mounted upon grinder frame 10 at post 174. Arm 173 is connected to arm 169 by a ball and socket connection 173a. Angular movement of operating arm 173 about post 174 to shift blade 166 is effected by hydraulic actuator 176 which is a double-acting hydraulic cylinder having an articulated piston rod 177 connected at 178 to angular arm 173.

The tooth rest assembly is illustrated in FIG. 7 in one of its two operative positions. In this position, the thrust of the cutter against the end of the blade 166 is resisted by actuator 176. When it is necessary to retract the

blade to permit rotation of the cutter, piston rod 177 is forced outwardly of cylinder 176 (upwardly in FIG. 7) by hydraulic fluid under pressure admitted into the cylinder. Arms 169 and 173 then swing counterclockwise about pivot 174 to retract the blade to the dotted line position 166b. The range of retracting movement of blade 166 is limited by the range of travel of piston rod 177.

Blade 166 is designed to engage a land of a cutter at a second operative position 166a which is spaced a short way from the full line position illustrated. This is accomplished by actuator 176 by the same admission of hydraulic fluid under pressure just described. However, to establish this second operative position the outward movement of piston rod 177 is limited by engagement of the arm with the hydraulically controlled stop 180. Stop 180 is a plunger projecting from hydraulic cylinder 181 which, when advanced by fluid pressure and held in the position shown in FIG. 7, limits the counterclockwise rotation of arm 173 about pivot 174 to place blade 166 at the dotted line position 166a. When full retraction of blade 166 is desired, hydraulic fluid is exhausted from cylinder 181 and stop 180 moves freely under contact with arm 173. The position of the tip of blade 166 in this second operative position can be adjusted by means of an adjustable stop 182 carried on the outer end of arm 173 and engageable with movable stop 180.

Electrical Circuit

The electrical circuit is illustrated in schematic form in FIG. 22. This circuit is common to all three stations and all components shown are used. Others may be added as desired.

The components of the circuit and their connections will be apparent, without detailed discussion, from inspection of FIG. 22. Briefly, there are five individual motors (MTR) which, respectively, drive a hydraulic pump 185 to provide power for the hydraulic system, drive the spindle 14 upon which grindwheel 12 is mounted, drive a pump for the coolant system as is common practice in machine tools, drive a fan in the heat exchanger unit for the coolant, and a fan for the mist collector. These last three motors are drive elements that are not directly related to the main invention and so are not described in detail.

The electrical circuit is typically connected to any suitable source of domestic power, for example a 440-460 volt source of three-phase alternating current. The motors are started by individual magnetic starters MS. In order to operate these starters, power is taken from the electrical supply lines ahead of the magnetic starters and the voltage is reduced through a transformer TR to a lower value for which conventional components are suited, for example 110-115 volts. This lower voltage is supplied to the control circuit shown in FIG. 22 to the left of the motors. It is in this control circuit that the various start and stop push buttons PB, and selector buttons are located. These buttons are manually operated to start and stop operation of the grinder and also to control certain operations. The circuit also includes pressure-responsive switches (PS) and solenoids (Sol) which cause certain operations to occur in the proper sequence, as will be further explained. These pressure-responsive switches are actuated by hydraulic pressure in the control system described below.

Control System

The grinder at each of the three stations is provided with its own automatic control system which completely automates all operations. Each station has its own sequence of operations in order to produce at that station a particular series of grinding operations. Accordingly, the programming of operations is different at each station, but the control systems have certain basic similarities.

The control system for station No. 1 is illustrated in FIG. 23. It is an air-hydraulic system. Not only may the control system be changed in detail as desired, but a different type of system may be chosen since an all-electrical system may be utilized. Hence the details of the control system are not limitative on other features of the grinder.

Referring to FIG. 23, there is shown as the extreme right of the diagram in an upwardly extending row the hydraulic power units, all of which have been described above, that produce and control the motions of the work head and the cutter held therein. Hydraulic fluid under a suitable pressure, typically 150 p.s.i., is supplied to these power units from pump 190 driven by electric motor 191, also designated as IMTR in the wiring circuit of FIG. 22. The flow of hydraulic fluid to the power units is controlled by a series of air-pilot valves 192-198 arranged in an upwardly extending row above pump 190. These flow control valves 192-198 are individually connected to a power unit, as shown schematically in FIG. 23. The hydraulic lines are shown in the diagram by the heavy connecting lines.

Valves 192-198 are four-way, two-position valves, which in one position provide for forward flow of hydraulic fluid to the connected power unit control and in the alternate position permit exhaust or reverse flow of fluid under pressure. In some cases, as 193, 195, and 196, reverse flow is under pressure to reverse the direction of motion of the driven unit.

Flow control valves 192-198 are pilot controlled valves actuated by air pressure applied to the valves by the air side of the control system illustrated to the left of the valves in FIG. 23. This air supply system may be considered to comprise two major parts. One of these is the units enclosed within dotted rectangle 200. These units are the programming portion of the air-hydraulic control system and may be conveniently mounted on the logic circuit panel indicated in FIG. 2 where all units are readily accessible. These units constituting the logic circuit are of the types shown in the legend for FIG. 23. Illustrative of the units suitable for this logic circuit are those manufactured by the Aro Corporation of Bryan, Ohio. The units are illustrated in detail and their operation described in the catalogue entitled "Pneumatic Logic Controls," issued by the Aro Corporation of Bryan, Ohio, in 1966, to which reference may be made.

The supply of air under pressure to the logic control units is controlled by a group of air supply valves indicated collectively at 205 in FIG. 23. Air for the control system may be derived from any suitable source, indicated diagrammatically at 206, supply of air to the system being controlled by a master valve 207 that is solenoid operated.

Valves 205 are two-position, mostly three-way, valves which in one position provide for forward flow of air, and in the alternate position shut off the flow of

air, with the exception of the selector valve for manual or automatic operation which controls the mode of operation. Where pressure is to be released, the valves vent to the atmosphere. Valves 205 are diagrammatically indicated as controlled manually, mechanically, or electrically, as desired, and the mechanical control may be by cam, limit stop, or air pilot.

Grinding Operation at Station No. 1

A typical grinding operation at station No. 1 is shown graphically in FIG. 16 wherein three successive stages of grinding a ball end mill are illustrated. Assuming that a ball end mill is to be ground as shown in FIGS. 13-14, the nose end of the mill is ground to place the cutting surfaces of the lands in a hemispherical surface while the cutting edges at the sides of the end mill are located in a cylindrical surface having the same radius as the hemispherical surface.

First the cutter or the blank 26 to be ground is mounted in a tool holder 27 as shown in FIG. 10. FIG. 10 shows a ball end mill 26 which has previously been ground and is to be reground or sharpened; but the operation described below applies if a blank is being ground for the first time. The cutter is securely mounted in the tool holder by tightening set screw 27a so that the cutter is gripped by its shank. This loaded tool holder is then inserted in the work head as shown in FIG. 9, chuck 38 being released so that the tool holder can be advanced manually. The tool holder and cutter are advanced until the nose end of the cutter comes into contact with the upstanding leg of locator 135, which may be assumed to be in the raised position. At this time, the cutter is so positioned that its longitudinal axis is horizontal, since the work head is tilted forwardly into the loading position shown in FIGS. 11a and 12a. The machine is now ready for starting the grind cycle.

As a preliminary to the grind cycle, the machine has been started and placed in standby condition. This is accomplished by pressing master start button 2PB (FIG. 22) which energizes the electric circuit and starts motor 191 to bring the hydraulic system up to a predetermined operating pressure. This also energizes master control relay CRM which in turn closes contacts within the relay to energize solenoid A that opens the master air supply or machine start valve 207, thereby pressurizing the air side of the air-hydraulic control system in FIG. 23.

When hydraulic pressure reaches a predetermined point, the pressure responsive switch 1PS closes, thereby energizing the magnetic starter 2MS which starts spindle motor 18, thereby rotating grindwheel 12, and supplies lubricant to the hydrostatic bearings. Now the machine has been started and is on standby. The machine is now ready to start a grind cycle and it returns to this same standby condition to the end of each grind cycle.

Now the operator presses cycle start push button which shifts supply valve 210 and the grind cycle is initiated. The first operation is to supply pressure fluid to cylinder space 40 in the work head causing chuck 38 to grip tool holder 27 and to turn on motor 3MTR supplying coolant under pressure to the grinding area.

Next, locator 135 is moved down by pressure fluid supplied to actuator 137. This clears the way for the cutter to be advanced into grinding engagement with

rotating wheel 12. The work head motor 42 now starts, rotating the tool forwardly.

The infeed of the tool toward the grindwheel now commences. This is C_2 rotation, the result of supplying pressure fluid to infeed cylinder 94. Infeed movement is angular motion about vertical axis Z_2 , moving the Z axis over a short arc to intersection with X and Y axes at a common point. At the time of engagement with the grindwheel, the conditions illustrated in FIG. 16(1) prevail.

At this instant, the longitudinal axis T of the cutter coincides with the Y axis. The X, Y, and Z axes of the machine intersect at a common point which is on the longitudinal cutter axis and is the center of the hemispherical surface to be ground on the end of the cutter. Cutter 26 is being rotated about its own longitudinal axis T, denoted as C_1 rotation in FIG. 12 and 16.

The next movement is A rotation, as the work head turns upwardly about the X axis, while in contact with the grindwheel and while the cutter rotates about its own axis. This A rotation is accomplished by supplying pressure fluid to cylinder 64 which causes the work head 28 to rotate upward from the forward or loading position of FIG. 12a to the raised position as illustrated in FIGS. 3 and 12. The extent of the A rotation is 90° for cylindrical cutters, but is less for tapered cutters. The axis of the cutter moves to the vertical position as in FIG. 16(2) in which the axis is coincident with the Z axis.

The next movement is Z_2 traverse down, which is accomplished by bleeding off at a controlled rate fluid within sleeve 20 and above piston 82. This downward traverse causes the cutter to move vertically along the Z axis while rotating continuously about that axis in contact with grindwheel 12. This continues for a distance determined by the length of the flutes on the cutter and is terminated by engagement of the underface of bell crank 88 with the upper face of limit stop 115. At the end of the downward traverse, a signal is generated by contact with a limit switch that shuts off fluid supply to cylinder 94 and exhausts hydraulic fluid from it. The cutter is now in the aspect shown at FIG. 16(3). The action of air spring 97 now causes a reverse rotation about the Z_2 axis, feeding the cutter out of engagement with grindwheel 12, which continues to rotate.

The next operation is to shut off the work head motor 42, stopping rotation of the cutter. The work head is now raised by an upward Z_2 traverse resulting from introduction of hydraulic fluid under pressure into the upper portion of cylinder 80, thus lifting the column supporting the work head and the cutter.

When the end of the upward Z_2 traverse is signalled, hydraulic actuator 64 is energized to cause A rotation downwardly of the work head, returning the work head from the raised position of FIG. 6 to the loading position of FIG. 11a. This permits the tool holder and tool to be removed from the work head when pressure on chuck 38 is released in response to reaching the end of the downward swinging movement of the work head about the X axis.

At this point, in preparation for return to the standby condition, hydraulic actuator 137 raises axial tool locator 135 into position to engage the next cutter to be ground. Also the supply of coolant to the cutter is shut off.

Normally after the complete grind cycle, the grinder is manually loaded by removing the tool holder and

tool from the work head and another holder loaded with another cutter is inserted in the work head and the grind cycle is repeated. However, after a predetermined number of grind cycles have been completed, the count being maintained by a cycle counter of which the clutch coil is indicated diagrammatically at CCC in the electrical circuit; a signal is generated by the counter which energizes the control system to automatically activate the wheel dresser assembly. This runs the machine through an automatic wheel dressing cycle in which the dressing unit is started, brought into engagement with the grinding wheel, and then retracted after the wheel is properly dressed. After the dressing cycle, the machine is then returned to standby.

At any time the machine may be shut off completely by pressing the master stop button 1PB in FIG. 22 which causes the magnetic starters to be de-energized and break the circuits to all of the motors. This not only stops the supply of electrical energy but depressurizes both the air and the liquid sides of the air-hydraulic control system.

There are various shapes of end mills; and for purposes of discussion here the straight end mill may be considered as being at the opposite end of the range of shapes from the ball end mill, the grinding of which has just been described. A straight end mill has a flat end surface perpendicular to longitudinal axis of the cutter, and this flat surface intersects the cylindrical surface containing the cutting edges of the lands at an angle with substantially no radius between the end and side surfaces. For a cutter of this latter type, the grinding is substantially limited to grinding the flat end and/or cylindrical side surfaces. In order to do this, the intersection of the X and Y axes is located at the intersection of the end and side surfaces of the cutter with the result that there is no grinding during the A rotation up.

This situation is diagrammed in FIG. 26 wherein the outlines of a ball end mill, a plain end mill and a radiused mill are shown. To grind there, the edge of wheel 12 remaining at a given position, the location of the X axis with respect to the locator 135 is at 211, 212, or 213, respectively. The starting elevation of the cutter axis is controlled by setting the upper limit of the Z₂ traverse at 110, 112. Also, the initial spacing from the wheel is changed by an equal amount by control of the X axis offset (FIG. 15) by manipulating handwheel 52 and slide 48. From FIG. 26 it will be seen that the locus of these positions of the X axis moves along a line at 45° to the horizontal and the initial loading position of the cutter axis T.

It will be appreciated that when the work head is tilted down to the loading position, the rectilinear movement of the work head produced by this slide 48 is vertical; but movement produced at the slide displaces the longitudinal cutter axis horizontally. This is identified in FIG. 15 as X axis offset.

A radiused end mill is one in which the flat end surface and the side surfaces are joined by a radius having a value intermediate zero and the radius of the cutter, as this latter value is the radius of the nose of the ball end mill. To grind a radiused cutter, the longitudinal axis of the cutter at the initial position of the work head is adjusted by means of handwheel 52 to bring the longitudinal axis of the cutter initially at some point below the intersection 213 of the X and Y axes by a distance equal to the radius to be ground and less than the radius of the cutter itself.

Except for the initial offset of the longitudinal axis of the cutter along the Z axis away from the X axis, the sequence of grinding operations is basically the same as already described except that a lesser amount of grinding takes place during the A rotation about the X axis.

GRINDING OPERATION AT STATION 2

The typical grinding operation at station No. 2 is shown graphically in FIG. 17 wherein four successive stages of grinding a ball end mill are illustrated. This is an end mill on which the rough grind operations described in connection with station No. 1 have been performed.

The operations of mounting the cutter 26 in the tool holder 27 need not be repeated since the tool holder and cutter as a unit can be transferred from station No. 1 to station No. 2 and mounted in the work head in the way as already described. Again, the tool holder and cutter are advanced until the end of the cutter comes into contact with the upstanding leg of locator 135, which is in the raised position. This is a normal position of the tool locator when the grinder is in standby condition which is arrived at by the same series of operations described above in connection with station No. 1.

At station No. 2, before any grinding is done, the cutter axis is offset horizontally from the Y axis as indicated in FIGS. 15 and 17(1) by the notation "Y axis offset." This offset is accomplished by turning handwheel 63. This action slides bracket 58 horizontally along dovetail guide 59 to place the Z axis at one side of the cutter axis by some predetermined distance which is ordinarily a function of the radius of the cutter. This offset remains constant for all cutters of the same geometric configuration ground at station No. 2.

The air-hydraulic control system for station No. 2 is illustrated in FIG. 24. The scheme of arrangement of the elements in the diagram of the control system is similar to that described above in connection with FIG. 23. Since there are more movements to effect or control, there are additional hydraulic flow control valves over and above those already described in connection with FIG. 23.

The logic circuit which programs the sequence of grinding operations is contained within the dotted rectangle 220. These units in the logic circuit are of the same type employed in the logic circuit of station No. 1, and they in turn are connected to air supply valves at the left-hand side of the diagram, which valves are similar to those shown at station No. 1. Without going into detailed operation of the control system, the sequence of grinding operations resulting from the control system will now be described.

Assume that the grinder is on standby, and that the cutter has been loaded into the work head and properly positioned by contact with locator 135. The machine is now ready to start a grind cycle; and to do this the operator presses the cycle start push button which changes the position of supply valve 210 in the air side of the control system and the grind cycle is initiated. Pressure fluid is supplied to cylinder space 40 to close chuck 38 on the work holder. Also actuator 137 moves locator 135 down, clearing the way for cutter 26 to be advanced into grinding engagement with grindwheel 12.

Next C rotation stop 128 is placed in the lower position to engage stop 132 which limits angular rotation about Z axis. The stop position automatically selects the deep feed for the cutter by pressurizing a selected cylinder 106 associated with a stop 104 or 105. Next, A rotation of the cutter upwardly about the X axis occurs as shown in FIG. 17(1). The cutter moves through an angle which is a function of the helix angle of the cutter and is substantially less than 90 degrees. Since the cycle normally ends with the work head in the lowered position with respect to traverse along the Z_2 axis, the cutter is now ready for infeed toward grind-wheel 12a. At the end of the infeed stroke, the parts are as shown in FIG. 17(2). Now C rotation takes place, revolving the cutter about the Z axis until lower stop 132 engages plunger 128. At the end of this rotation, the cutter 26 is being ground by the lower ridge on wheel 12a as shown in FIG. 17A, the rake angle being applied to the face of one land while tertiary relief or flute blending is being ground on the opposite side of the flute on the adjoining land. This grinding is all limited essentially to the ball end of the cutter. These areas are indicated by the legends in FIG. 13. The angular swing of the cutter about Z axis is limited by the engagement of stop 132 with stop 128; and when this engagement takes place a signal is generated causing feed-out movement to take place. This is movement about axis Z_2 which retracts the tool and work head to disengage the tool from grinding contact with the cutter. This outfeed movement is followed by return C rotation, this being the movement about the machine Z axis that restores the cutter axis to its initial position parallel to the Y axis. At this point one complete gashing grind has been completed, that is the rake angle upon one land and the tertiary relief on an adjoining land have been ground at the nose of the cutter.

If a center-cutting end mill is being made, the next operation is a notching of the same land on which the rake angle has been ground. This notching grind is accomplished automatically by the logic circuit which brings about a Z_2 traverse up which brings the nose of the cutter opposite the upper ridge on grindwheel 12a, as shown in FIG. 17(4) and in FIG. 17A in the broken line position of cutter 26 in the latter figure. Now C rotation stop 128 rises to the elevated position and selects the shallow feed position of feed stops 104 and 105; and the subsequent C rotation is through a smaller angle than the deep rotation previously required for the gash grind. This latter C rotation is limited by engagement of stop 130 with plunger 128. Preceding the C rotation, there is infeed movement of the cutter, which is C_2 rotation, which brings the nose of the cutter into engagement with the grindwheel. During the subsequent C rotation, a notch is ground in a land at the extreme tip of the cutter, as indicated in FIG. 13.

At the end of the swinging movement of the C rotation, a signal is generated which causes outfeed movement, that is return rotation about the Z_2 axis, which is followed by return C rotation which again returns the longitudinal axis of the cutter to a position in which it is parallel to the Y axis. This return rotation is followed by Z_2 traverse down so that the cutter has now returned to its initial starting position with A rotation up. In a complete cycle of operations, both a gash and a notch have been ground on one land.

At the end of the Z_2 traverse down, fluid pressure is reversed on pistons 156 and 162 (see FIG. 20), moving

them outwardly away from lock discs 151 and 152, respectively. This movement not only shifts spool valves 154 and 160 but unlocks the index motion of the work head so that work head motor 42 is now freed to rotate the tool holder and cutter. The work head motor drives at high speed until nose 160a of the index lock moves into shallow recess 152b, slowing down the motor, the motor stopping completely when the nose enters the deep recess 152a. Since there is but a single notch 151a in disc 151, spool valve 154 is held in the retracted position as the nose of the valve body rides against the periphery of the disc. Valve 154 signals the end of a grind cycle, which requires one complete revolution of the cutter; but valve 160 signals the end of each indexing movement that rotates the drill by the angle between successive flutes.

With the index lock in the next successive recess 152a, the tool becomes stationary and the cycle of operations described above to accomplish a gash on the second land are repeated in the sequence given.

Assuming that the cutter is a four-flute cutter as illustrated in FIGS. 13 and 14, the gash grind takes place at all four of the flutes or lands, but a notch is ground at only two diametrically spaced lands. Accordingly, this last gash grind is not followed by a notch grind as described originally, but instead the indexing movement brings a third land into grinding position and at this land the complete gash grind and notch grind as initially described is repeated. This is then followed by a gash grind only at the last remaining land.

The result is that two of the lands are substantially continuous across the center of the cutter and the cutter can drill downwardly in the manner of a twist drill. The intermediate lands are operated from the first and third lands by the notch either side of the first and third lands. Thus the first and third lands present a substantially continuous cutting edge which has an S-shape when viewed axially as in FIG. 14.

Since cam disc 152 is selected ahead of time to have the same number of peripheral recesses that the cutter has lands, the end of the fourth grinding operation is accompanied by the simultaneous entry of index lock 154a into the single notch 151a of cam disc 151. This moves spool valve 154 forward to the position shown in FIG. 20, and a signal is generated indicating the end of a complete grinding cycle for the cutter. This signal causes the logic circuit to signal for A rotation down, bringing the cutter to the initial starting position. This is followed by pressurizing actuator 137 to raise axial locator 135 and a release of fluid pressure in cylinder 40, causing chuck 38 to release tool holder 27. Also the supply of coolant is shut off and the machine is now placed on standby so that when a new cutter is placed in the work head manually, the complete grind cycle described is repeated automatically.

The above sequence of operations is a preferred one but is not unnecessarily unvariable. For example, the gash grind has been described as preceding the following notch grind. This sequence of operations can be reversed if desired and the notch grind accomplished. Furthermore, if the cutter has six flutes instead of four, four of the flutes are ground only with a gash grind and only two of them with a notch grind. This is done in order to achieve the distinctive S-shape of the two diametrically opposite lands which affords a substantially continuous cutting edge across the nose of the cutter.

From the foregoing description of the operation of the machine at station No. 2, the method of grinding the rake angle and also of gashing and notching the lands on the nose of a ball end mill cutter will be evident. The initial step of positioning the end mill blank or cutter by engagement with locator 135 involves positioning the cutter in two respects. In addition to positioning the cutter axially or lengthwise by contact with the locator, as was done also at station No. 1, it is now necessary to orient the cutter angularly about its own axis. For this purpose the locator is provided with a suitable lip or projection which engages a selected land on the cutter, thereby allowing the operator to position the end mill angularly about its longitudinal axis as a function of the helix angle of the end mill.

The helix angle of the end mill also determines the length of the arc through which the cutter swings during the A rotation.

The extent of the A rotation is determined in combination with the extent of C rotation in order to effect a smooth blend of the rake angle ground on the side face of the land at the nose of the ball end mill with the same side face of the land along the portion of the mill of uniform diameter. Also as an element in obtaining the proper configuration of the cutter, the profile of the lower ridge on the grindwheel is carefully determined.

Because of the initial action in offsetting the longitudinal cutter axis from the Y axis so that the two axes are parallel but horizontally spaced apart, C rotation now takes place about an axis that is transverse to the cutter axis but does not intersect it. As a result of this C rotation combined with the infeed of the cutter toward the grindwheel, both the tertiary clearance on one land and the rake angle on an adjoining land at the end of the mill are ground at the same time by the lower longitudinal ridge around the grindwheel. The amount of the Y axis offset is determined by the size of the cutter, that is by the cutter diameter. Accordingly both the amount of such offset as well as the swing radius, which is the distance from the center of C rotation to the surface of the grindwheel, may be regarded as functions of the cutter diameter.

GRINDING OPERATION AT STATION NO. 3

A typical grinding operation at station No. 3 is shown graphically in FIG. 18 which illustrates four successive stages in the entire operation of grinding primary and/or secondary relief angles on a ball end mill. These are finish grind operations on a mill which has already passed through stations No. 1 and No. 2, or has had equivalent operations performed on it.

The tool holder and cutter of the unit are manually transferred from station No. 2 to station No. 3 and loaded into the work head in the same way already described. Here again, the tool holder and cutter are advanced in the work head until the nose or forward end of the cutter comes into contact with the upstanding leg of locator 135 which is in the raised position when the grinder is in standby condition. The cutter is axially and radially located by contact with locator 135, this locator having a lip or projection (not shown) that engages the side of a selected land to orient the cutter angularly, i.e., about its own axis. This positioning brings a selected land into contact with the grindwheel and exact orientation is determined by the helix angle of the cutter.

At station No. 3, before any grinding is done, the work head is adjusted downwardly by comparison with its position at stations No. 1 and No. 2 to adjust the position of the X axis with respect to the grindwheel. As may be seen by reference to FIG. 18(1) the X axis, and consequently the Y axis which intersects the X axis, is now located at or near the lower edge of grindwheel. This is the "X axis adjustment" noted in the FIG. 15; and is done in order to avoid any undesired or adverse contact between the grindwheel and the cutter during A rotation of the grinding operation. This adjustment of the X axis is accomplished by resetting the upper limit of Z₂ traverse. This upper limit is established by the position of collar 110 on the lower end of sleeve 86, and adjustment of the collar position is effected through manipulation of handwheel 112 at the front of the grinder.

The air-hydraulic control system for station No. 3 is illustrated in FIGS. 25 and 25B. The general arrangement of the elements of the control system in the diagram is similar to that described above in connection with FIG. 23. However, additional valves and flow control elements are provided in order to produce the desired movements of the parts in the proper sequence.

In the air-hydraulic control system, the logic circuit which programs the sequence of operations is contained within the dotted rectangle 225. These units in the logic circuit are of the same types employed in the logic circuit of station No. 1 and station No. 2. They are connected to the air supply valves at the left-hand side of the diagram, which valves are, as indicated, similar to those shown at station No. 1. In turn the logic units are connected to the air-pilot valves which control the flow of hydraulic fluid to the power units at the right-hand side of the diagram and which have been described in connection with the structure of the grinder.

Without reciting in detail the operation of the control system, the sequence of operations produced by the control system will now be described. Assuming that the positional adjustments have been made and that the tool holder with a cutter has been loaded into the work head, the cycle start button is now depressed by the operator. This action changes the position of air supply valve 227 and the grind cycle is initiated. Automatically, pressure fluid is supplied to cylinder space 40 to close chuck 38 on the work holder. Hydraulic actuator 137 moves locator 135 downwardly, thereby permitting cutter 26 to be advanced into grinding engagement with grindwheel 12.

Now C rotation about the Z axis occurs. This movement is clockwise viewed from above and moves the X axis through an angle equal to the primary relief angle to be ground on the cutter. The extent of C rotation is limited by stop 128 engaged by stop 130 which, through the control system, selectively pressurizes a cylinder 106 to set one of the feed stops 104 or 105 for shallow infeed rotation about axis Z₂. This angular shift in the X axis is indicated in FIG. 18(2). Then the infeed movement takes place, which is angular movement about Z₂ axis, the purpose of which is to bring about grinding engagement with the grindwheel. Now the tooth rest is brought into operation. This is done by swinging blade 166 into position (full line in FIG. 7) to engage the side of a land on the cutter, this inward movement of the tooth rest assembly being accom-

plished by the introduction of pressure fluid into hydraulic actuator 176. To engage the blade with the side of a land and hold the cutter against tooth rest blade 166, work head motor 42 is driven in reverse slowly. This is accomplished by changing the direction of the fluid flow through the motor, which is reversible.

The cutter is now in contact with the grindwheel; and as A rotation upwardly takes place about the X axis, the cutter moves from the position of FIG. 18(2) to FIG. 18(3). During this arcuate movement, the primary relief angle is ground along the nose portion of the land. The extent of A rotation is normally 90 degrees but is less when grinding a tapered cutter. At the end of the A rotation, Z₂ traverse downwardly takes place, and this continues for the length of the flutes on the cutter, this downward motion being shown in FIG. 18(4). During the A rotation and the subsequent Z₂ traverse just described, the cutter rotates slowly under power applied by the work head motor to keep the side of the land in engagement with tooth rest blade 166, thereby presenting always to the grindwheel the edge of a cutting land. This latter movement is made possible by the over-running clutch 149 which allows the cutter to be turned by motor 42 in a direction reverse to indexing rotation while the index and cycle locks are engaged.

At the end of the Z₂ traverse down, the tooth rest is moved clear of the cutter by hydraulic actuator 176 which swings the tooth rest assembly counterclockwise around pivot 74. Removal of the tooth rest signals indexing rotation and simultaneously reverse C₂ rotation takes place which feeds the cutter outwardly from the grindwheel. These movements are followed by A rotation down and Z₂ traverse up which return the cutter to the position of FIG. 18(1) in which the cutter axis is horizontal. At the end of the Z₂ traverse up, fluid pressure is reversed on pistons 156 and 162 (FIG. 20), moving them outwardly away from cams 151 and 152, respectively. This shift of the spool valves unlocks the cams in the work head so that work head motor 42 is now free to rotate the tool holder and cutter. The work head motor drives forward at high speed until nose 160a of the index lock moves into the shallow recess 152, thereby slowing down the motor, after which the motor stops completely when the nose enters the deep recess 152a and locks the tool holder in place. This motion advances the cutter by the angle between successive lands. There being but a single notch 155a in disc 151, spool valve 154 is held in the retracted position and the nose of the valve body rides against the periphery of the disc.

With the completion of the indexing motion of the cutter, the cycle of movements already described is duplicated at the second land and is then repeated at each of the other lands until one complete revolution of the cutter has been made. At this point index lock 154a enters the single notch in disc 151, generating a signal indicating the end of a cycle of grinding primary relief angles on all the lands of the cutter. If only a primary relief angle is desired, the end of a grind cycle is also indicated; but ordinarily a secondary relief angle is also desired on the same lands, and consequently the end of grinding primary relief angles results in starting the second half of the cycle for grinding the secondary relief angles.

To grind secondary relief angles, the same sequence of operations as described above is repeated except

that the initial C rotation about the Z axis is over a greater angle than before. This rotation is now equal to the secondary relief angle; and shifts the X axis through a total angle equal to the secondary relief angle. This shift in the X axis is not indicated in FIG. 18 but it is in the same direction and of larger magnitude than the shift indicated for the primary relief angle. The positions of the C rotation stops are reversed for this purpose. Stop 132 engages plunger 128 and the control system pressurizes the other cylinder 106 of the infeed stops 104 and 105 to effect deep infeed about axis Z₂. Otherwise the sequence of operations is the same as just described, each land being ground individually as before with the cutter being rotated slowly during Z₂ traverse down as a result of power applied to it through the work head motor. This power holds the land in contact with the tooth rest, thereby presenting to the grind wheel continuously a desired portion of the helical land.

As was also the case at station No. 2, disc 152 is selected to have the same number of peripheral recesses that the cutter has lands; and at the end of the last grinding operation there is simultaneous entry of index lock 154a into the single notch 152a of disc 51 and entry of cycle lock 160a into the notch 152a. Forward movement of spool valve 154 to the position shown in FIG. 20 generates a signal indicating the end of a complete grinding cycle for the cutter. This causes a logic circuit to signal for A rotation down, bringing the cutter back to the initial starting position with its axis horizontal. This is followed by pressurizing actuator 137 to raise axial locator 135 and the release of fluid pressure in cylinder 40, causing chuck 38 to release the tool holder 27. Also, the supply of coolant is shut off. The tool holder and the cutter therein can be removed, and the machine is in standby condition ready for repetition of a full grind cycle when a new cutter and tool holder are loaded into the work head.

The above cycle of operations assumes that a ball end mill is being ground. However, the series of operations can be modified as desired to fit specific types of cutters. For example, in the case of a cutter having only the peripheral cutting edges and none on the nose or end, no grinding operation takes place during the A rotation up. Grinding a ball end mill cutter is described as it makes full use of the possible movements of the work head and to grind other styles of cutters may utilize only a portion of the movements or operations disclosed above.

From the foregoing description it will be appreciated that the structure of the grinder is such that a great variety of motions or sequence of motions can be applied to cutters of various sizes, shapes, and styles, and that the logic circuit can be modified accordingly to automate these operations. All such changes in motions of the cutter and work head or in the control system may be made without departing from the spirit and scope of the present invention.

I claim:

1. A mill grinder for machine tool cutters constructed with reference to X, Y, and Z geometric axes that are mutually perpendicular and intersect at a common point, comprising in combination:

a frame;

a grindwheel rotatably mounted on the frame to revolve about an axis parallel to and spaced from the Z axis;

a work head including tool holding means, the tool holding means mounting a cutter in the work head for movement of the cutter about the longitudinal axis of the cutter;

means mounting the work head on the frame for independent movement about the X axis and for movement along the Z axis with the axis of the cutter coincident with the Z axis;

motor means for turning the tool holding means and the cutter about the axis of the cutter;

motor means moving the work head to feed the cutter into and out of engagement with the grindwheel;

motor means traversing the work head along the Z axis with the cutter axis coincident with the Z axis; and

motor means for swinging the tool holder and cutter about the X axis.

2. A grinder for cutters according to claim 1 in which the tool holder and cutter swing about the X axis through an arc of substantially 90°.

3. A grinder for cutters according to claim 1 including means for forming said cutter with a plurality of circumferentially spaced flutes that define cutter teeth, and in which the means for turning the cutter includes means to index the cutter by angular increments determined by the number of flutes on the cutter.

4. A grinder for cutters according to claim 3 which also includes a tooth rest engageable with the cutter, and in which the means for turning the tool holding means is reversible and rotates the cutter in one direction to index the cutter and rotates the cutter in the opposite direction against the tooth rest to grind a surface on a land of the cutter.

5. A grinder for cutters according to claim 1 in which the means for feeding the cutter into and out of engagement with the grindwheel includes means swinging the work head forward and back in an arc about an axis parallel to but offset from the Z axis.

6. A grinder for cutters according to claim 1 that also comprises means adjustably mounting the grindwheel on the frame for compensatory movement of the grindwheel axis toward and away from the Z axis and along the Y axis.

7. A grinder for cutters according to claim 1 including means adjustably mounting the work head on the frame for movement of said common point of intersection of the axes relative to the cutter along a locus lying at 45° to the Y axis.

8. A grinder for cutters according to claim 1 in which the means for turning the cutter includes motor means for rotating the cutter continuously while the cutter is in engagement with the grindwheel.

9. A mill grinder for machine tool cutters constructed with reference to X, Y, and Z axes that are mutually perpendicular and intersect at a common point, comprising in combination:

a frame;

a grindwheel rotatably mounted on the frame to revolve about an axis parallel to and spaced from the Z axis;

a work head including tool holding means, the tool holding means mounting a cutter in the work head for movement of the cutter about the longitudinal axis of the cutter, said point of intersection of said X, Y and Z axes lying on the longitudinal axis of said cutter in the tool holder;

means mounting the work head on the frame for independent movement about the X axis and along the Z axis;

motor means for turning the tool holding means and the cutter about the axis of the cutter;

motor means moving the work head to feed the cutter into and out of engagement with the grindwheel;

motor means traversing the work head along the Z axis; and

motor means for swinging the tool holder and cutter about the X axis.

10. A mill grinder for machine tool cutters constructed with reference to X, Y, and Z axes that are mutually perpendicular, comprising in combination:

a frame;

a grindwheel rotatably mounted on the frame to revolve about an axis parallel to and spaced from the Z axis;

a work head including tool holding means, the tool holding means mounting a cutter in the work head for movement of the cutter about the longitudinal axis of the cutter;

means mounting the work head on the frame for independent movement about the X axis and along the Z axis;

motor means for turning the tool holding means and the cutter about the axis of the cutter;

motor means moving the work head to feed the cutter into and out of engagement with the grindwheel;

motor means traversing the work head along the Z axis; and

motor means for swinging the tool holder and cutter about the X axis between an initial position in which the cutter axis is coincident with the Y axis and a subsequent position in which the cutter axis is coincident with the Z axis.

11. A mill grinder for machine tool cutters constructed with reference to X, Y, and Z axes that are mutually perpendicular, comprising in combination:

a frame;

a grindwheel rotatably mounted on the frame to revolve about an axis parallel to and spaced from the Z axis;

a work head including tool holding means, the tool holding means mounting a cutter in the work head for movement of the cutter about the longitudinal axis of the cutter;

means mounting the work head on the frame for independent movement about the X axis, along the X axis and along the Z axis;

motor means for turning the tool holding means and the cutter about the axis of the cutter;

motor means moving the work head to feed the cutter into and out of engagement with the grindwheel;

motor means traversing the work head along the Z axis;

motor means traversing the tool holder and cutter therein along the X axis; and

motor means for swinging the tool holder and cutter about the X axis.

12. A grinder for cutters according to claim 11 in which the tool holder moves between an initial position with the tool holder axis parallel with the Y axis and a final position with the tool holder axis parallel with the Z axis after said swinging motion about the X axis.

13. A grinder for cutters according to claim 11 in which the tool holder positions the cutter axis initially parallel to but offset from the Y axis and after swinging about the X axis positions the cutter axis parallel to but offset from the Z axis.

14. A grinder for cutters according to claim 13 which also comprises means for traversing the cutter along the Z axis holding the cutter axis parallel to but offset from the Z axis.

15. A machine tool cutter grinder comprising in combination:

a frame;

a grindwheel and motor means driving the grindwheel mounted on the frame;

a work head;

a tool holder adapted to hold a cutter and rotatably mounted in the work head to turn the cutter about the longitudinal axis of the cutter therein;

means mounting the work head on the frame, for controlled movement of the work head relative to the grind-wheel,

said mounting means comprising

a post having its longitudinal axis vertical and mounted for oscillation about its axis, said post having a laterally extending arm;

a block pivotally connected to said post arm to swing relative to the post about a second vertical axis;

and means pivotally connecting said work head to the block to move about a horizontal axis intersecting said second vertical axis;

and motor means for swinging the work head and cutter about said horizontal axis.

16. A cutter grinder according to claim 15 that also includes means on the work head providing rectilinear movement of the tool holder and cutter relative to said block in horizontal and vertical directions.

17. A cutter grinder according to claim 16 in which the horizontal and vertical movements of the work head and cutter are respectively parallel to and perpendicular to said horizontal axis about which the work head is mounted on the block.

18. A cutter grinder according to claim 15 which also comprises means raising and lowering the post along its vertical axis.

19. A cutter grinder according to claim 15 that also comprises means for adjustably positioning the grindwheel toward and away from a cutter in the tool holder by movement in a direction parallel to a vertical plane containing the axis of revolution of the grindwheel and the axis of the cutter.

20. A cutter grinder according to claim 15 that also comprises motor means carried on the work head for continuously rotating the tool holder with the cutter in contact with the grindwheel.

21. A cutter grinder according to claim 15 that also includes indexing means on the work head that turn the cutter by angular increments in response to the number of flutes on the cutter.

22. A cutter grinder according to claim 21 that also includes means for keeping one land on a cutter in grinding engagement with the grindwheel during downward movement of the post along the first mentioned vertical axis.

23. A cutter grinder according to claim 15 that also comprises means for swinging the block and work head together about said second vertical axis.

24. An end mill grinder according to claim 23 in which the grindwheel is a shaped wheel having a circumferentially extending ridge.

25. A grinder constructed with reference to X, Y, and Z axes that are mutually perpendicular and intersect at a common point for forming a cutter with a plurality of circumferentially spaced flutes that define cutter teeth comprising in combination:

a frame;

a grindwheel rotatably mounted on the frame to revolve about a vertical axis parallel to but spaced from the Z axis;

a holder for holding a cutter to be ground;

a work head mounting the cutter holder for turning movement about the axis of the cutter therein;

means for mounting the work head on the frame and moving the work head both angularly and linearly with respect to the grindwheel,

means for mounting the work head angularly about the X axis, and

means for placing the cutter axis coincident with the Z axis.

26. A grinder for grinding the cutting end and the shank of a fluted end mill comprising, in combination:

a frame;

a power driven grindwheel supported by the frame, said grindwheel having an annular grind surface;

a workhead supported on the frame, said workhead including a work holder mounting an end mill in said workhead for rotation on the longitudinal axis of the end mill;

a drive motor for constantly rotating said end mill in said head on its said longitudinal axis;

means for placing said workhead and end mill held therein relative to said grinding surface in a position with the cutting end of said end mill bearing against said annular grinding surface, and with the longitudinal axis of the end mill normal to said annular grinding surface at the point of engagement;

means for effecting a movement of said workhead relative to said grinding surface, between said position and a second position, said movement comprising a relative swing of said end mill about a swing axis which is perpendicular to said longitudinal axis of said end mill and which intersects the end mill at a distance from the extremity of the cutter end of the end mill which is no greater than half the radius of the end mill, such swing being of an angular extent of the approximate order of a right angle; and

means for translating said end mill along its longitudinal axis between said second position and still another position, in order to grind the shank of the end mill along the fluted length thereof.

27. The subject matter of claim 26, wherein a ball end mill is to be ground, and said swing axis intersects the longitudinal axis of the end mill, and wherein the point of intersection of said axes is located a distance from said extremity of the end mill substantially equal to the radius of the shank of the end mill, said swing axis being at right angles to the direction of said translation.

28. The subject matter of claim 26, wherein a flat end mill is to be ground, said swing axis intersecting the end mill substantially at the intersection of the flat cutter end of the end mill and the side surface of the shank

thereof, and being at right angles to the direction of said translation.

29. The subject matter of claim 26, wherein the cutter end of the end mill is to be ground with a radius between its shank surface and cutter end which is less than that of the shank of the end mill, said swing axis intersecting a center point about which such radius is struck, being at right angles to the direction of said translation.

30. A grinder for end mill cutters, constructed with reference to mutually perpendicular geometric reference axes X, Y and Z, comprising in combination:

a frame in fixed relation to said X, Y and Z axes;

a grindwheel rotatably mounted on the frame to revolve about an axis contained in the Y-Z plane;

a workhead including holding means for an end mill cutter, said holding means mounting an end mill cutter for movement of the cutter about its longitudinal axis;

means mounting the workhead relative to the frame for pivotal movement about an axis perpendicular to the Y-Z plane and in the vicinity of the X axis;

means mounting the workhead relative to the frame for pivotal movement about said Z axis;

means positioning the cutter holder on the workhead with its longitudinal axis in a plane offset from the X-Z plane;

means for pivotally moving the workhead about said axis perpendicular to said Y-Z plane; and

means for pivotally moving the workhead about said Z axis.

31. The grinder of claim 30, wherein said grindwheel axis is substantially parallel with said Z axis.

32. The grinder of claim 30, including also feed and retract means supporting said workhead and its mounting means for pivotal movement towards and from said grindwheel, about an axis parallel to said Z axis.

33. A cutter grinder as in claim 25 in which the work head mounting means also includes:

means mounting the work head for feeding the cutter toward and away from the grindwheel by swinging movement about a vertical axis parallel to but offset from the Z axis.

34. A cutter grinder as in claim 25 which also comprises:

a tooth rest engaging the cutter during grinding; and the work head includes means for turning the cutter in a direction to maintain contact of the cutter with the tooth rest during grinding.

35. A cutter grinder as in claim 34 in which the work head includes reversible motor means for turning the cutter to engage and disengage the tooth rest.

36. A cutter grinder as in claim 25 which includes means indexing the cutter by angular increments equal to the angle between successive flutes.

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