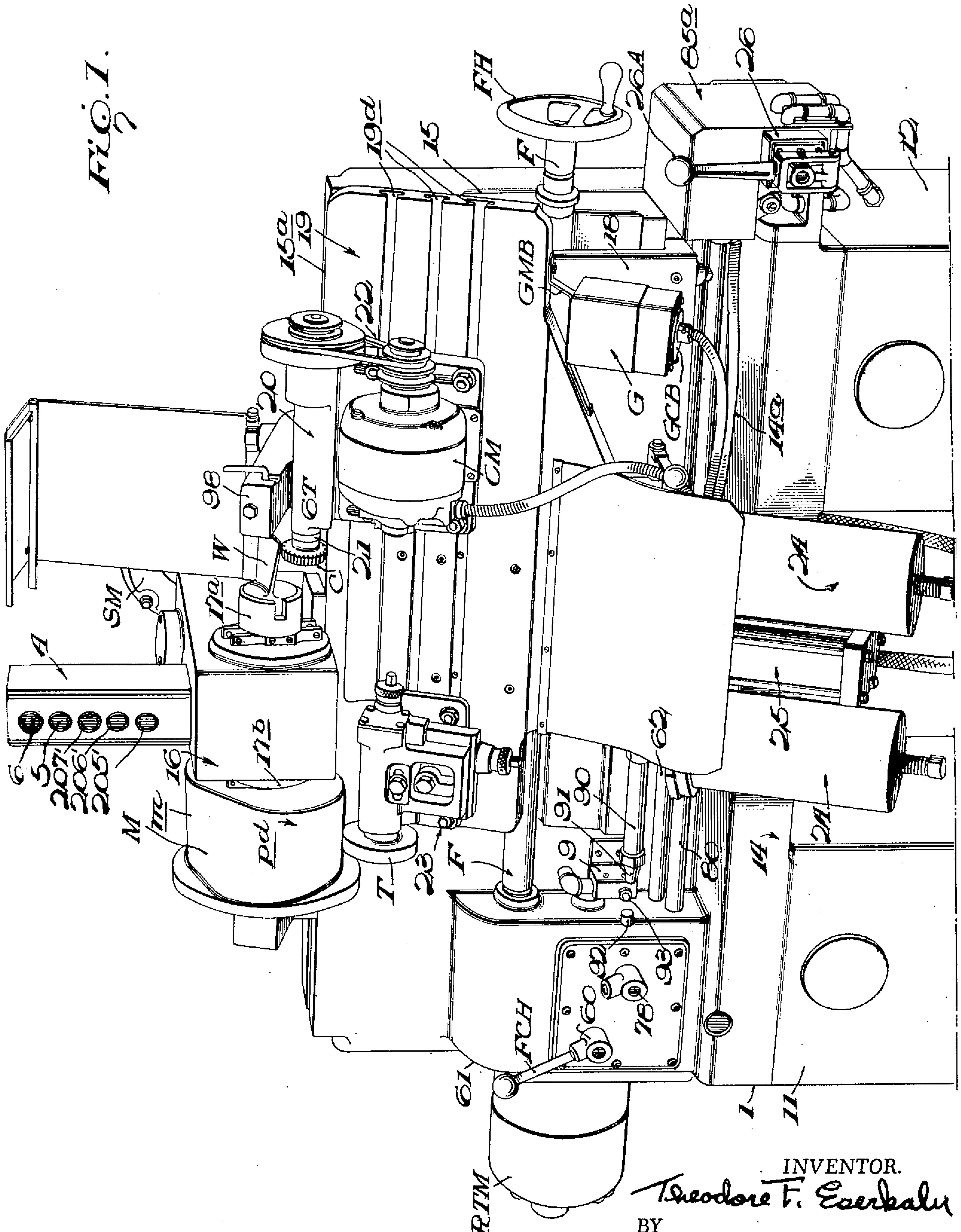
Feb. 24, 1953 T. F. ESERKALN **2,629,844**

CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

Filed May 20, 1949 11 Sheets-Sheet 1

FIG. 1.



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CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

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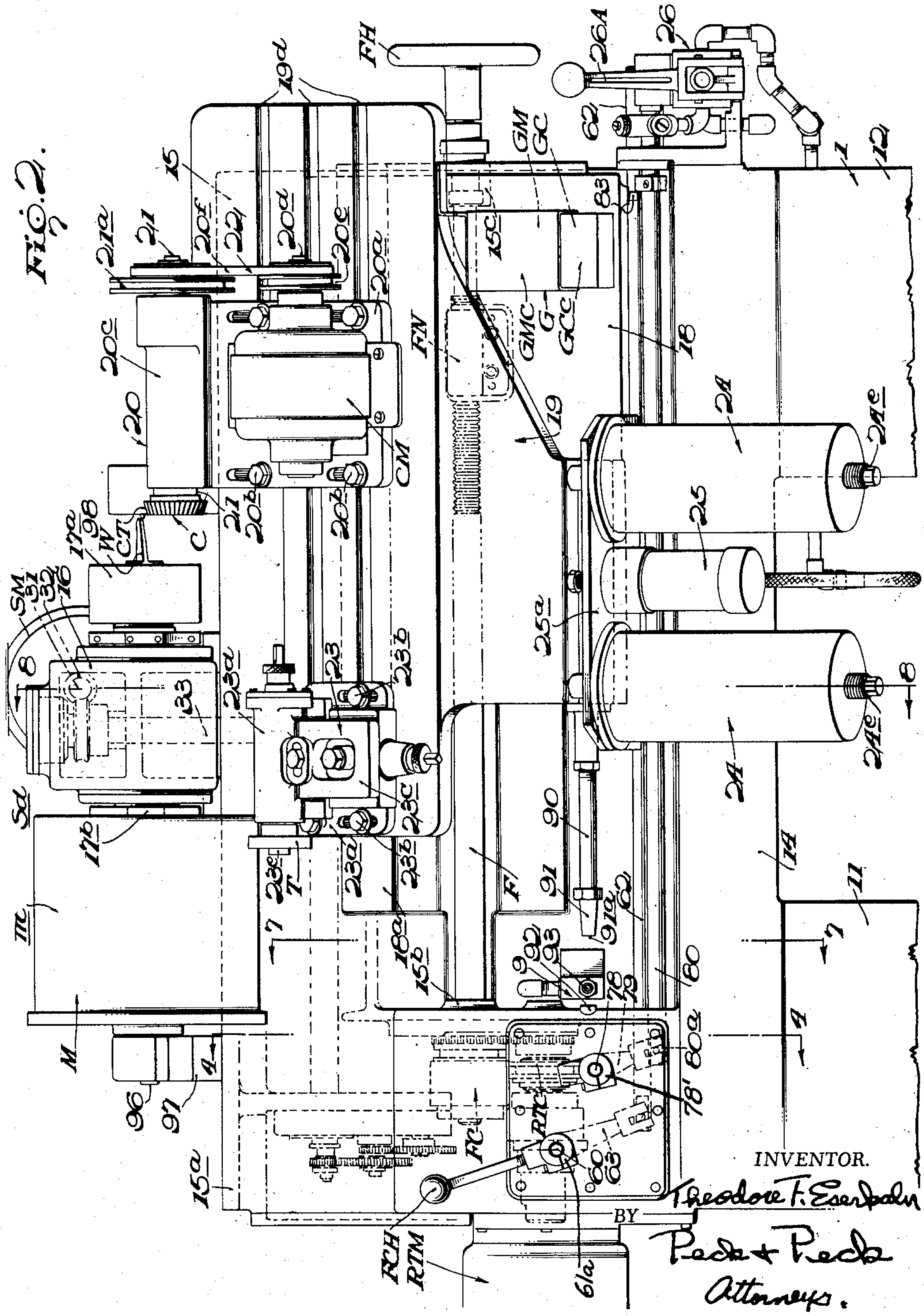

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CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

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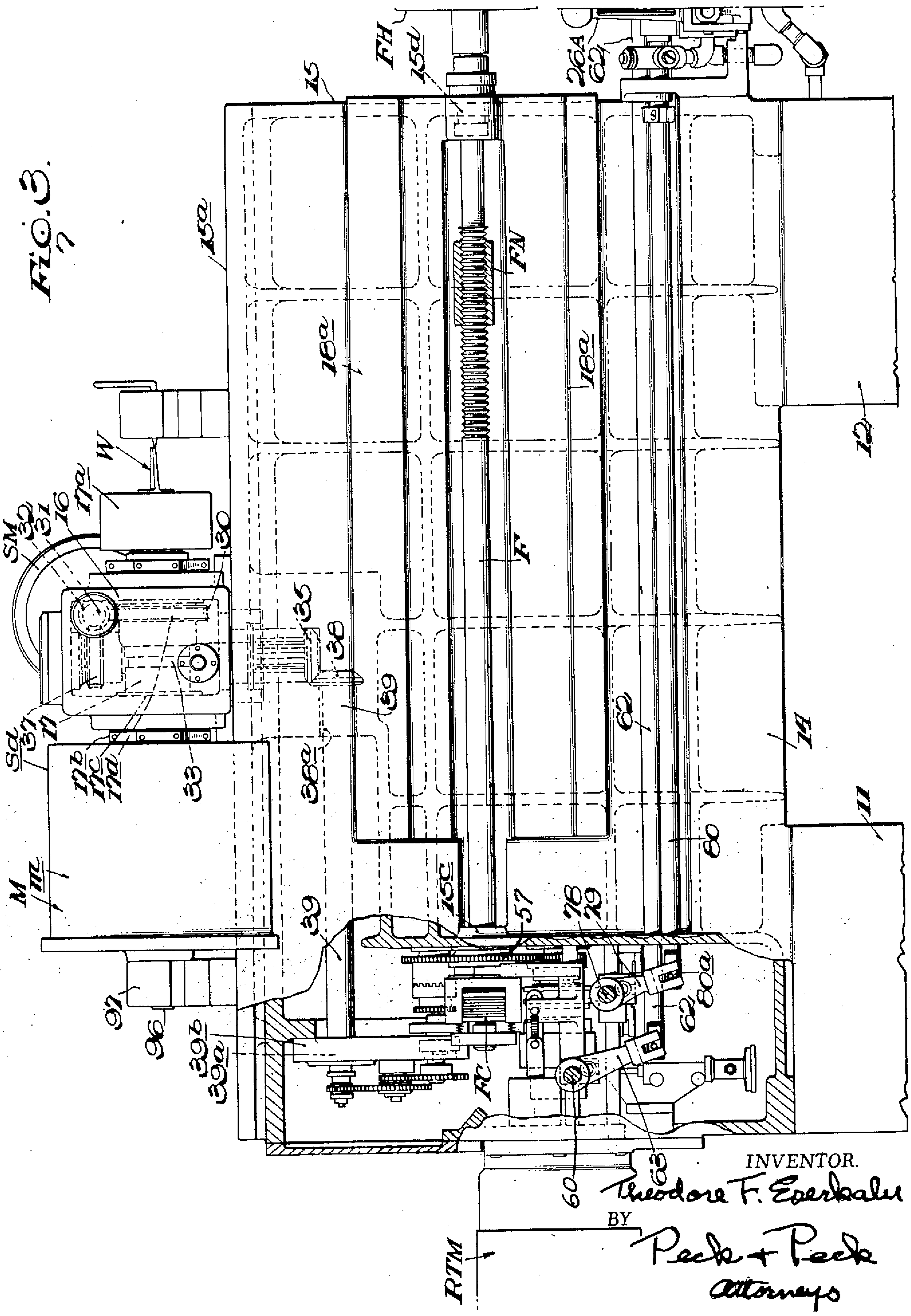

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CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

Filed May 20, 1949 11 Sheets-Sheet 4

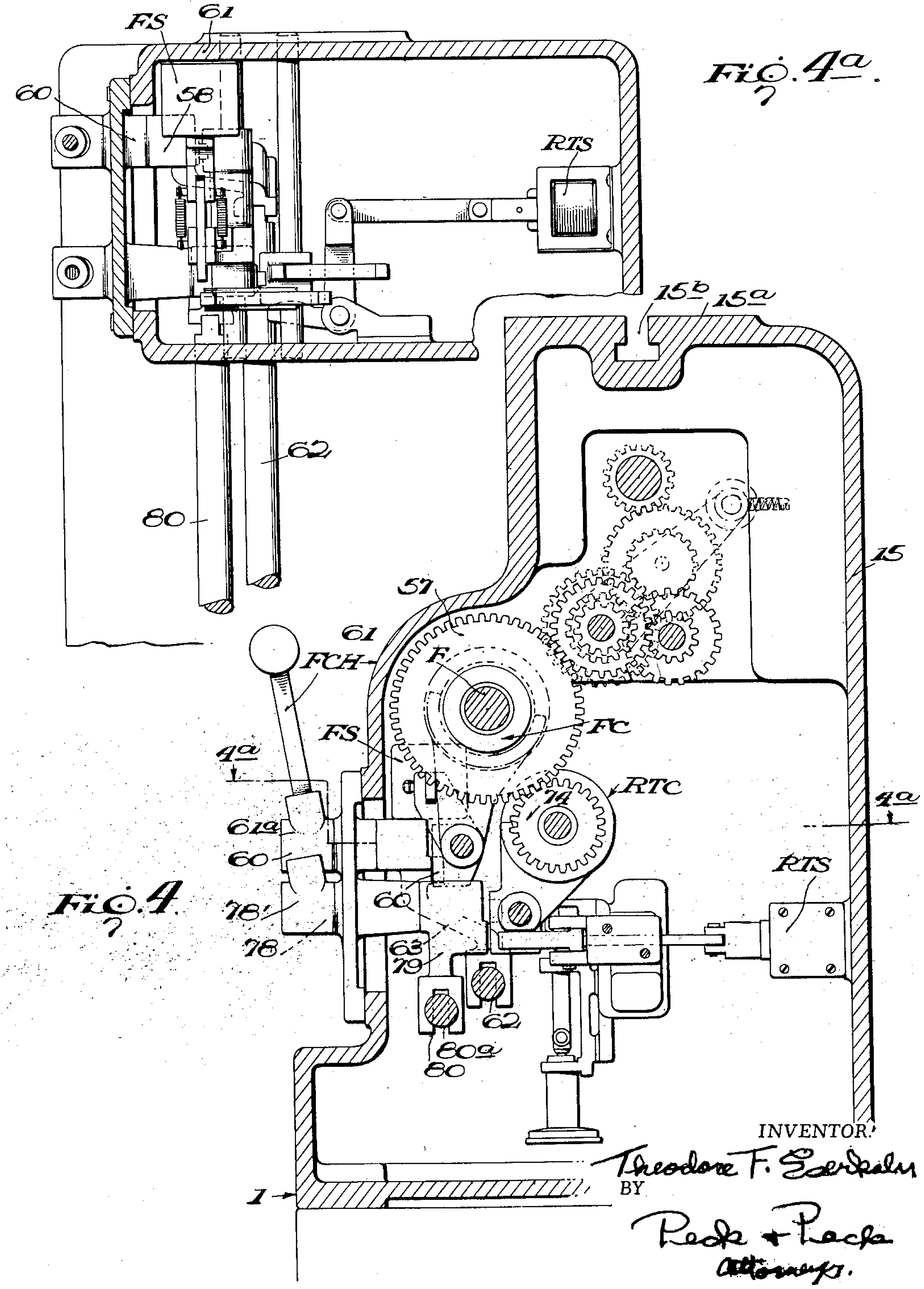

Fig. 4a.

Fig. 4.

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CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

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FIG. 5.

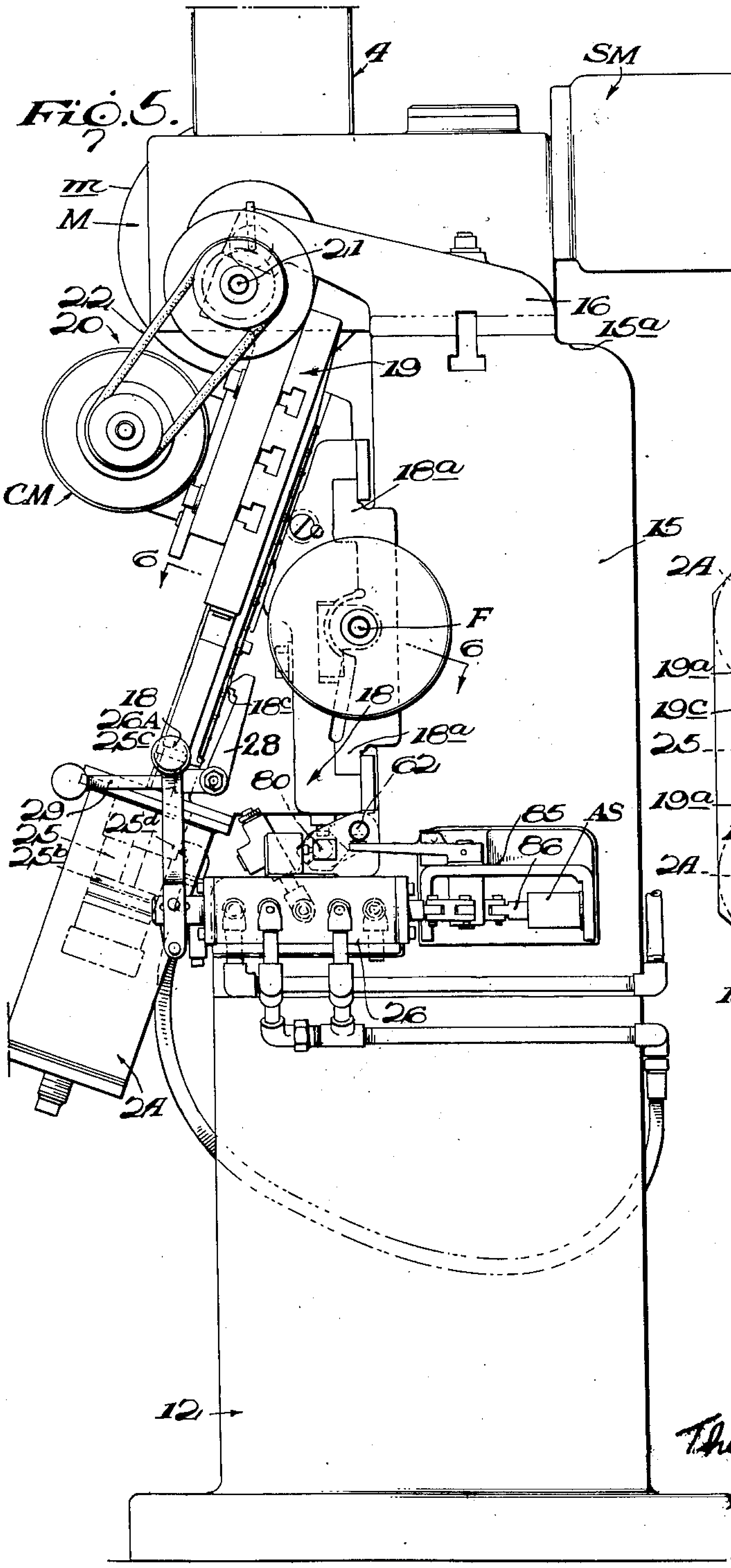
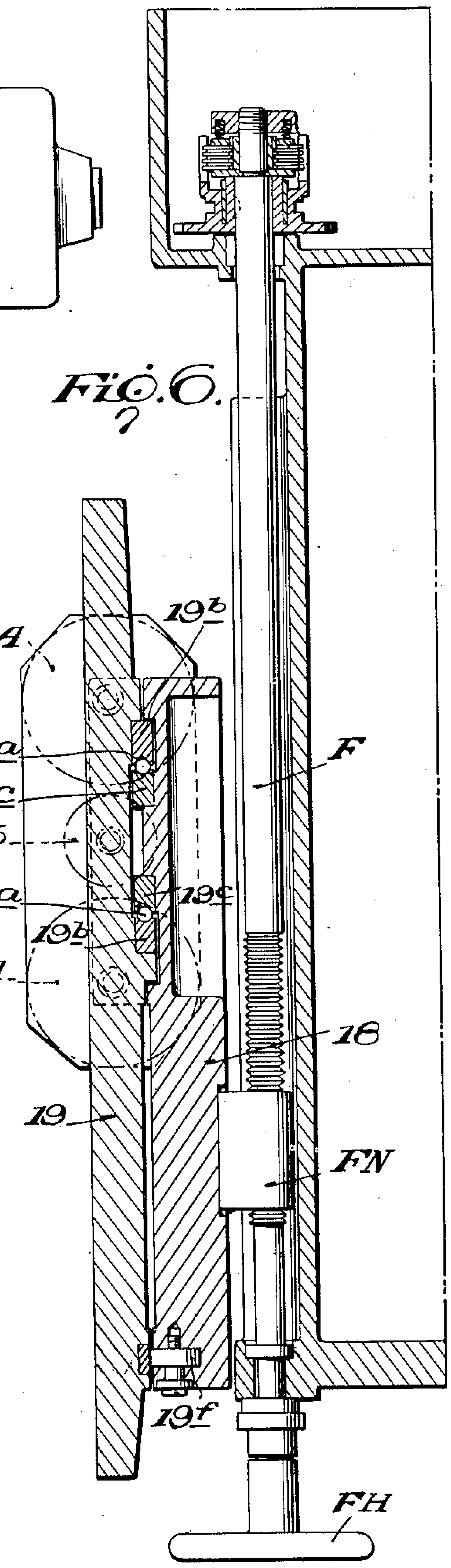


FIG. 6.



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CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

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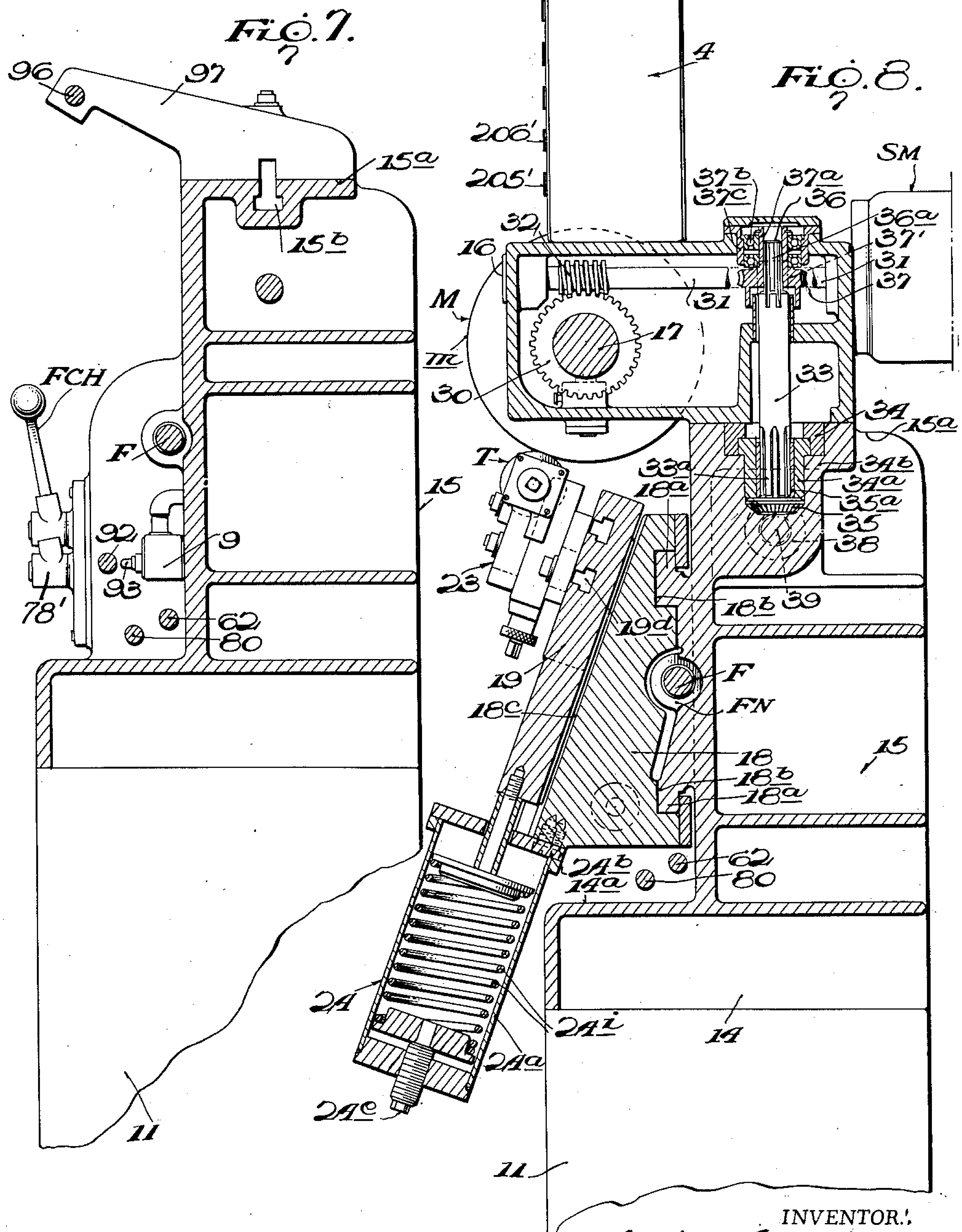

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CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

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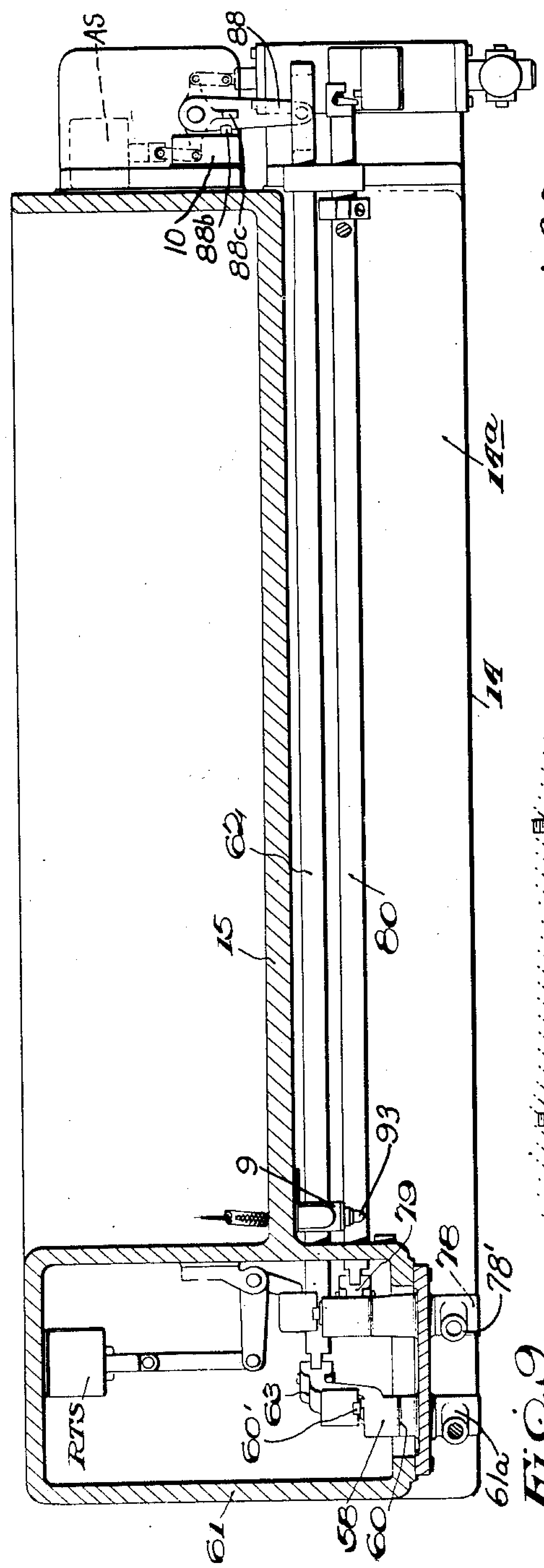

FIG. 9.

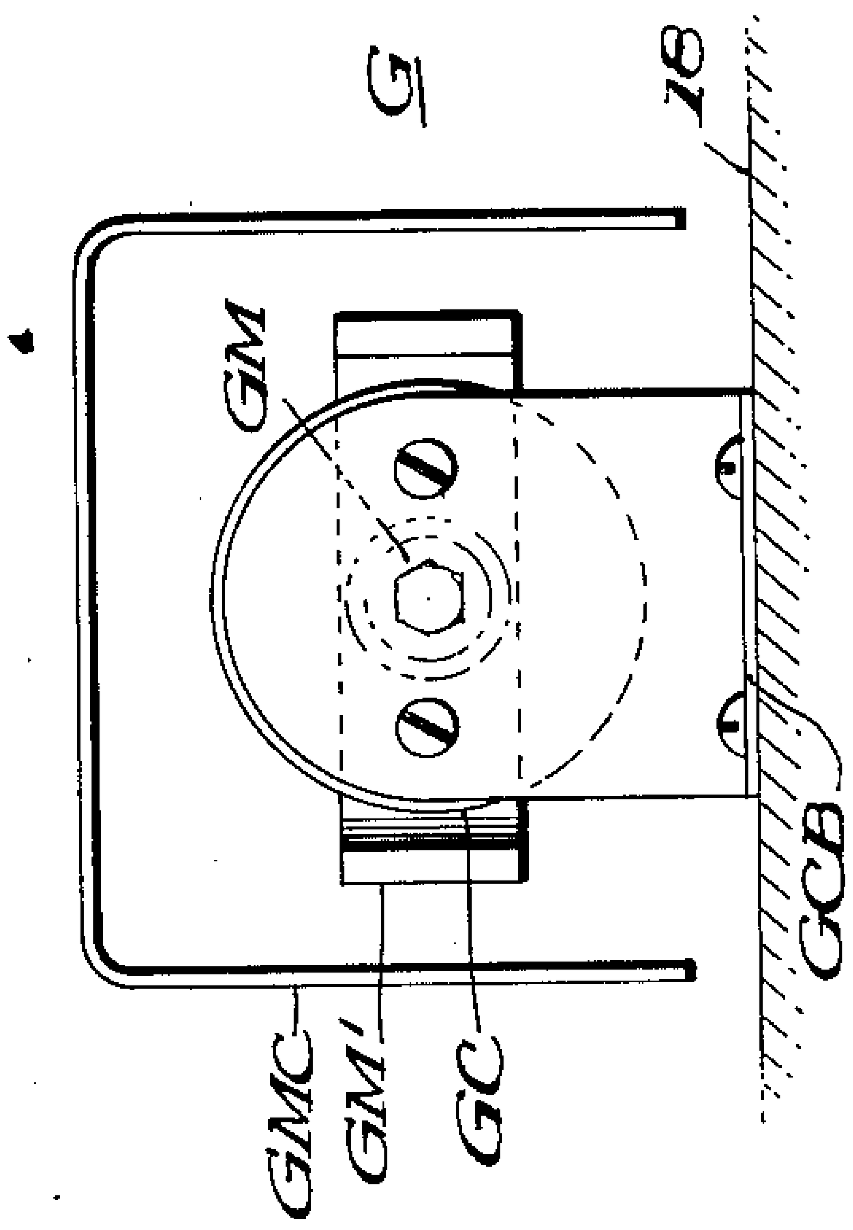

FIG. 20.

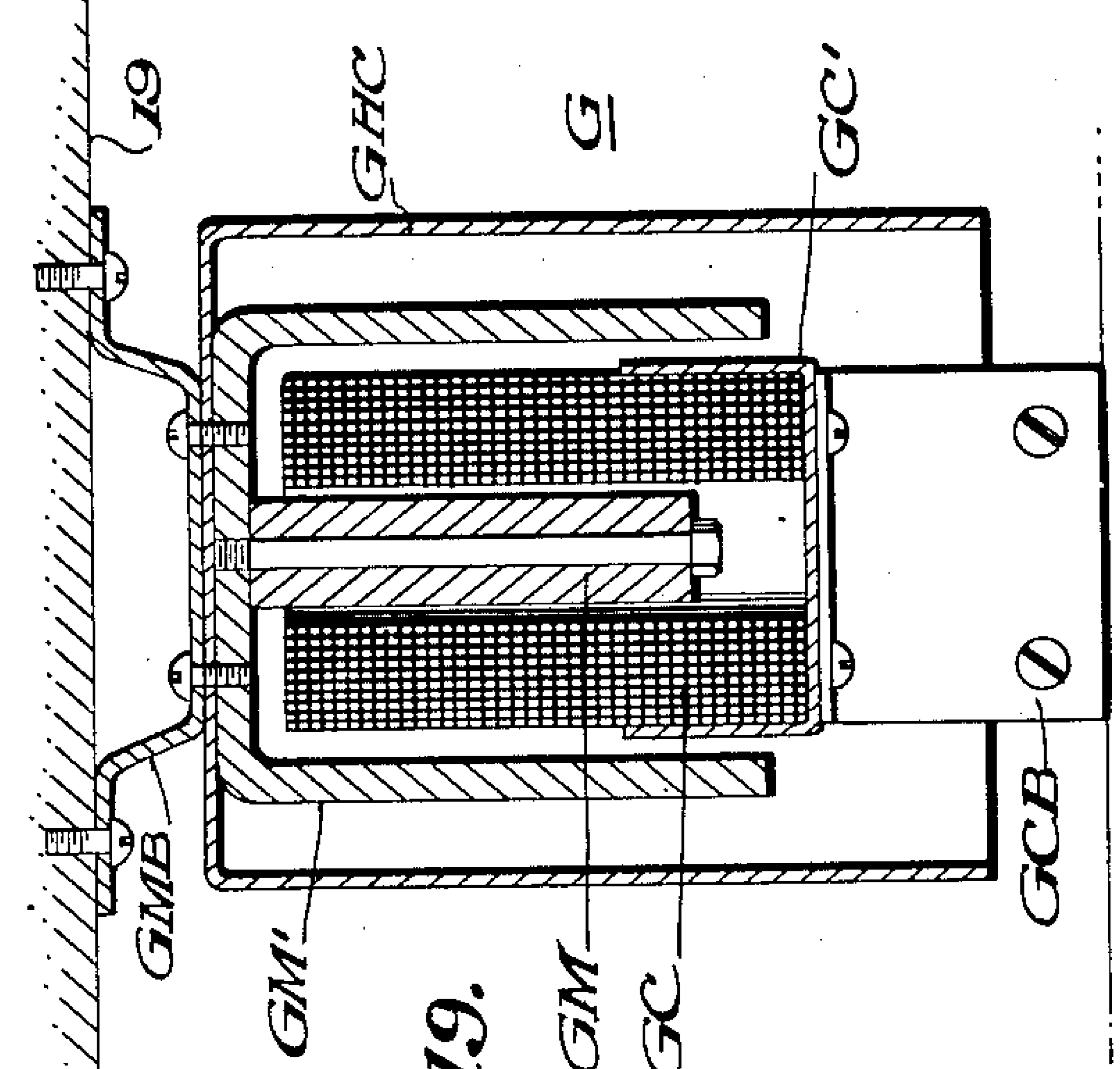

FIG. 19.

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CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

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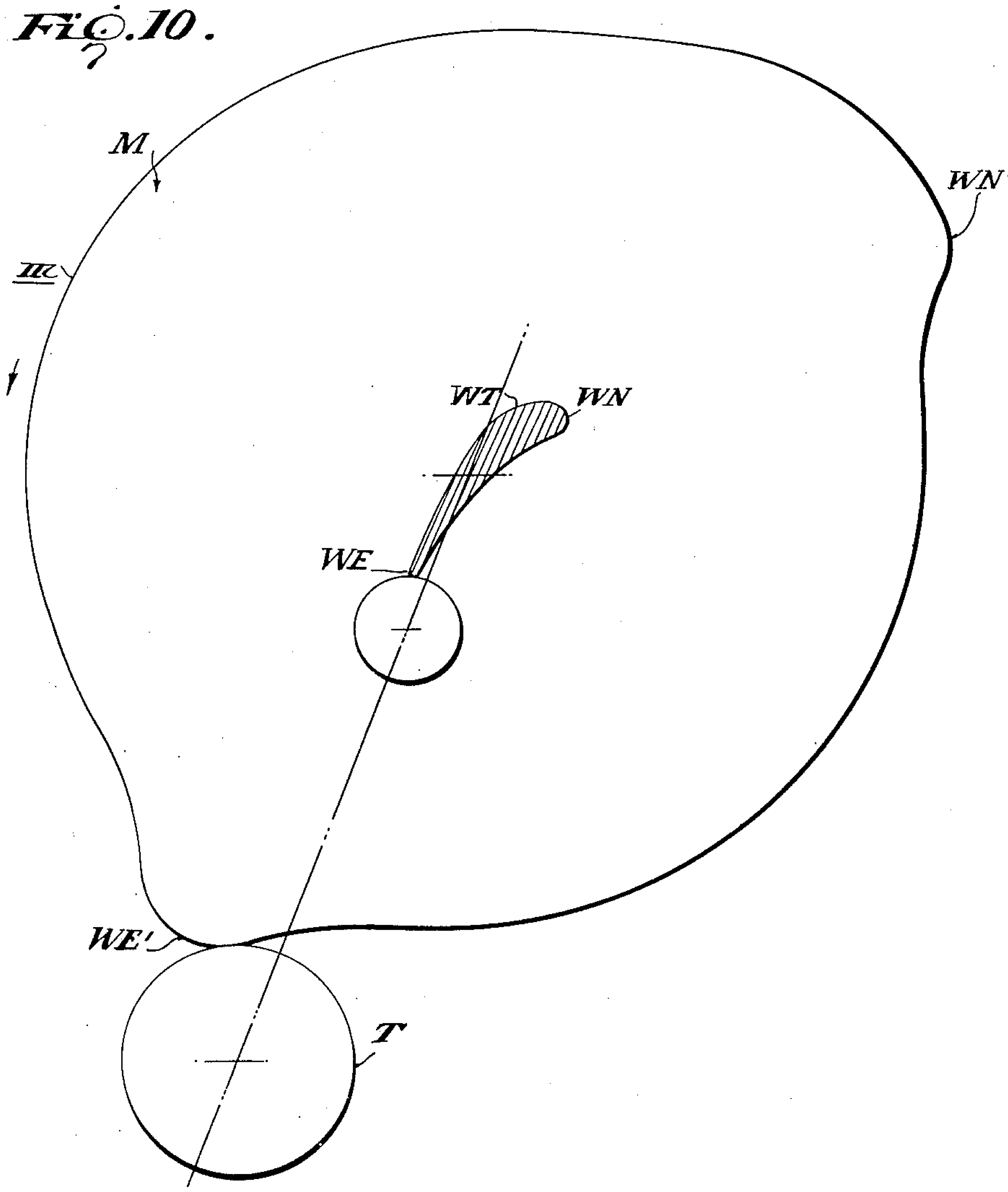
FIG. 10.



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Feb. 24, 1953 T. F. ESERKALN 2,629,844

CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

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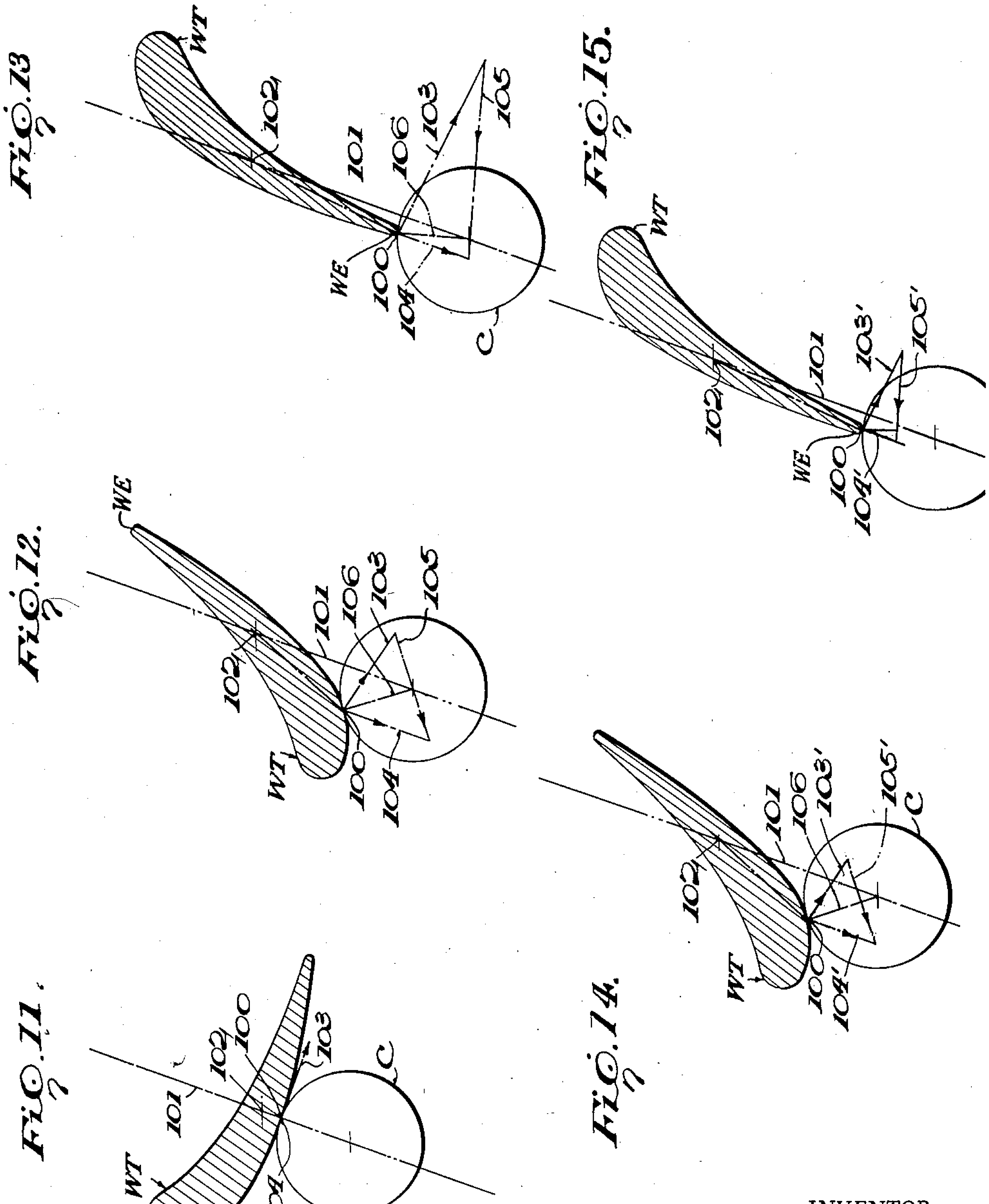

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CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

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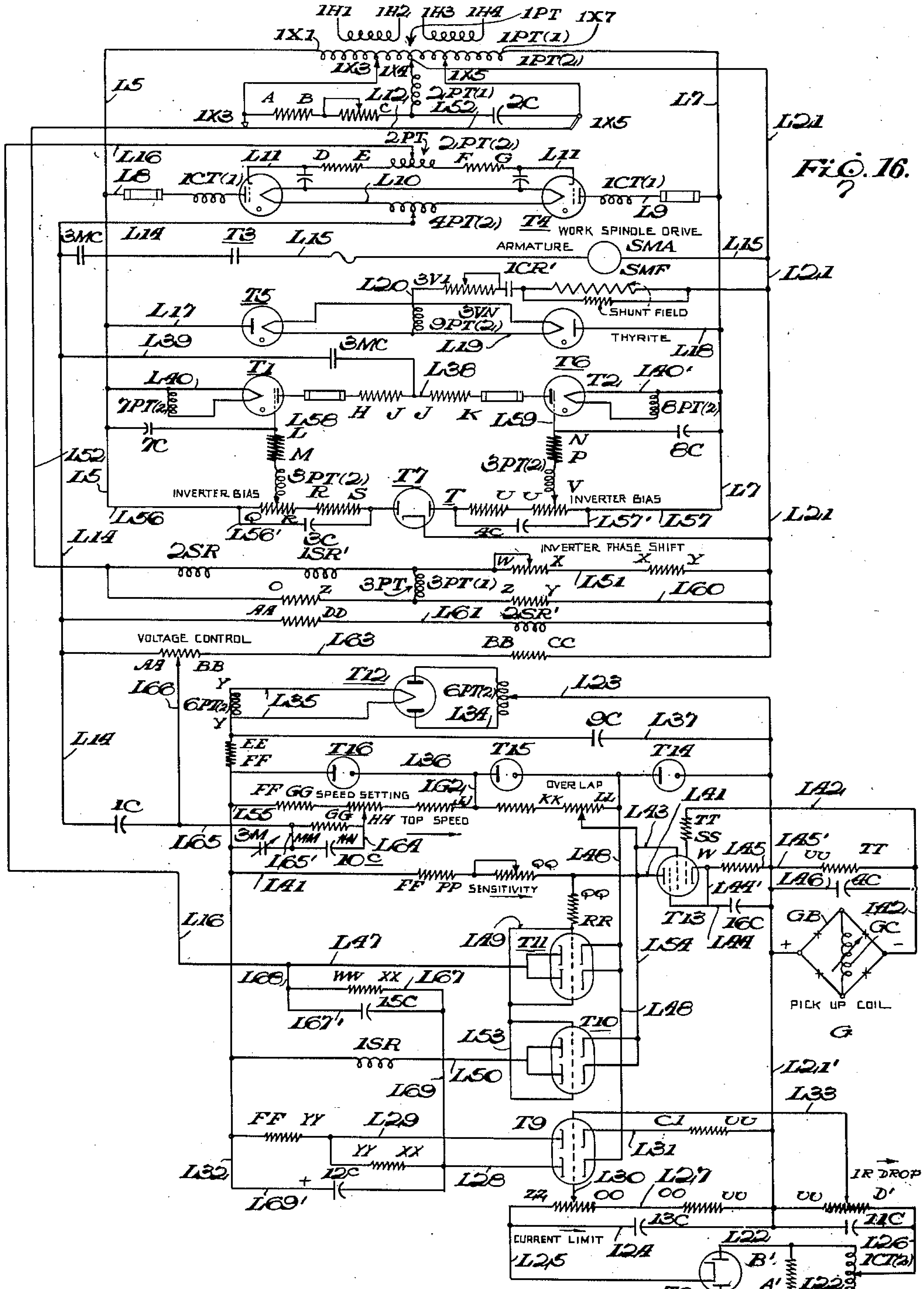

FIG. 16.

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CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

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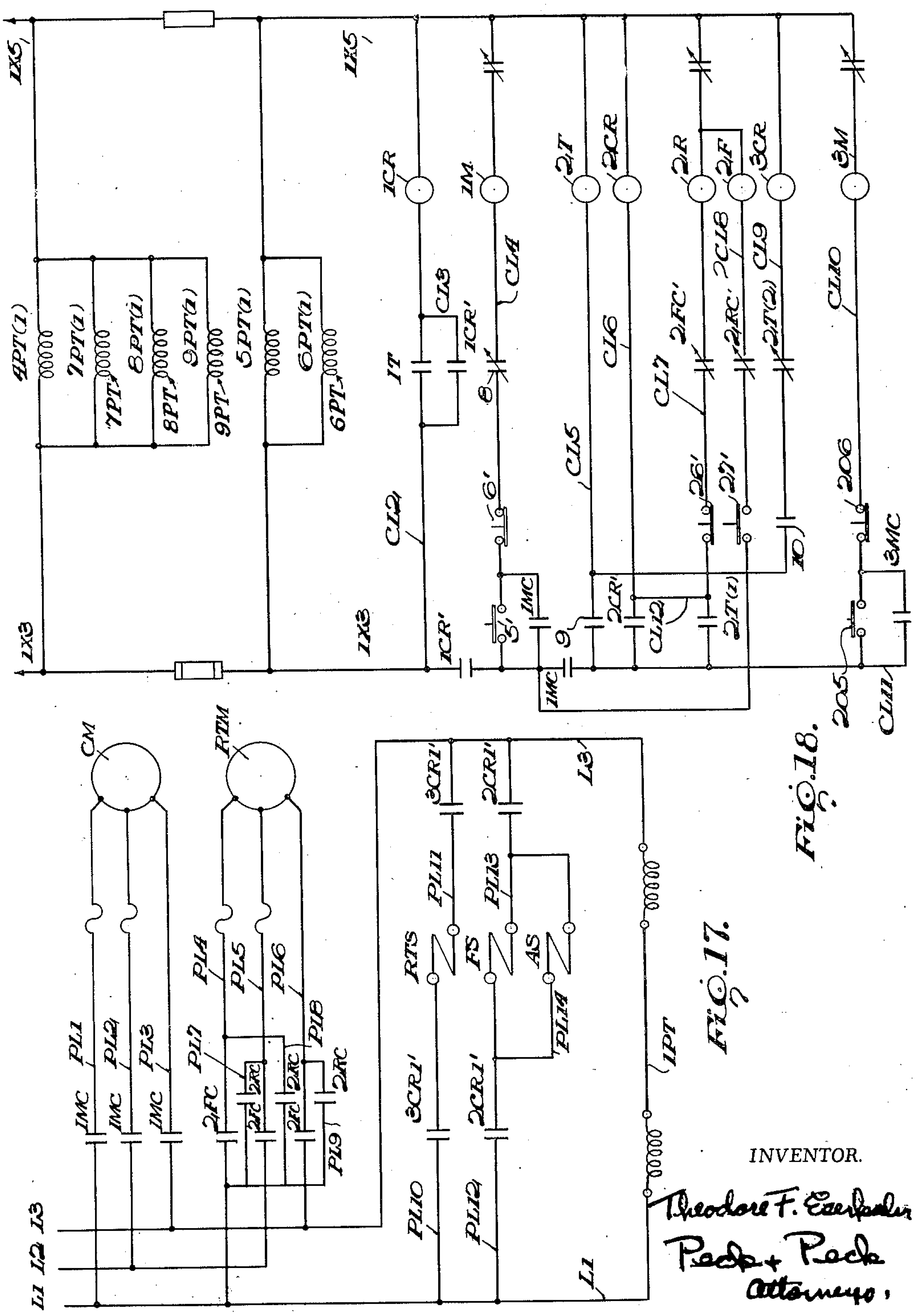

Fig. 18.

Fig. 17.

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Patented Feb. 24, 1953 2,629,844

UNITED STATES PATENT OFFICE

2,629,844

CONTROL SYSTEM FOR ROTARY DUPLICATING MACHINES

Theodore F. Eserkaln, Wauwatosa, Wis., assignor to George Gorton Machine Co., Racine, Wis., a corporation of Wisconsin

Application May 20, 1949, Serial No. 94,390

8 Claims. (Cl. 318—39)

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This invention relates to certain improvements in control system for rotary duplicating machines and the like, and particularly such machines designed for efficiently machining to finished form articles of irregular contours; and the nature and objects of the invention will be readily recognized and understood by those skilled in the arts to which the invention relates in the light of the following explanation and detailed description of the accompanying drawings illustrating what I at present consider to be a preferred form and embodiment of control system of my invention, from among various other forms, embodiments, designs and arrangements thereof, and of constructions, combinations and subcombinations of elements making up such a system, of which the invention is capable within the spirit and scope thereof as defined by the claims hereinafter appended.

My invention is primarily directed to the problem of manufacturing by milling, grinding or other material removing or finishing methods from work pieces or blanks, various articles having external shapes of irregular contours axially therealong and/or radially therearound, such as typified by turbine blades, vanes and the like articles, characterized by a large thickness to width or chord ratio, so that, a cross section of such an article at stations along its major length presents a "thin" section shape or contour lying within a generally rectangular area having a large thickness to width ratio, that is to say, of a generally "flat" rectangular shape in cross section. While the invention is not limited or restricted to the production by such methods of such articles as turbine blades, compressor vanes, buckets and the like, it is particularly adapted thereto because the conditions and problems to the solution of which the invention is directed, are met with to an accentuated degree in the production of such articles by automatic or semi-automatic power driven machines.

A machine of my invention for producing articles of irregular contours from a work piece by pattern controlled material removal from the work piece has been selected as exemplifying certain of the problems to the solution of which a control system of my present invention is directed. In this type of machine the work piece is revolved and the material removing tool is moved toward and from the work piece while being maintained in material removing engagement therewith under the control of a pattern and while being fed in one direction axially along the work piece. In order to efficiently and accurately machine the work piece to the contours of the pattern it is necessary to control the rate of rotation of the work piece relative to the rate or velocity of radial in and out movements of the tool as well as to control the rate of feed movement of the tool axially along the work piece if the particular article being machined from the work piece requires the latter movement.

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It is therefore one of the objects of the invention to provide for automatic and precise control of the rate of speed of revolution of the work piece in direct proportion to the rate of movements radially inwardly or outwardly of the tool from any at rest position thereof, toward or from the work piece, to effect a slow down or reduction in the rate of revolution of the work piece upon movement of the tool either inwardly or outwardly, and to restore instantly the maximum speed of rotation of the work piece when the tool comes to rest in any position thereof radially relative to the work piece.

Another object is to revolve the work piece and to feed the tracer and tool axially of the work piece simultaneously from a common power source under the control automatically of the movements of the tracer and tool unit either in a direction toward or a direction away from the work piece, to cause said common power source to effect simultaneously a slow down or reduction of the rate of revolution of the work piece and of the rate of linear feed of the tool, irrespective of the direction but in direct proportion to the rate of such "in" and "out" movements.

It is a further object to provide a highly accurate and sensitive electronic control system or network for controlling the power source for revolving the work piece and for feeding the tracer and tool unit, to effect slow-down or reduction in the rate of revolution of the work piece and correlated rate of linear speed of the tool in direct proportion to the rate of movement or velocity of the tool in or out relative to the work piece as dictated by the pattern contour.

Another object is to provide a direct current electrical motor as the common power source for revolving the work piece and feeding the tool and tracer therealong, together with an electronic control system which includes grid-biased, gaseous power tubes for controlling the rate of speed of such motor, with the control of the grids of such power tubes effected by signals in the form of an electrical potential or voltage imposed on said electronic control system to cause functioning thereof to reduce the motor speed in direct proportion to the rate of movement of the tracer and tool "in" or "out" relative to a work piece and to restore such electronic system to normal condition for maximum speed of operation of the motor with maximum rate of revolution of the work piece and feed of the tracer and tool when the tool is at rest radially or in directions "in" or "out" relative to a work piece.

Another object is to provide an electrical instrumentality for generating a signal by movements of the tool toward or from, i. e. "in" or "out" relative to the work piece, in the form of an electrical potential or voltage of a magnitude in direct proportion to the rate of any such movements for causing operation of the electronic system to effect a slow down in the rate of speed of the work revolving and feeding motor in direct proportion to the magnitude of the generated signal.

And a further object is to provide such a signal generator in the form of a coil electrically connected into the electronic control system, and a permanent magnet, with the magnet and coil mounted for current generating movements relative to each other by movements of the tracer and tool unit toward and from a work piece, for generating by such relative movements the signal potential or voltage for operating the electronic control circuits.

It is another object to provide such an electronic control system or network for controlling the rate of speed of the motor for revolving the work piece and feeding the tool therealong, in which the inertia of the motor following a slow down or speed reduction thereof, is effectively braked electrically to thereby instantly bring the motor to the lower rate of speed without appreciable lag or time delay.

With the foregoing and various other objects, features and results in view which will be apparent from the following detailed description and explanation, my invention consists in certain novel combinations and arrangements of parts, elements and organizations, and in the design and construction thereof, all as will be more fully and particularly referred to and specified hereinafter.

Referring to the accompanying drawings in which similar reference characters refer to corresponding parts and elements throughout the several figures thereof:

Fig. 1 is a perspective view taken from the front of a rotary duplicating machine of my invention, showing a turbine blade blank mounted therein for automatic pattern controlled machining of the blade to completed form.

Fig. 2 is a view in front elevation of the machine of Fig. 1, certain elements of the work spindle drive and saddle and carriage unit feed and rapid traverse being shown in dotted lines.

Fig. 3 is a view in front elevation of the machine of Fig. 2 with the saddle and carriage unit removed, a portion of the machine frame structure being shown in vertical section to disclose certain of the gear trains and clutches of the feed and rapid traverse drive transmissions.

Fig. 4 is a vertical transverse section through the feed and rapid traverse drive transmissions, taken as on the line **4—4** of Fig. 2.

Fig. 4*a* is a horizontal sectional view taken as on the line **4*a*—4*a*** of Fig. 4 and showing in top plan the shiftable clutch actuators and associated operating mechanisms.

Fig. 5 is a view in elevation of the right hand end of the machine of Fig. 1, showing particularly the pull-back cylinder air controlling valve unit, the control mechanism therefor, and the lines thereto.

Fig. 6 is a horizontal section taken as on the line **6—6** of Fig. 5, showing particularly the anti-friction slide mounting of the cross feed carriage on the saddle and the feed clutch for the saddle and carriage unit feed screw.

Fig. 7 is a transverse, vertical section taken as on the line **7—7** of Fig. 2.

Fig. 8 is a vertical transverse section taken as on the line **8—8** of Fig. 2, and showing particularly the work spindle and its drive and the construction of one of the cross feed carriage spring loading units.

Fig. 9 is a top plan view showing the feed control rod and rapid traverse clutch control rod and associated mechanisms at the opposite ends thereof, respectively.

Fig. 10 is a purely schematic view showing the relationships between the peripheral pattern surface of the master cam and the contour of the finished article from which generated, with the tracer roller and cutter, respectively.

Figs. 11, 12 and 13, are diagrammatic views illustrating by vector diagrams the variations in the magnitude of the velocity of movement of a contour surface of a revolving work piece past the point of cutting engagement therewith of a material removing tool in different locations around the contour of the work piece when the speed of the rotation of the work piece is not correlated with the velocity of radial movements of the tool toward and from the work piece.

Figs. 14 and 15 are diagrammatic views illustrating by vector diagrams the maintenance of constant velocity of movement of the contour surface of the revolving work piece past the point of material removing engagement therewith of the tool by the control provided by the invention.

Fig. 16 is a schematic diagram of the circuits and associated electrical elements constituting the spindle motor electronic speed controlling and braking network.

Fig. 17 is a schematic diagram of the power circuits for the cutter spindle and rapid traverse motors, and for the rapid traverse clutch, feed clutch and air cylinder control valve actuating solenoids.

Fig. 18 is a schematic diagram of the control circuits for the power circuits of Fig. 17.

Fig. 19 is a vertical section taken through the signal generating magnet and coil unit.

Fig. 20 is a bottom plan view of the signal generating magnet and coil unit.

A machine organization has been selected and is illustrated and described herein by way of example as of a type in which the work piece or blank to be machined is positioned and mounted for rotation about a horizontally disposed axis, with the cutting tool pattern controlled for cross feeding toward and from the work piece or blank in either direction along a straight line path disposed radially of and passing through the axis of revolution of the work piece. However, it is to be understood that the control system and the combination thereof with the components of a machine of the invention are not limited to adaptation to the particular machine organization of the example having such relative positioning of the work piece and cutter, as the invention contemplates and includes adaptations to and combinations with machine organizations in which the work piece may be revolved about a vertically or angularly disposed axis with the cutting tool cross fed under the control of the pattern, inwardly and outwardly relative to the work piece along a path disposed radially of and relative to such a vertical or angular axis of work piece revolution.

The illustrated example machine organization of the invention, referring now to Figs. 1, 2, 3 and 5, in particular, includes a main frame structure 1 which may be in the form of a single casting, or may be built-up from separate elements or components to provide a composite structure.

This main frame structure 1 comprises, in this instance, vertical, spaced supporting columns or pedestals 11 and 12 which may be of hollow construction and are in this example, of generally rectangular cross section; a horizontally disposed bed or bench 14 extending across and between pedestals 11 and 12 and providing by its upper side a horizontal bed or bench surface 14*a*; and a vertically disposed wall structure 15 which is "set back" from the forward side of bed or table 14 and extended upwardly therefrom along and across the rear side thereof. The upper edge or top wall 15*a* of vertical wall structure 15 provides a horizontal, relatively narrow mounting base or supporting surface extending across substantially the full width of the machine. This mounting base 15*a* is preferably provided with T-slots 15*b* disposed longitudinally therealong.

General machine organization

At an intermediate location on the top edge wall 15*a* of vertical wall structure 15, there is provided and mounted a work spindle head 16 in the form of a generally rectangular casing disposed transversely of wall structure 15 and being projected a distance forwardly therefrom above bed 14*a*. A power driven work and pattern spindle 17 is mounted and journaled in horizontally disposed position extending through head 16, and generally longitudinally of the machine. The work spindle 17 is positioned in the forward portion of head 16 with the inner or right hand end thereof being provided with and mounting a work holding chuck or the like fixture 17*a*, into which one end of a work piece or blank W to be machined may be secured in mounted position for revolution by the spindle about a horizontal axis. The opposite, outer or left hand end of spindle 17 is provided with a suitable mounting fixture or holder 17*b* for attachment thereto in mounted position thereon, of a circular pattern or master cam M for rotation by spindle 17 about the horizontal axis of revolution of the work piece W. Head 16 houses a suitable power drive to be hereinafter described, for rotating spindle 17 from a motor SM which, in this example, is of the variable speed, shunt wound, D. C. type.

A saddle structure 18, referring to Figs. 5, 6, 7 and 8, is slidably mounted in vertically disposed position on the forward or front side of the vertical wall structure 15 below the spindle head 16 but above bed 14, for movements longitudinally of the machine in either direction along a straight line path generally parallel with the axis of the work spindle 17. This saddle structure 18 is translated along its straight line path of movement from right to left on its feeding cycle, by a feed screw F driven from the spindle motor SM through a suitable power transmission or drive, as will be described hereinafter. The feeding movement of the saddle 18 is effected at a rate of linear feed which is in direct proportion to the rate of revolution of the work piece W by the work spindle 17.

The movement of saddle 18 in the reverse direction, that is, from left to right relative to the machine in this instance, is effected at a rapid traverse rate by a separate and independent motor RTM located at the left hand end of the machine, through a drive transmission to be later described, and adapted to be engaged selectively either automatically or manually under the control of the operator with the saddle feed screw F. The rapid traverse drive transmission is associated and interlocked with mechanism for disconnecting the feed screw F from the feed drive driven from the spindle motor SM, before the rapid traverse drive is connected with feed screw F, and for disconnecting the latter drive before the feed drive is connected.

A cutter and tracer cross feeding slide or carriage 19 is slidably mounted on and carried by the saddle structure 18. Carriage 19 is movable upwardly and downwardly, i. e. "in" or "out" to a work piece, on saddle structure 18 independently thereof along and constrained to a straight line path radially disposed relative to the axis of revolution of the work piece W, and being perpendicular to the path of horizontal feed and rapid traverse movements of the saddle structure 18. Thus, the carriage 19 is movable for cross feeding a cutter tool and tracer "in" and "out" radially relative to a work piece W and a master cam M, respectively, and for feeding and rapid traverse movements as a unit with saddle 18, axially along the workpiece and master cam.

The cross feed carriage 19 thus mounted, is moved bodily laterally along the work piece and master cam with the saddle 18 on all longitudinal feed and rapid traverse movements of the latter. The carriage 19 mounts thereon at the right hand upper end portion thereof a self-contained power driven cutter spindle unit 20 which, in this instance, includes the cutter spindle 21, an electric motor CM, and a suitable power transmission or drive 22 from the motor to the spindle.

The inner end of the cutter spindle 21 is adapted to mount thereon a circular cutting tool such, for example, as a circular milling cutter C having cutting teeth or cutting edges CT spaced around the periphery thereof.

At the opposite, left hand end of the cross feed carriage 19, there is mounted a tracer unit 23, which includes a circular tracer element or cam follower in the form of an idler roller T mounted and positioned opposite master cam M for rotation about an axis parallel with the axis of revolution of the cam M, by rolling contact with the cam as the latter is revolved.

The cutter spindle unit 20 and the tracer unit 23 are adjustably mounted and attached on cross feed carriage unit 19 for the required positioning thereof relative to each other to properly position the cutter C and the tracer T relative to a work piece W and master cam M, respectively.

A biasing means is provided acting continuously to yieldingly bias the cutter and tracer cross feed carriage unit 19 along its radial path of feed inwardly toward the master cam M and work piece W in order to position and engage the tracer roller T with cam M and the cutter C in cutting engagement with a work piece W. Such biasing means, in this example, is of the spring loading type embodying a pair of spring units 24 mounted and supported on and in position depending from the lower side of the saddle structure 18, with suitable force transmitting mechanism to be hereinafter described, operatively connecting units **24** with the cross feed carriage unit **19** for spring loading such carriage from the units **24**.

A mechanism which may be automatically and/or manually controlled, is provided for retracting the cross feed carriage unit **19** from operative, spring biased position engaging tracer roller T and rotary cutter C with master cam M and work piece W, respectively, against the biasing forces exerted on the carriage by the spring loading units **24**. In the machine organization of the present example, such retracting or "pull-back" mechanism is constituted by a fluid pressure actuated cylinder and plunger unit **25** mounted and supported on and depending from the lower portion of the saddle structure **18**, and a pressure fluid control valve unit **26** mounted at the right hand end of bed **14** of frame structure **1**, for controlling either automatically or manually the cylinder and plunger unit **25**.

In automatic cycling, the control valve unit **26** is caused to be operated to "pull back" or retract cross feed carriage **19** to withdrawn position relative to the master cam M and the work piece W, by the arrival of the saddle structure **18** at the end of its feed movement and prior to the rapid traverse of the saddle structure back to starting position for the next machining cycle. The control valve unit **26** also includes a hand lever **26A** by which the valve may be manually operated to effect "pull back" of the cutter and tracer cross feed carriage unit **19**.

With the work piece W in mounted position in the revolving work holder of the spindle shaft, and a master cam M providing the peripheral contour surface therearound constituting an enlarged or "blown-up" and precise reproduction of the contours radially and axially of the portion of the work piece or blank W which it is desired to machine out to completed form, the machine organization is set for effecting such machining by releasing the cross feed carriage **19** to the action of the spring loading units **24**, so that, the carriage is spring biased and forced thereby upwardly and inwardly at a controlled rate toward the master cam M and work piece W, until the tracer roller T is engaged and maintained yieldingly in engagement with the peripheral pattern surface *m* of the master cam. By properly adjusting the cutter spindle unit **20** of the cutter C thereof on the carriage **19** relative to the tracer unit **23** and its tracer roller T, the cutter C with the carriage unit **19** in such spring biased position will be properly located for machining engagement with the work piece W for the start of the machining cycle.

The spindle motor SM is then placed in operation to revolve the work piece and simultaneously to rotate the feed screw F for feeding the saddle structure **18** and the tracer and cutter carriage **19**, axially along the work piece W and the master cam M. As the master cam M is revolved with the tracer roller T spring biased yieldingly into engagement with the cam, the cross feed carriage **19** is moved inwardly toward and outwardly away from the work piece W as the tracer roller T follows the pattern surface of the revolving cam, being forced outwardly away from the work piece by portions of the cam surface of greater radius and being forced or biased inwardly by the spring loading from units **24**, to follow and maintain "sensing" engagement with the portions of the cam surface of lesser radius.

An important and basic feature of the invention, resides in controlling automatically the rate of rotation of the work piece W and the rate of linear feed of the saddle structure **18**, by the rate of movements either inwardly or outwardly of the cutter and tracer cross feed carriage **19**, radially relative to the axis of revolution of the work piece. By this feature, as will be hereinafter explained in detail, when the cross feed carriage **19** is at rest, the motor SM is operated at its maximum speed setting to revolve the master cam M and the work piece W and to feed saddle structure **18** and the cross feed carriage **19** at maximum rates of rotation and linear feed, respectively. But upon movement of the cross feed carriage unit **19** in either direction, that is, inwardly or outwardly, along its radial path of movement, the rate of speed of the motor SM is reduced to thereby reduce both the rate of revolution of work piece W and cam M and the rate of linear feed of the saddle structure **18**, in direct proportion to the rate of movement of the cross feed carriage.

In this example, such "slow down" control is effected through the medium of an electronic control system or network which is caused to function and control the rate of speed of the motor SM through the imposition on the network of an electrical signal in the form of a potential or voltage of a magnitude dependent upon the rate of movement of the cross feed carriage. Such signal impulses are generated by a signal generator G which is actuated by the cross feeding movements of the carriage **19** to generate and impose on the electronic motor control network a signal in the form of an electrical potential or voltage of a magnitude in direct ratio to the rate of carriage movement at any instant, that is, the higher the rate of movement the greater the magnitude and the lower the rate of movement the lower the magnitude, of the electrical potential or voltage of the signal imposed on the electronic network.

Work and pattern spindle and drive therefor

The work and pattern spindle **17**, referring now to Figs. 2, 3 and 8, is in this particular example of general barrel or drum form having a low diameter to length ratio. Spindle **17** is mounted in horizontal position across and within the forward side of the head **16**, with its opposite ends journaled in suitable antifriction bearing assemblies **17*c*** and **17*d*** secured in opposite side walls, respectively, of the casing forming the head **16**. A worm wheel **30** is provided on and around spindle **17** adjacent the right hand end thereof within head **16**. The variable speed, direct current motor SM is mounted in position on and extended rearwardly from the rear of head **16** with the motor shaft **31** horizontally disposed with its axis generally perpendicular to the axis of work spindle **17**.

The motor shaft **31**, or an extension thereof, is extended forwardly through head **16** across the upper side of and generally tangential to the worm wheel **30**. Motor or power shaft **31** mounts on the forward end thereof a worm **32** in driving mesh with the worm wheel **30** of spindle **17**. Thus, operation of motor SM rotates the engaged worm **32** and worm wheel **30** to revolve the work spindle **17** at a rate of speed determined by the rate of rotation of motor SM and the gear ratio between worm **32** and worm wheel **30**.

The motor SM is of the variable speed type and may be manually controlled for starting and stopping by the "Start" button **5** and the "Stop" button **6** located at the control push button station 4 mounted on the upper side of the spindle head 16. Control buttons 5 and 6 are suitably connected in the control circuit for the motor SM, as will be clear by reference to Fig. 21.

Longitudinal feed and drive therefor

The feed of the saddle and cross feed carriage unit 18—19, is effected through a suitable power transmission mechanism driven by the motor SM and driving the longitudinal feed screw F. This transmission feeds the carriage unit 18—19 with cutter C and tracer roller T, axially along a work piece W and the master cam M, respectively, in a direction from right to left relative to the machine, in this example. Feed screw F is mounted in horizontally disposed position longitudinally of the machine at the forward side of the vertical wall structure 15 and extends across the rear side of saddle structure 18, being operatively engaged therewith by a suitable feed screw nut unit FN. The feed screw F is supported and journaled adjacent its opposite ends in suitable anti-friction bearings 15c and 15d, respectively, carried on or from adjacent portions of the vertical wall structure 15 of the machine frame. In this example, feed screw F is extended outwardly at its right hand end beyond the adjacent end of vertical wall structure 15 and mounts thereon a suitable hand wheel or crank FH for selective operation to manually operate the feed screw to move the saddle structure 18 either in a feed or in a rapid traverse direction.

The drive or power transmission from motor SM to the feed screw F comprises a system of shafts and gears, including a power input or drive shaft and a change speed gear train for selective setting to cause feeding rotation of the feed screw within a selected range of several ranges of feeding speeds. Such drive shaft 33, referring now to Figs. 2, 3 and 8, is mounted and journaled in vertically disposed position spaced to the rear of spindle 17 and extending a distance upwardly through and into the head 16. Shaft 33 extends downwardly from head 16 through an annular bearing holder 34 mounted in a vertical opening formed in the top wall 15a of vertical wall structure 15. A bearing sleeve 34a is mounted at its upper end in bearing carrier 34 and depends downwardly therefrom with its bore in axial alignment with the axis of shaft 33. Bearing sleeve 34a is received in and extends downwardly through a vertical bore formed in fixed structure 34b within the frame.

A bevel gear 35 is positioned in the bore in structure 34b between the lower end thereof and the lower end of bearing sleeve 34a. The bevel gear 35 is provided with an upwardly extended sleeve forming hub 35a which is journaled in the bearing sleeve 34a. The bevel gear 35 and its hub are formed with an axial bore therethrough having its surrounding wall longitudinally splined. The lower length of shaft 33 is provided with longitudinal splines 33a thereon and extends through the splined bore of bevel gear 35 in driving engagement with that gear.

The drive shaft 33 terminates in the upper portion of head 16 in a reduced diameter section 36 having thereon the longitudinal splines 36a. Splined section 36a extends upwardly through the splined axial bore of a worm wheel 37 and its upwardly extended hub forming bearing sleeve 37a, so that, drive shaft 33 is in driven relation with worm wheel 37. The hub forming sleeve 37a of worm wheel 37 is journaled in a set of anti-friction bearing assemblies 37b mounted in an annular wall formed by a flange 37c depending into the head 16 from the upper side thereof.

The worm wheel 37 is in driven engagement with a worm 37′ on the motor drive shaft 31. Hence, when motor SM is operating to drive work spindle 17, the worm wheel 37 is simultaneously driven from the worm 37′ to drive shaft 33 and the bevel gear 35 at the lower end thereof.

A bevel gear 38 having an extended sleeve forming hub 38a is mounted in horizontal position in a bearing 38b in structure 34b with the bevel gear 38 in driven engagement with bevel gear 35. A horizontal shaft 39 is mounted with its inner end extended into the hub 38a of bevel gear 38 in driven relation therewith. Shaft 39 extends horizontally and downwardly within wall structure 15 toward the left hand end of the machine, and at its outer end is supported and journaled in an anti-friction bearing assembly 39a mounted in vertically disposed fixed structure, such as the wall or plate member 39b, within the vertical frame structure 15. At its outer end at the outer side of plate member 39b, the shaft 39 mounts and has keyed thereto a pinion 40 in driven relation therewith.

A change speed gear train is provided between and connecting driven pinion 40 with the feed screw F, through a feed clutch unit FC. This change speed gear train is of the two-speed type so as to give two (2) ranges of speed within which feed screw F may be driven by the variable speed motor SM.

Operating mechanism for the clutch FC is provided and includes a manually operable rock shaft 60 mounted and journaled in the machine frame structure extending through the forward wall of a gear casing 61 which extends forwardly from frame structure 15 at the left hand end of the machine. Hand lever FCH is removably mounted in a socket member 61a secured on the exterior end of shaft 60 for rocking this shaft to cause operation of clutch FC to place motor SM in driving connection with feed screw F or out of driving connection with the feed screw.

A clutch actuator 58 is coupled by mechanism 60′ with the inner end of shaft 60. Actuator 58 is also operable by a feed rod 62 which is mounted extending across the machine above bench 14. The left hand end of feed rod 62 is pivotally coupled with the end of a crank arm 63 on shaft 60. Feed rod 62 is mounted for movements axially in either direction by swinging of crank arm 63, or conversely, for movements in either direction by forces applied to the rod at the right hand end of the machine.

In this example, the clutch FC is adapted to be actuated to position for driving feed screw F by manual operation of rock shaft 60, and to be actuated to position out of driving connection with feed screw F by either manual actuation of shaft 60 or automatically by energization of a solenoid FS.

Rapid traverse drive

For rapid traversing the saddle and cross feed carriage 18—19, the feed screw F after being disconnected from the feed train, may then be driven from the rapid traverse motor RTM in a direction and at a rate to rapid traverse the saddle and carriage unit 18—19 to the right from its position at the conclusion of a feed cycle, through a drive mechanism which includes a clutch unit RTC.

Operating mechanism is provided for the clutch RTC. This mechanism includes a manually operable rock shaft 78 mounted and journaled in the machine frame structure in position extending through the forward wall of gear casing 61. In this instance the rock shaft 78 is positioned parallel with but spaced downwardly and forwardly relative to the rock shaft 60 for the feed clutch FC. Socket member 78' is secured on the exterior end of shaft 78 for removably receiving a suitable hand lever for rocking the shaft.

A crank arm 79 is mounted on the inner end of rock shaft 78 and depends downwardly therefrom. A rapid traverse clutch control rod 80 is pivotally and slidably connected to the lower end of crank arm 79 by a pin 80*a* which is received in the vertically slotted, bifurcated end of the crank arm, as will be clear by reference to Figs. 3 and 4. Rod 80 extends from the crank arm 79 across the machine at the forward side of vertical wall structure 15 and immediately above the upper surface 14*a* of bench 14, to the right hand end of the machine where the rod is suitably slidably journaled in an end wall of stricture 15. Thus rapid traverse clutch control rod 80 is mounted for movements axially in either direction by swinging or oscillation of crank arm 79, or conversely, is movable axially to swing that arm in either direction by forces applied to the rod acting axially thereof.

The rapid transverse clutch RTC is adapted to be engaged and disengaged automatically in the normal work piece machining cycle of the machine. The clutch is engaged automatically by energization of the rapid traverse clutch actuating solenoid RTS which, in this instance, is mounted within the casing 61 on the rear wall of vertical frame structure 15, as will be clear by reference to Figs. 4 and 4*a*.

The rapid traverse clutch RTC in the normal operating cycle of the machine is disengaged mechanically but automatically after engagement by the solenoid RTS, by actuation of the rapid traverse carriage control rod 80 from the saddle and carriage unit 18—19.

Rapid traverse clutch RTC may also be selectively engaged and disengaged manually by the operator by rocking shaft 78 from a suitable hand lever such as lever FCH, inserted in the socket member 78'.

Saddle and cross feed carriage unit

The saddle and carriage unit 18—19 includes the saddle 18 mounted for movements longitudinally of the machine parallel with the axis of the work spindle 17, and the cross feed carriage 19 mounted for movements on saddle 18 in a path perpendicular to the path of longitudinal movements of the saddle and disposed radially of the axis of rotation of the work spindle 17. The cross feed carriage 19 mounts thereon the tracer T and the rotary cutter C which are moved with the carriage simultaneously in a fixed relationship toward and from master cam M and a work piece W, respectively, along straight line paths disposed radially of and which in this instance pass through the common axis of rotation of the master cam M and a work piece W.

Referring to Figs. 3 to 8, in connection with Fig. 2, the saddle 18 is constituted by a body structure which may be in the form of a casting slidably mounted and constrained to straight line movements on vertically spaced, parallel and horizontal ways 18*a* provided on the forward side of the vertical wall structure 15 in locations thereon parallel with the axis of rotation of the work spindle 17. The inner side of saddle 18 is provided with slide ways 18*b* in which the ways

18*a* are received to slidably mount and confine the saddle in its operative position on frame structure 15. The forward side of saddle 18 provides an upwardly and rearwardly (downwardly and outwardly) inclined forward surface or bed 18*c* which at its lower outer side terminates in an edge portion positioned spaced a distance forwardly of the vertical plane of the forward sides of pedestals 11 and 12 and bench 14. Thus mounted, the saddle 18 is horizontally slidable on ways 18*a* in either direction along a straight line path longitudinally of the machine to the right or left.

At its rear side the saddle 18 mounts the feed screw nut FN providing an internally threaded bore through which the feed screw F extends with the external threading thereof in engagement with the internal threading of the feed nut FN. The feed screw F is located intermediate and within the space between ways 18*a* with the feed nut FN extended inwardly into the space between the ways in driven engagement with the feed screw.

The cross feed carriage 19 is constituted by a table forming structure mounted on the forward, inclined side of saddle 18 and having a length longitudinally of the machine considerably greater than the width of saddle 18, so as to provide for mounting thereon the tracer unit 23 and the powered cutter spindle unit 20 for operative positioning thereon relative to master cam M and the work piece W, respectively. Carriage 19 is preferably of such a length horizontally as to extend beyond the right hand end of vertical wall structure 15 when the saddle and carriage unit is at its limit of rapid traverse movement to the right in position for feeding into a work piece at the start of a machining cycle. If desired, as in the example hereof, the right hand end section of carriage 19 may have bearing engagement with a bearing surface provided on the adjacent portion of saddle 18, as indicated at 19*e* in Fig. 6.

Carriage 19 is mounted on the forwardly inclined bed provided by saddle 18 for movements upwardly or downwardly thereon, that is, in or out relative to master cam M and a work piece W, along a path perpendicular to the path of longitudinal movements of saddle 18 and radially disposed relative to the work piece 17. The plane of the outer surface of the table structure provided by carriage 19 is generally parallel with the plane of the inclined forward surface of the saddle body, so that, forward surface of carriage 19 is disposed and movable in an upwardly and rearwardly (downwardly and forwardly) inclined plane disposed generally radially relative to work spindle 17.

In this example, carriage 19 is mounted on and constrained to such path of movements by an arrangement of spaced, vertically disposed series of anti-friction balls 19*a* confined in rolling, minimum friction contact between pairs of rails or tracks 19*b* and 19*c*, with the rail or track 19*b* of each pair mounted on and movable with carriage 19 and the opposite rail 19*c* of each pair fixed on saddle 18, as will be clear by reference to Fig. 6. Thus mounted, cross feed carraige 19 is movable on and independently of saddle 18 for its cross feed movements "in" and "out," with minimum friction and constrained to the path of such movements by these spaced, anti-friction ball slide arrangements.

Cross feed carriage 19 is provided with the horizontal, vertically spaced T-slots 19*d* in the front side thereof, by which the tracer unit **23** and the powered cutter spindle unit **20** may be adjustably mounted and positioned on the carriage.

Tracer unit and cutter spindle unit

The tracer unit **23** includes a mounting frame structure or carrier having a base **23***a* secured in position adjusted longitudinally of carriage **19**, by the attaching bolts **23***b* engaged in a T-slot **19***d*, and a frame **23***c* mounted on this base for adjustment horizontally and vertically of the base. The upper end of frame **23***c* has a tracer spindle mounting head **23***d* positioned thereon extending horizontally thereacross. The head **23***d* mounts and journals therein the horizontal tracer spindle **23***e*. Spindle **23***e* extends longitudinally through head **23***d* and mounts at the left hand, exterior end thereof the circular tracer roller T for rolling sensing engagement with the pattern surface *m* around the master cam M. The tracer mounting frame or carrier is preferably arranged for micrometer adjustments horizontally and vertically for set-up purposes.

The powered cutter spindle unit **20** includes a base **20***a* secured on the right hand end portion of carriage **19** by bolts **20***b* engaged in the T-slots **19***d* for adjustment of the position of the unit longitudinally of carriage **19**. Bolts **20***b* are received in vertically disposed slots in the base which permit of adjusting the unit **20** vertically on carriage **19**, this is, "in" or "out" relative to work spindle **17** and a work piece W mounted therein.

A cutter spindle head **20***c* is provided in horizontally disposed position on and across the upper side of base **20***a* and mounts and journals therein a cutter spindle **21**. Spindle **21** extends through head **20***c* and provides at its left hand end for detachable mounting thereon of a suitable circular cutter, such as a rotary milling cutter C. The right hand end of cutter spindle **21** mounts thereon suitable belt pulleys **21***a* of different effective diameters, respectively.

On the base **20***a* below cutter head **20***c* there is mounted the cutter spindle drive motor CM as a component of the unit **20**. Motor CM is positioned with its shaft **20***d* disposed horizontally. Motor shaft **20***d* mounts on its right hand end the pulleys **20***e* of different effective diameters, respectively, for selective driving engagement with the pulleys **21***a*, of cutter spindle **21** by the belt **20***f*.

The arrangement and adjusted mounting of the tracer unit **23** and of the cutter spindle unit **20** relative to each other and relative to the master cam and a particular work piece W to be machined, is such that the axes of rotation of the tracer roller T and of a cutter C on spindle **21**, lie in a radial plane passing through the common axis of rotation of the master cam and the work piece, such plane constituting the path of straight line "in" and "out" or cross feeding movements of the carriage **19** and being inclined forwardly and downwardly relative to a vertical plane.

As will be explained hereinafter, the width of the peripheral pattern surface *m* around the master cam M is the same as the length of that portion of a work piece W to be machined, so that, tracer unit **23** and cutter spindle unit **20** are mounted in an adjusted, horizontally spaced fixed relationship such that the tracer roller T will engage the right hand side or starting portion of pattern surface *m* at exactly the moment that the rotary cutter C first makes machining contact with the right hand or outer end of the work piece W at the start of the machining cycle. And such relationship as "set up" for a particular work piece and master cam therefor, remains fixed throughout the machining and rapid traversing cycles.

Cross feed carriage biasing mechanism

In the machine of this example, the cross feed carriage **19** is spring biased upwardly, that is, inwardly, toward master cam M and a work piece W by the spring loading units **24**. Referring to Fig. 8 in connection with Figs. 1, 2 and 5, each spring loading unit **24** embodies a cylindrical casing **24***a* mounted and supported at its upper end by a bracket or mounting structure **24***b* from the lower forward side of saddle **18**, in position depending downwardly from the saddle into position at the forward side of the machine. Two (2) such units are employed in this instance, mounted in position depending from the saddle **18**, spaced equidistant from the vertical or medial center of the saddle (see Fig. 2).

Under the combined biasing forces of the two units **24**, the carriage **19** is continuously spring biased upwardly to a position to engage tracer roller T with master cam M and to position cutter C for machining engagement with a work piece W. The biasing forces may be adjusted by adjusting the threaded stems **24***e* to increase or decrease the compression of springs **24***i*, as well as for adjustment relative to each other to equalize the biasing forces applied by these units to the carriage **19**.

It is to be here noted that the cross feed carriage **19** is so mounted on and positioned by the forwardly inclined bed provided by saddle **18**, that the carriage moves along and is constrained to a straight line path in a plane inclined at an angle forwardly and downwardly (rearwardly and upwardly) to the horizontal. In this particular example, such angle is of the order of approximately 70° to the horizontal, so that, the cross feed carriage is in effect canted or inclined at an angle of approximately the order of 20° from the vertical. By this arrangement and mounting of the cross feed carriage, the operational sensitivity of the carriage is increased, and hence, contact pressures required for accurate following are thereby reduced with resulting increase in precision and efficiency in operation.

Cross feed carriage "pull back" mechanism

In order to retract or "pull back" the cross feed carriage **19** downwardly to a position with the tracer roller T and the cutter C out of engagement with and clear of master cam M and a work piece W, for rapid traverse of the saddle and carriage unit **18**—**19** from its position at the end of the machining cycle to its position for the start of the next machining cycle, a carriage retracting or "pull back" mechanism is provided which in this example is of the air pressure actuated type. This pull back mechanism includes the air cylinder **25**, a control valve **26** with a control lever **26A**, and suitable air lines connected between the valve and the cylinder and connecting the valve with a source of air under pressure.

The air cylinder **25**, referring now to Figs. 1, 2 and 5 in particular, is mounted by a suitable bracket structure **25***a* to the lower forward portion of saddle structure **18** in position between spring loading units **24** and extending downwardly and forwardly from the saddle structure in general parallelism with the units 24. Cylinder 25 includes a piston 25b reciprocal therein and having a piston or actuating rod 25c extending upwardly and outwardly through a suitable sealing gland in which it is slidably received in the upper end head of cylinder 25. The upper end of this plunger 25c is connected to the lower edge portion of carriage body 19 as will be clear by reference to Fig. 5. Such connection may be effected by threading the upper end of rod 25c into a tapped bore opening through the lower edge of carriage body 19, or in any other suitable manner.

Cylinder 25 is provided through the side wall adjacent the upper end thereof, with an inlet-outlet port 25d for discharge of pressure fluid into the cylinder above piston 25b to force the piston downwardly in the cylinder, and for discharge of pressure fluid from the cylinder to relieve the pressure therein to permit of the piston being drawn upwardly in the cylinder under the action of the spring loading units 24 on carriage 19. Thus, by discharging pressure fluid through port 25d above piston 25b the piston is forced downwardly to thereby retract or pull back carriage 19 against the biasing forces exerted thereon by units 24. When pressure fluid to the cylinder is cut off and port 25d is opened to atmosphere for releasing the pressure in the cylinder by exhausting therefrom the contained fluid, the spring biasing units 24 then take over and return carriage 19 upwardly to operatively position tracer roller T and the cutter C.

In this instance the operation of pull back cylinder 25 is effected through the medium of the control valve 26.

Control valve 26 may be of any of the familiar three-way types suitable for the purpose.

Air cylinder control valve solenoid and feed clutch interlock

The solenoid AS is provided for actuating automatically the control valve unit 26 from air cylinder exhausting position to position for discharging air under pressure to the air cylinder 25. This solenoid AS is mounted in horizontally disposed position extending forwardly from a rear depending wall portion of a bracket and housing structure 85, supported from the right hand side wall of frame structure 15 to the rear of valve unit 26 (see Fig. 5). Solenoid AS includes an armature 86 projecting forwardly therefrom with its axis generally parallel with and in the same horizontal plane as the axis of the valve plunger 26c of valve unit 26 suitable mechanism is included operatively coupling the valve plunger with armature 86.

When the solenoid FS is energized at the end of the feed cycle, the clutch FC is moved to position disconnecting feed screw F from the feed gear train from motor SM. Simultaneously with the energization of solenoid FS, the control valve solenoid AS is energized and forces valve plunger 26c outwardly to set the valve unit 26 for discharge of air under pressure into the cylinder 25 to effect pull back of the carriage and saddle unit 18—19.

After the completion of the rapid or return traverse and with the saddle and carriage unit 18—19 in position for starting the next machining cycle, the operator may, after manually releasing the safety latch 28 by means of hand lever 29 to release feed carriage 19 (see Fig. 5), swing the control lever 26A to its intermediate position for throttled release of pressure from cylinder 25 to atmosphere to thus effect a controlled, slow, upward projection of the saddle and carriage unit to operative position for starting the next feed cycle.

Feed stop rod and feed limit switch

The saddle 18 mounts a horizontally disposed feed stop rod 90 which is adjustably secured to the left hand side of the saddle and which projects a distance outwardly therefrom with its axis parallel with the path of feed and traverse movements of the saddle and carriage unit 18—19.

Referring to Figs. 1, 2 and 7, this feed rod 90 has at its outer (left hand) end a conical head 91 which provides a camming surface therearound, with the outer end of the head providing a flat abutment surface 91a for engaging a fixed stop member 92 secured in position on the right hand side wall of the casing 61, in line with feed rod 90, to stop feed movement of the carriage unit at a predetermined point.

A feed limit switch 9, which in this example may be considered to be of the well-known micro switch type, is mounted in position on vertical frame structure 15 adjacent the right hand side wall of casing 61. Feed limit switch 9 includes a spring loaded switch contact actuating pin 93 which projects forwardly into position in the path of the head 91 of feed rod 90 for engagement by the conical camming surface of that head. Feed limit switch 9 is of the normally open contact type and is closed by forcing the actuating pin 93 inwardly. Upon release of inward forcing pressure from pin 93, the switch restores automatically to circuit opening position.

During the feed cycle, as the saddle and carriage unit 18—19 approaches the end of its feeding movement, the camming surface of the conical head 91 of feed rod 90 engages and forces limit switch 9 to circuit closing position in advance of the engagement of the abutment end 91a of head 91 with the stop 92. As will be more fully explained hereinafter, closing of limit switch 9 sets into operation certain timing relays which, after a predetermined period of time, will effect energization of solenoid FS to cause operation of slip clutch FC to disengage gear 57 from feed train gear 46 and thus disconnect feed screw F from driven connection with the feed train.

Rapid traverse interlock switch

An interlock switch 10, referring to Fig. 9 in particular, is mounted on frame structure 85 at the right hand end of the machine in position adjacent and opposite the inner side of crank arm 88. This switch 10 may be of the micro-switch type familiar in the art, and is of the normally open contact type. Switch 10 includes a spring loaded actuating pin 88b which projects outwardly from the outer side thereof and which on inward displacement closes the switch contacts and the circuit connected therewith. Upon release of inward acting pressure therefrom, actuating pin 88b springs outwardly to restore the switch to circuit opening position. An abutment member 88c is provided on crank arm 88 in position for engaging switch actuating pin 88b to close switch 10 when arm 88 is swung to the left to the position which it takes when clutch FC is moved to position disengaged from the feed gear train from motor SM. When lever 88 is swung to the right to its position with clutch FC engaged with the feed train, abutment 88c is swung out of engagement with switch actuating pin 88b to permit the switch 10 to restore to circuit opening position. Interlock switch 10 functions to close the energizing circuit to the rapid traverse clutch actuating solenoid RTS after that circuit has been set up and conditioned for closing by certain timing relays, as will be referred to hereinafter.

The master cam

The master cam M and a work piece W mounted in the work holding fixture 17a in the example machine hereof, are rotated about a common horizontal axis provided by the work spindle 17, with the master cam controlling through the cam follower or tracer roller T, the cross feeding movements of the circular, rotary cutter C toward and from the work piece W, as the cutter is fed axially along the work piece, to cause the cutter to mill out precisely the required contours of the finished article as dictated and controlled by the pattern surface *m* of the master cam.

In accordance with my invention, I provide a master cam M having therearound the peripheral pattern surface *m* which has been generated from and is an expanded or enlarged contour surface of the required contour of the finished article to be machined from a work piece or blank. The contours radially along the width of pattern surface *m* of master cam M correspond to and provide expanded reproductions of the contours radially of and angularly around the finished article, while the contours of the pattern surface *m* longitudinally or axially of the master cam at every location therearound are exact and precise expanded reproductions of the contours longitudinally or axially around the finished article. The width of the peripheral pattern surface *m* of master cam M is equal to the axial length of the portion of the work piece to be machined.

Referring to Fig. 10, I have designated schematically a cross section taken through a finished turbine blade WT of relatively flat, thin air foil section, the contours of which both radially and axially, are required to be reproduced in expanded or enlarged form radially and angularly therearound at the corresponding section or station on the master cam to be generated for use in machining from a work piece or blank W, the finished turbine blade WT. The contour of the corresponding cross section of the master cam M is shown surrounding and generated about the axis of revolution of the turbine blade WT, any desired or suitable method of generation having been utilized.

Thus, the contour surface *m* around the master cam M at the particular section illustrated, or at any section therethrough, is an enlarged or expanded contour radially of and angularly around the contour at the corresponding section or station or the relatively thin, generally rectangular air foil section of the turbine blade WT. It will be noted, for instance, that the contours angularly of the blade WT which sharply reverse in direction in following around the nose or leading edge portion WN thereof are flattened out and made less severe or sharp angularly, in the enlarged reproduction thereof at WN' on the pattern surface *m*, while the very thin trailing edge portion WE which provides contours having extremely abrupt reversal in direction in following around the trailing edge, are expanded and made less severe or critical in the radially and angularly expanded reproduction WE' thereof on the master cam pattern surface *m*. As the contours around the master cam M are formed or generated on radii of greater length than the radii of the corresponding contours on the turbine blade WT about the common axis of generation, the contours on the master cam are thus expanded angularly and are substantially smoothed out and made less severe around the pattern surface *m* of the master cam, so that, less severe or critical pressure angles will be presented between the cam follower or tracer roller T of the pattern surface *m* in following and maintaining efficient and accurate sensing contact with and around the contours presented by the master cam pattern surface *m*.

In Fig. 10, the cam follower or tracer roller T is illustrated schematically in rolling, sensing contact with the master cam pattern surface *m* at a location thereon about to be forced to climb over and trace around the portion WE' of the pattern surface which constitutes the radially and angularly expanded or enlarged contour corresponding precisely to the contour at and around the trailing edge portion WE of the turbine blade WT. The circular rotary cutter C is shown in its fixed relationship with the tracer roller T which is in milling or machining contact with the turbine blade WT at the precise location thereon corresponding to the location of roller T on the master cam pattern surface *m*. Thus, as the master cam M is rotated about the common axis of rotation of this cam and of the work piece W from which turbine blade WT is to be machined, the milling cutter C will be moved inwardly and outwardly radially relative to the work piece under the control of the tracer roller T as the latter is moved inwardly and outwardly, or will be at rest, as dictated by the high, low or concentric portions, respectively, presented by the enlarged or expanded blade contour presented by the pattern surface *m* of the master cam M.

A master cam M is generated for the contour of each particular article to be machined, and is removably mounted in the machine for rotation with the work piece about a common axis, by the work spindle 17 driven from motor SM. Thus, a master cam may be readily removed and replaced by a cam for controlling the machining of an article of different contour.

The master cam M, referring now to Figs. 1, 2, and 7, is mounted in position at the left hand side of head 16 in driven relation with the work spindle 17 and a work piece W mounted in the work holder or fixture 17a. Cam M is secured on a suitable mandrel or arbor 96 and is mounted in operative position in the machine by attaching the cam and mandrel at the right hand side thereof to the work fixture 17b in driven connection therewith and by mounting and journaling the opposite, extended left hand end of the mandrel in a bearing provided at the outer end of a bearing hanger 97, which is adjustably secured on the upper side wall 15a of vertical wall structure 15, by suitable attaching bolts secured in a T slot 15b.

A work piece W from which the turbine blade WT of this example is to be machined, is removably secured rigidly held at its root end in the work holding fixture or chuck 17a in position for rotation thereby on a common horizontal axis with the master cam M. A suitable dead center 98 may be provided for the outer tip end of the work piece W if desired or found necessary. The use of such dead center is dependent on the particular work piece being machined. The dead center 98 is provided by a forwardly extended arm or hanger bracket removably secured for adjustment to the required position longitudinally of the upper side 15a of wall structure 15 by a suitable bolt or the like removably attached in a T slot 15b.

Rotary circular cutter and tracer roller

The rotary cutter C is circular and in this instance may be considered to be a milling cutter having teeth CT disposed around and transversely of its periphery at spaced intervals, the number of teeth and the spacing and angular relationship thereof to the axis of rotation of the cutter being primarily dependent upon the particular article to be machined and the material of which it is formed. It has been found that in the machining of an article such as the thin, generally flat rectangular section exemplified by the turbine blade WT of this example, it is preferable to utilize a circular cutter having as large a diameter as may be practically possible.

The master cam M is mounted in position in the machine so that the end of the pattern surface *m* which defines the contour of the extreme tip of the blade WT to be machined, is located at the right hand end of the cam. Usually a dwell *sd* is provided around cam M at the right of pattern surface *m* and joining the start of the blade tip contour of such pattern surface, with this dwell concentric with the axis of rotation of the master cam for a purpose to be referred to hereinafter.

The cam follower or tracer roller T is so positioned by the tracer unit **23** on the cross feed carriage **19**, that when such carriage is in position at the end of the rapid traverse cycle, and is projected upwardly by spring loading units **24**, the tracer roller T will be held in yielding engagement with the concentric dwell *sd* formed at the right hand end of the pattern surface *m*. This is the position of the saddle and carriage unit **18**—**19** for starting a machining cycle (see Fig. 2).

When the saddle and carriage unit and tracer roller T are in such starting position, the powered cutter spindle unit **20** is positioned on cross feed carriage **19** to locate the cutter C spaced to the right of the portion of the work piece W which is to be machined out as the tip of the turbine blade WT, a distance precisely equal to the distance at which tracer roller T is positioned to the right of the start of the blade tip contour portion of the pattern surface *m*, as clearly shown by Fig. 2 of the drawings.

Tracer roller T and the effective work piece engaging cutting periphery of cutter C are spaced apart radially of the common axis of rotation for the master cam M and the work piece W to position the effective tracing surface of roller T and the effective material removing surface of cutter C, a fixed distance apart which corresponds to the ratio of enlargement of the pattern surface *m* of master cam M to the contour of the turbine blade WT to be machined out from the work piece W. Hence, as the tracer roller T is moved inwardly or outwardly by the changes, either rising or falling, of the contour of the pattern surface, the cross feed carriage is actuated to cause a corresponding inward or outward movement of the cutter C in 1:1 reproduction ratio, so that, the effective peripheral cutting edge of the cutter is forced to move radially inwardly or outwardly the required distances to precisely move through and define the contour of the turbine blade WT.

As the work piece W is revolved, and the rotating cutter C is moved inwardly and outwardly radially of and with its effective cutting periphery in machining engagement with a work piece W, the velocity of the surface of the work piece past the point of cutting engagement of the periphery of the cutter with the work piece will vary in accordance with the distance of the point of cutting contact from the axis of revolution of the blade. With the machining from a work piece of an article such as the turbine blade WT having a relatively thin, flat, rectangular section, this variation in velocity will be over a relatively wide range and is in direct ratio to the distance of cutter contact from the axis of rotation of the work piece. This velocity variation has a direct effect on the quality of the machining and of the surface finish produced thereby from a rotary, circular peripheral cutting edge cutter, such as exemplified by the milling cutter C of this example, as well as upon the rate of machining a work piece to completed article form.

The variation in the velocity of the surface of a work piece such as blank W past the point of cutting contact between a material removing tool such as the cutter C of this example, and the surface of the work piece, when the rate of work piece rotation is constant, is graphically illustrated by the vector diagrams of Figs. 11, 12 and 13. In each of the vector diagrams the point **100** represents the point of tangency or material removing contact between the effective cutting periphery of the circular cutter C and the surface of the contour of the blade WT at a particular instant. **101** is the radius drawn from the point **100** to the center of axis of rotation **102** of the blade WT. Hence, the vector **103** erected perpendicular to the radius **101** represents the velocity of the blade WT about its center of rotation **102**. The vector **104** is erected parallel to the ways or straight line path of cross feed movement of the carriage **19**, and represents the velocity of cross feed of that carriage at any instant. The resultant vector **105** is erected perpendicular to **106**, which is the radius of the cutter C, hence this vector **105** represents the velocity of the surface of the blade past the point **100** on the cutter at a particular instant of operation.

In Fig. 11, the blade WT is in position relative to cutter C in which the point of tangency **100** falls on the line representing the path of "in" and "out" radial cross feed movements of the carriage **19**. Hence, at this instant the vector **104** becomes zero (0) and the vector **105** representing the velocity of movement of the surface of the blade WT past the point **100**, is equal to but opposite in direction to the vector **103**.

In Fig. 12, the blade WT is shown in position rotated a distance beyond its position of Fig. 11. In the position of Fig. 12, the vector **105** has increased in value to indicate an increase in velocity of the surface of the blade past the cutting point or point of tangency **100**, the length of radius **101** having substantially increased over the length of that radius in the position of the blade and cutter shown in Fig. 11.

In Fig. 13, the blade WT has rotated from the position of Fig. 12 to the position in which the cutter C has moved outwardly to and is in position at and passing across the trailing edge WE of the blade. At this instant the velocity represented by the vector **105** has substantially increased over that of Fig. 12, and for the particular turbine blade being machined has approached the maximum end of the velocity range.

Thus, as blade WT rotates and cross feed carriage 19 is moved inwardly and outwardly toward and from the axis of rotation of the blade, the velocity of the surface or contour of the blade past the point of effective cutting contact of the cutter C with the blade surface, is constantly varying for an irregularly contoured article. This condition presents a severe problem in attempting to finish machine an article to precise contours with very small allowable tolerances and with a high surface finish, by a material removing tool, such for instance as a rotating circular and peripheral cutting edge type of cutter utilized in the present example. The problem is particularly acute in machining an article of irregular contour in the exaggerated form as presented by a turbine blade or the like. Where a circular, rotary cutter is used, such as the cutter C of this example, a further factor is encountered which contributes to and complicates the problem. This factor arises from the feeding of the rotating cutter axially along the work piece or blank in machining out the contours of the finished article along the length thereof. I have overcome or substantially reduced this problem by my present invention in providing for the maintenance automatically of a constant velocity of movement of the surface of the work piece past the point of effective cutting engagement thereof with the cutter, throughout the machining cycle while cross feeding the cutter toward and from the work piece and feeding it axially along the work piece.

Such maintenance of constant velocity is effected by controlling the rate of rotation of the work piece and the rate of feed of the cutter axially along the work piece in such a manner that upon any movement of the cutter in either direction along its path of cross feed toward and from a work piece, occasioned by change in the contour of the work piece radially, a slow down of the rate of speed of operation of the work spindle drive motor SM will be effected in direct ratio to the rate of change of contour, as reflected by the rate of movement "in" or "out" of the cutter by the cross feed carriage 19 under the control of the master cam M. By the arrangement of the invention, the velocity of the movement of the surface of the work piece past the cutter is maintained substantially constant by effecting the slow down of the motor in accordance with the rate of change of contour in directions inwardly and outwardly radially relative to the work piece. The critical factor is the rate of change of cross feed velocity of the cutter and not the relative positioning between the cutter and the axis of rotation of the work piece or the direction of movement of the cutter radially relative to such axis of rotation.

I have by Figs. 14 and 15 graphically illustrated the maintenance as a constant of the velocity of the movement of the surface of the work piece past the cutter, by the control of my invention. Fig. 14 corresponds in position of cutter and turbine blade to the position of Fig. 12. As indicated by Fig. 12, the velocity of the blade surface has increased as the blade was revolved counterclockwise from the blade and cutter positions of Fig. 11. By the slow down control of the invention, as the cutter C is moved radially outwardly from the position of Fig. 11, the rate of rotation of blade WT is reduced or slowed down in direct proportion to the velocity of radial movement of the cutter outwardly under the control of the master cam M, so as to maintain the velocity of the surface of the blade past the cutting point 100 at a constant velocity as represented by the vector 105' in Fig. 14. This is effected by the slow down control, which is reflected graphically in Fig. 14 by the adjustments of the vectors 103 and 104 of Fig. 12 to the values or magnitudes represented by the vectors 103' and 104' of Fig. 14. As the counterclockwise rotation of blade WT continues to the blade and cutter positions represented by Figs. 13 and 15, the slow down control of the invention maintains the velocity of blade surface past the cutter at the constant represented by vector 105', doing so by adjustments of the velocities represented by vectors 103' and 104', and such adjustments being effected by the reduction in the rates of rotation of the work piece in direct ratio to the velocities of radial outward movements of the cutter under the control of the master cam.

Thus, by controlling the rate of rotation of a work piece to slow the rate down in direct proportion to the rate of cross feed in either direction of the tool, the rate of velocity of movement of the surface of the work piece past the point of effective cutting engagement at any instant between the cutter and work piece, is maintained substantially constant. The vector 105' of Figs. 14 and 15 represents in effect an addition or subtraction to the speed of material removal from the work piece, so that, there results material removal at a constant rate around the periphery of the work piece by the tool. Where, as in the instant example, a rotary cutter is used, the cutting speed is generally set by the rate of rotation of the cutter, but where the cutter is being rotated at a relatively low rate, say as an example a rate of the order of six hundred (600) R. P. M., the effect of the rate of cutter rotation on the cutting speed may be taken to be negligible or a minor factor.

In considering the change in velocity of the surface of the contour of an article, such as the turbine blade WT, past the area of material removing contact of the cutter with the work piece, it is to be noted that in the majority of the positions of the work piece as it is revolved in material removing engagement with the cutter, a surface of the work piece is presented to the cutter which is substantially radially disposed, as indicated, for example, by the relative positions illustrated in Fig. 12. It is the rate of speed or velocity of this radial movement of the surface of the work piece past the tool for which my present invention provides a control. And in this connection, the control is so set that the rate of speed of rotation of the work piece or blade in the positions shown in both Figs. 11 and 13 may be considered to be the same, notwithstanding the fact that the cutter C in such positions operates on a different diameter generated about the axis of rotation 102 of the work piece or blade WT. Hence, the primary condition or factor to be considered is the velocity of radial movement of the surface of the work piece past the cutter rather than the speed of rotation of the surface about the axis of rotation of the work piece determined solely by the radial distance from such axis of rotation.

In the example machine hereof, I have provided for the speed control of the motor SM and the resulting control in the rate of rotation of the work piece as a direct function of the velocity of cross feed movements of the cutter, through the medium of an electronic network and a signal generator and pick-up unit for imposing control signals on such electronic motor controlling network.

Signal generator and pick-up

The shunt wound, D.-C. motor SM which drives the work spindle 17, and from which the saddle and cross feed carriage unit 18—19 is translated on its feeding cycle, has its rate of speed regulated and controlled by movements of the feed carriage 19 radially toward and from a work piece as dictated by the master cam and its tracer follower. When the cross feed carriage is at rest in directions radially relative to a work piece W, the motor SM is operated at the maximum rate of speed for which the control system is adjusted. When the cross feed carriage 19 is moved either inwardly or outwardly radially relative to the work piece, motor SM is slowed down to an extent or degree in direct proportion to the rate of speed or velocity of the "in" or "out" movement of the cross feed carriage. Upon such reduction in speed of the motor SM, the coasting armature of the motor is braked by absorbing the kinetic energy thereof, so that, the slow down to the reduced speed as dictated by the rate of movement of the cross feed carriage, is effected with great rapidity. When such "in" or "out" movement stops and the cross feed carriage comes to rest, the motor SM is accelerated instantly from the reduced rate of speed to the maximum rate of speed for which the motor speed controlling electronic network has been set.

The slow down and braking of the motor SM from its maximum speed of operation and the acceleration thereof up to maximum speed after a slow down, is effected in this example through the medium of a speed regulating and controlling electronic network or system purely schematically diagramed in Fig. 16, and described and explained hereinafter. This electronic network is caused to function to regulate and control the rate of speed of motor SM, by a signal in the form of an electrical impulse constituted by a potential or voltage imposed on the electronic network, of a magnitude in direct proportion to the rate of speed or velocity of movement of the cross feed carriage in either a direction toward or a direction away from a work piece W being revolved by the work spindle 17.

In accordance with an important feature of my invention, I generate such signal by the cross feed movements "in" or "out" of the cross feed carriage 19 and cutter C relative to the work piece W, in a manner such that the magnitude of the signal, that is, the electrical potential or voltage thereof, is in direct proportion to the rate of speed of any such cross feed movement of the carriage 19. For this purpose, in the example hereof, I have provided a signal generator and pick-up G in the form of a coil GC of many turns mounted in fixed, vertically disposed position on and relative to structure of the saddle 18 below the cross feed carriage 19, and a permanent magnet GM mounted on carriage 19 in position above and depending into coil GC for movements relative thereto with the carriage 19, as the carriage is displaced "in" or "out" on its cross feeding movement.

In this instance, referring now to Figs. 19 and 20, the magnet GM is of the Alnico type mounted at its upper end on a U-shaped yoke GM' of a suitable material, such as steel, with the magnet G depending down into the hollow core of the coil GC and with the opposite depending legs of yoke GM' depending down along and spaced from diametrically opposite sides, respectively, of the coil. The magnet GM and steel yoke GM' are secured at their upper ends into the depending, cup-like, open bottom brass shielding casing GMC which extends down over and around coil GC. Magnet GM, yoke GM' and shielding casing GMC are mounted and supported in position depending from cross feed carriage 19 by a suitable supporting bracket structure GMB. Coil GC is mounted at its lower end in a suitable brass yoke GC' which in turn is secured to a supporting bracket structure GCB attached to saddle 18. Magnet GM—GM' and its brass shielding casing GMC are thus mounted and supported in position on cross feed carriage 19 depending therefrom over and in telescopic relation with coil GC.

This permanent magnet GM is positioned with the coil GC in the magnetic field of the magnet, so that, movements of the magnet "in" and "out" relative to the coil by cross feeding movements of carriage 19, will cause the coil to traverse the field of the magnet and thus generate in the coil an electrical potential or voltage of a magnitude in direct proportion to the velocity of the movement of the magnet. When the magnet GM is at rest relative to the coil GC, no potential or voltage is induced in the coil, and the signal receiving circuit connected thereto is "dead" and without current. In this instance, the signal generator and pick-up G, with the range and speed of movements accorded to it by the cross feed carriage 18 of the particular example machine hereof, may be considered to have the capacity to produce a signal potential or voltage of a range from the order of a fraction of one (1) volt up to a maximum of the order of ten (10) or twelve (12) volts.

The signal voltage generated in the coil GC of the signal generator and pick-up G, is fed into a full wave selenium rectifier bridge GB which gives the generated signal voltage the same polarity regardless of the direction of motion of the magnet GM in the coil GC.

The D.-C. motor SM includes an armature SMA and a shunt field SMF, as schematically shown in Fig. 16. The magnitude of the power current supplied to the armature SMA is controlled by the signal generated in the generator G, in direct proportion to the magnitude of that signal, by the motor speed regulating and controlling electronic network or system.

Work spindle motor speed controlling electronic network

The electronic system or network through the medium of which the above control of the work spindle and feed motor SM is effected, is schematically diagramed in Fig. 16, to which reference is now made.

This electronic system is supplied with primary power in the form of single phase, 60-cycle, A.-C. current of the order of 500-volts, from the secondary 1PT(2) of the power transformer 1PT, the primary 1PT(1) of which is supplied with single phase, 60-cycle, A.-C. current of 440-volts from the power supply lines L1 and L3, as will be clear by reference to Fig. 16 in connection with Fig. 17. Power supply circuit lines L5 and L7 are connected to and lead from connections 1X1 and 1X7 of the secondary winding 1PT(2) of power transformer 1PT.

An electron tube, full-wave rectifier is connected across L5 and L7 to convert the alternating current delivered thereto from the transformer 1PT, to direct current of the required voltage for exciting and powering the armature SMA of the work spindle and feed motor SM. This full wave rectifier includes electron tubes T3 and T4, which in this instance, are grid controlled, gaseous rectifiers generally known as thyratrons. In this example the tubes T3 and T4 may be considered to be rated as 6.4 amperes each, to thus give the rectifier circuit a capacity of 12.8 amperes. The length of time during each half-cycle that these grid controlled, gaseous rectifier tubes conduct is governed by the voltage applied to their grids with respect to their filaments. Such voltage determines at exactly what time in each half-cycle the tube becomes a conductor. These rectifier tubes T3 and T4 are connected across the power circuit lines L5 and L7 by the plate or anode circuit lines L8 and L9, respectively. And in this plate circuit the primary windings 1CT(1) of a current transformer are connected into the circuit lines L8 and L9 to the tubes T3 and T4.

The cathode or filament circuit L10 for the tubes T3 and T4 is supplied with filament current from the secondary winding 4PT(2) of the power transformer 4PT, the primary 4PT(1) of which is connected across the 110-volt control circuit lines 1X3 and 1X5 (see Fig. 18).

The grids of the thyratron tubes T3 and T4 are supplied with control voltages by the grid circuit line L11 which is connected into the secondary winding 2PT(2) of the power transformer 2PT, the primary winding 2PT(1) of which is connected across a center tap at 1X4 of the secondary 1PT(2) of transformer 1PT and a circuit line L12 which is connected across circuit lines 1X3 and 1X5. The grid voltage supplied from the center tap on 2PT(2) is shifted in time phase with respect to the plate voltage of tubes T3 and T4 by means of a phase shift bridge.

Rectified A.-C. current is delivered from the rectifier tubes T3 and T4, as direct current to the motor power circuit comprised of lines L14 and L15, with line L15 connected into the armature SMA across line L14 and the circuit line L21 which leads from the center tap 1X4 of the secondary winding 1PT(2) of transformer 1PT.

The control voltage for the grids of the thyratron tubes T3 and T4 is made up of a fixed A.-C. voltage plus a variable D.-C. voltage. The fixed A.-C. voltage is supplied from a bridge made up of the resistor A—B and the variable resistor B—C in the circuit line L12; transformer 1PT and taps 1X3, 1X4 and 1X5 of the secondary 1PT(2) of power transformer 1PT; and the capacitor 2C in the circuit line L12. The voltage appearing across the secondary 2PT(2) of transformer 2PT is approximately 110° lagging in phase with respect to the secondary voltage of the transformer 1PT. This gives an A.-C. voltage with a fixed phase shift in regard to the plate voltage of the thyratron tubes T3 and T4.

The D.-C. voltage component of the grid control voltage for the tubes T3 and T4 is made up of a number of different voltages, all representing quantities which must be measured and utilized in order that the control will operate the motor SM to the best advantage. To this end, the secondary 2PT(2) of transformer 2PT leads by a circuit line L16 to the control tube section of the network where it is placed in series with a variable D.-C. voltage as will as explained hereinafter.

The shunt field SMF of motor SM is excited by a full wave rectifier which includes the rectifier tubes T5 and T6. Power or plate current is supplied to the plates of tubes T5 and T6 by circuit lines L17 and L18 connected across the A.-C. supply lines L5 and L7. The filament circuit L19 for rectifier tubes T5 and T6 is supplied with filament current by the secondary winding 9PT(2) of the power transformer 9PT, the primary 9PT(1) of which is in a circuit across the control circuit supply lines 1X3 and 1X5. The A.-C. current supplied to tubes T5 and T6 is rectified and supplied as D.-C. current to the shunt field SMF by the circuit line L20, which includes therein a variable resistor 3V1—3VN. The shunt field SMF is connected into the circuit line L21 which leads from center tap 1X4 of the secondary winding of transformer 1PT, the shunt field being thus connected across circuit lines L5 and L21. The current for field SMF is adjusted by the variable resistor 3V1—3VN.

A full wave rectifier tube T8 is provided for converting the A.-C. output of the secondary 1CT(2) of the current transformer 1CT, to a D.-C. voltage which is proportional to the current drawn in the plates of the thyratron tubes T3 and T4, such latter current being actually that being drawn by the armature SMA of motor SM. The secondary 1CT(2) of current transformer 1CT, is connected with the plates of tube T-8 by circuit line L-22 across which there is connected a resistor B′—A′. The filament current for the rectifier tube T8 is supplied from a center tap of the secondary 6PT(2) of transformer 6PT, by a circuit including circuit lines L23, L21′, L24 and L25. Circuit line L24 is connected across line L25 and a circuit line L26 from a center tap of the secondary 1CT(2) of current transformer 1CT. This circuit line L24 includes therein capacitors 11C and 13C. A circuit line L27 is connected across circuit lines L25 and L26, and includes therein the variable resistor ZZ—OO, resistor OO—UU and variable resistor UU—D′.

A duo triode tube T-9 is provided which is controlled by the D.-C. output of the grid biased rectifier tube T-8. The lower half of this tube T-9 provides a current limiting control voltage into the grids of the rectifier tubes T3 and T4. The plate circuit for the lower half of tube T-9 includes the circuit line L28 connected into the circuit line L29 which leads to the plate of the upper half of this tube. Resistor YY—XX is connected in plate circuit line L28. The grid of the lower half of tube T-9 is connected by line L30 into the adjustable tap of a variable resistor ZZ—OO in the circuit line L27.

The upper half of the tube T-9 provides a voltage control triode which tends to maintain a constant terminal voltage at the work spindle drive motor SM. The filament circuit for the upper half of tube T-9 is constituted by a circuit line L31 connected into circuit line L21′ from the center tap of the secondary 6PT(2) of transformer 6PT. Circuit line L31 has a resistor C′—UU connected therein. The plate circuit for the triode provided by the upper half of tube T-9 is constituted by the circuit line L29 in which there is connected a resistor FF—YY. The plate circuit line L29 is connected into circuit line L32 from a secondary winding 6PT(2) of the power transformer 6PT. The grid circuit for the upper triode of tube T-9 is constituted by the circuit line L33 connected into the adjustable tap of the variable resistor UU—D′ in circuit line L27.

A full wave rectifier tube T12 supplies plate voltage to the control tube T-9. This tube T12 has plate circuit L34 from a secondary winding

6PT(2) of transformer 6PT and a filament circuit L35 from another secondary winding 6PT(2) of this transformer 6PT. The circuit line L32 into which the plate circuit lines L28 and L29 are connected is also connected to that secondary 6PT(2) of transformer 6PT of the filament circuit L35 for tube T12.

Voltage regulator tubes T14, T15 and T16 are provided in a circuit line L36 connected across circuit lines L32 and L21. These tubes T14, T15 and T16 function to stabilize the output of the rectifier tube T12. Between rectifier tube T12 and the voltage regulator tubes T14, T15 and T16, a capacitor 9C is connected across circuit lines L32 and L21, by a circuit line L37. A resistor EE—FF is connected in circuit line L32 between the connections thereto of circuit lines L36 and L37.

Tubes T1 and T2 are grid controlled gaseous tubes or thyratrons of the same type as tubes T3 and T4, but instead of functioning as rectifiers to convert A.-C. to D.-C. current, they function as inverters to change D.-C. current back to A.-C. current and to feed such A.-C. current back into the A.-C. power line. These tubes T1 and T2 have a plate current circuit constituted by a circuit line L38 which is connected across the plates of the tubes.

A circuit line L39 connects plate circuit line L38 with circuit line L14 from the rectifier tubes T3 and T4. Included in the plate circuit line L38 are the resistors H—J and J—K. A set of normally open contacts of the magnetic contactor unit 3M is connected in the circuit line L39 between circuit line L14 and the plate circuit line L38 of the tubes T1 and T2. Filament current for tube T1 is supplied by a filament circuit L40 which is connected with a secondary winding 7PT(2) of power transformer 7PT, and with the A.-C. power circuit line L5. The filament current for the tube T2 is supplied by a filament circuit L40′ connected to a secondary winding 8PT(2) of power transformer 8PT and to the circuit line L7 of the A.-C. power circuit. These inverter tubes T1 and T2 are under the control of their grids which are in turn controlled by various other of the electron tubes of the network, as will be hereinafter explained.

A pentode tube T13 is provided to function as an amplifier tube controlled by the magnitude of the signal voltages generated by the pick-up coil GC of the signal generator G. Tube T13 has a plate circuit which includes a circuit line L41 connected into circuit line L32. A resistor FF—PP and a variable resistor PP—QQ are each connected in line L41, the variable resistor providing a sensitivity control as will be referred to hereinafter. The control grid of the pentode tube T13 is connected by circuit line L42 with one arm of the signal receiving bridge GB of the pick-up coil GC of the signal generator G. A resistor SS—TT is connected in series with circuit line L42. The screen grid of tube T13 is connected to a circuit line L43, while the suppressor grid is connected into the circuit line L21 by a circuit line L44. The filament circuit includes a circuit line L45 connecting the filament of tube T13 with the circuit line L42 from the signal pick-up coil to the control grid of the tube. Resistors W—UU and UU—TT are connected in circuit line L45. Circuit line L46 is connected across circuit lines L21 and L42 by the pick-up coil GC of the filament circuit L45 and includes therein a capacitor 4C. Circuit line L44 to the suppressor grid of tube T13 includes therein a capacitor 16C, and a circuit line L44′ is connected across line L44 and the filament circuit line L45.

Duo triode tube T11 is provided with its elements connected in parallel so that the tube functions essentially as a triode amplifier. The purpose of this tube T11 is to apply signal voltage on the control grids of the rectifier tubes T3 and T4 which function as the power tubes for supplying D.-C. current for driving the work spindle motor SM. This duo triode tube T11 is directly controlled by the pentode tube T13 which receives the signal picked up by the coil GC of the signal generator G. The circuits for the plates of tube T11 include the circuit line L47 which is connected to line L16 and completes therewith the grid control circuit to the tubes T3 and T4. The circuit for the filaments of tube T11 includes the circuit line L48 connected into the voltage rectifier tube circuit line L36 which is connected across circuit lines L32 and L21. The control grid circuit for the grids of tube T11 includes the circuit line L49 connected into plate circuit line L41 of tube T13, a resistor QQ—RR being connected in line L49 between the two grids and circuit line L41.

A duo triode tube T10 has elements connected in parallel so that the tube functions as a triode and is under the control of tube T13 and the signal generator G. Tube T10 has circuit for the plates thereof, which includes a circuit line L50 connected to circuit line L32. Plate circuit line L50 includes the control element 1SR′ of a saturable reactor 1SR, the other element of which is connected in a circuit line L51 connected across circuit line L21 and a circuit line L52 from circuit line 1X5 of the 110-volt control circuit. The grids of the control tube T10 are connected to a grid control circuit L53 connected with and forming a common grid control circuit with the circuit L49 for the grids of control tube T11. The circuit for the filaments of the tube T10 is constituted by a circuit line L54 which connects the filaments with the adjustable tap of a variable resistor KK—LL connected in a circuit line L55 which is connected across circuit line L32 from the secondary of transformer 6PT and the filament circuit line L48 from the voltage regulator circuit line L36 to the filaments of tube T11.

When current is drawn by the tube T10 as the result of a signal voltage imposed on its grids from the pick-up coil GC of signal generator G and the tube T13, the resulting saturation of the reactor 1SR will unbalance the bridge circuit and cause an A.-C. voltage signal which will phase on the inverter tubes T1 and T2 by an amount proportional to the strength of such A.-C. signal.

A full wave rectifier tube T7 is provided for furnishing a D.-C. grid bias voltage on the inverter tubes T1—T2. Tube T7 is connected across the A.-C. circuit supply lines L5 and L7 by the plate circuit line L56 from one of its plates to circuit line L5 and by a circuit line L57 from the other of its plates to the circuit line L7. Variable resistor Q—R and a resistor R—S are connected in plate circuit line L56 with a capacitor 3C connected across these resistors by a line L56′. Similarly, in plate circuit line L57 there are connected a variable resistor UV and a resistor 2U, with a capacitor 4C connected across these resistors by a circuit line L57′. The grid of inverter tube T1 is connected to a secondary winding 3PT(2) of a transformer 3PT by a circuit line L58, while the grid of inverter tube T2 is connected with a secondary winding 3PT(2) by a circuit line L59. A resistor L—M is connected in line L58 and a similar resistor N—P is connected in grid circuit line L59. The secondary windings 3PT(2) in the grid bias circuit lines L58 and L59, respectively, are connected to the adjustable taps of the variable resistors Q—R and U—V in the plate circuits L56 and L57, respectively, of the tubes T1 and T2.

An inverter phase shift bridge is provided comprised of saturable reactor 1SR, saturable reactor 2SR, variable resistor W—X, resistor X—Y, all connected in the circuit line L51 across lines L52 and L21 and resistors O—Z and Z—Y connected in a circuit line L60 across line L51 and circuit line L21, together with the primary 3PT(1) of a transformer 3PT connected across circuit lines L51 and L60. This bridge supplies an A.-C. voltage bias component for the grid voltage imposed on inverter tubes T1 and T2.

A circuit line L61 is connected across line L14 and circuit line L21, and includes therein the component 2SR′ of the saturable reactor 2SR, the other component of which is in the circuit line L51 as an element of the inverter phase shift bridge referred to above. Circuit line L61 also has connected therein a resistor AA—DD, between the component of 25R and circuit line L14.

The circuit line L55 includes therein resistor FF—GG and the variable resistors GG—HH and HH—JJ which form components of a "speed setting" section of the control network. This circuit line L55 also includes therein a resistor JJ—KK and a variable resistor KK—LL which form components of an "over-lap" control section of the network. A circuit line L62 is connected across circuit lines L36 and L55 between resistors HH—JJ and JJ—KK. The adjustable tap of the variable resistor GG—HH is connected with the circuit line L32 from the filament circuit for the tube T12 by a circuit line L64. In line L64 there is included a capacitor 10C and a set of normally closed contacts of the magnet actuated contactor 3M of the power control circuits shown in Fig. 18. A line L65 connects line L64 between the adjustable tap of resistor GG—HH and the capacitor 10C with the direct current circuit line L14. A circuit line L65′ connects line L64 between contact set 3M and capacitor 10C with the line L65. The foregoing components complete the speed setting section of the control network by which the maximum speed to which motor SM is to be operated may be set.

A circuit line L63 is connected across D.-C. circuit line L14 and circuit line L21, between circuit line L61 and tube T12 and its associated plate and filament circuits L23 and L35. A variable resistor AA—BB is connected in circuit line L63 and a resistor BB—CC is connected in this line between the variable resistor AA—BB and the circuit line L21. The adjustable tap of the variable resistor AA—BB is connected by a circuit line L66 with the circuit line L65, and a capacitor 1C is connected in line L65 between line L66 and the direct current circuit line L14. The foregoing components and associated circuits make up the "voltage control" section of the network.

A controlling element in the form of a resistor WW—XX is connected in series with the grids of the motor power tubes T3 and T4 for the purpose of controlling these grids in response to any signal received by the pentode tube T13 from the pick-up coil GC. This resistor WW—XX is connected in a circuit line L67 connected across a circuit line L68 connected into line L47 and a circuit line L69. Circuit line L47 is connected to the control circuit line L16 of the grids of the tubes T3 and T4. Circuit line L69 is connected by circuit line L69′ into the circuit line L32 and includes therein a capacitor 12C. A circuit line L67′ is connected between lines L68 and L69 across resistor WW—XX, and includes therein a capacitor 15C.

Operation of the work spindle motor speed controller

As it is desirable to at least have a constant voltage system to apply to the work spindle and feed motor SM, a part of the drop across AA—BB (designated as "voltage control" in Fig. 16), that is, that part of the drop from AA to the tap, is used to obtain a voltage proportional to the armature voltage. This voltage, as will be clear by reference to Fig. 16, is in series with a standard voltage across the resistor FF—GG and across the variable resistor GG—HH from GG to the tap thereof. Both of these resistors are in circuit line L55 across lines L32 and L54 and form with the associated circuits and their components the "speed setting" section of the control network, as will be clear from Fig. 16. When the voltages across AA—BB and across FF—GG and GG to the tap of GG—HH are equal and opposite, the bridge constituted by such components and such associated circuits would be balanced. However, the armature never actually reaches this value, as it is necessary to have a slight difference therebetween in order that the system will work. In series with the above two (2) voltages, there is placed a drop across resistor FF—YY in plate circuit line L29 of tube T-9 which is proportional to the current in the armature circuit and represents "IR drop." When the current in the armature circuit increases, the drop across resistor FF—YY in the plate circuit line L29 for the upper half of tube T-9 decreases so that the grids of the thyratron or power tubes T3 and T4 for the motor SM are allowed to go more positive and hence to thereby increase the terminal voltage of the motor SM by the amount lost in the motor due to resistance.

Normally the lower half of the tube T-9 is at plate current cut off and the voltage drop across resistor YY—XX in the plate circuit line L29 is small and due only to the grid current to the thyratron tubes T3 and T4. However, when the armature current gets too high, the grid of the lower half of tube T-9 is driven more positive and the plate of this lower half of the tube finally draws current through resistor FF—YY into resistor YY—XX. As the voltage drop across these resistors is in series with the grids of the thyratrons or power tubes T3 and T4 and drives the grids negative, there is thus obtained a current limitation on the current drawn by the armature SMA of the motor SM.

Since the control of the speed of the work spindle motor SM is to respond to a signal generated by the signal generator G and picked up in the bridge circuit GB thereof, and as the motor SM must be slowed down on any signal, it is necessary to have one element of control to shut off or modify the driving force behind the motor SM. The resistor WW—XX is connected in the circuit comprised of circuit lines L16, L68 and L67 in series with the grids of the thyratron tubes T3 and T4 for this reason. The tube T11 is one of the tubes directly controlled by the pentode tube T13, and tube T11 functions so that current is drawn through WW—XX whenever a signal is received by the control grid of tube T13 from the pick-up coil GC of signal generator G. The resulting voltage drop drives the grids of the rectifier thyratron tubes T3 and T4 negative and thus removes the power source or current supply from the motor SM.

Operation of the armature braking inverter system

When the power has been removed from the motor SM as a result of a signal voltage generated in the coil GC of the signal generator, as referred to above, it then becomes necessary to absorb the kinetic energy of the coasting armature SMA of the work spindle motor SM in order that the desired slow down may be accomplished easily and in a very minute interval of time. The thyratron tubes T1 and T2 of the inverter section of the network effect this braking by pumping the power generated by the coasting armature SMA of the work spindle motor back into the A.-C. current circuit lines L5 and L7. The inverter tubes T1 and T2 are grid controlled and are governed by a time-shift A.-C. voltage applied to their grids. This grid voltage which is applied to the grids of tubes T1 and T2 is made up of two parts. The first part is a D.-C. current bias derived from the tube T7 and the resistors G—R, R—S, T—U, U—V, and the capacitors 3C and 4C, all associated with the tube T7. The second part is an A.-C. bias voltage taken from the bridge comprised of 1SR, 2SR, W—X, X—Y, O—Z, Z—Y and the transformer 3PT.

By saturating reactor 1SR, the inverter tubes T1 and T2 can be turned or phased on, which means that these tubes would then fire and absorb armature power and thus quickly absorb the kinetic energy of the coasting armature and thereby quickly effect the completion of the motor slow-down signaled for by the signal generator G. The saturation of the reactor 1SR is controlled by the current which is drawn through the tube T10, which is in turn under the control of the pentode tube T13 of the signal pick-up coil GC. An increase in current in the D.-C. winding of the saturable reactor 1SR will cause the inverter tubes T1 and T2 to be phased on by an amount proportional to the strength of the signal generated by the motion of the magnet GM of the signal generator G, and the strength of the signal so generated and picked up will be in direct proportion to the rate of speed or velocity of the movement of the magnet GM relative to the coil GC.

When the operation of the work spindle motor SM is started the motor will come up to the speed which has been set on the speed setting variable resistor or potentiometer HH—JJ, but always under control of the "current limit" of the motor control section of the network. When the magnet GM of the signal generator G is moved in either direction, that is, either "in" or "out" relative to the axis of rotation of the work spindle 17, by a variation in contour of the master cam M, a signal will be generated and picked up in the coil GC. This signal will be imposed on the control grid of the pentode tube T13 in such a sense as to cause the plate current of tube T13 to decrease. This decrease in plate current of tube T13 will drive the grids of the tubes T10 and T11 more positive so that they will conduct current. Up to this time,

tubes T10 and T11 had been at plate current cut-off as referred to hereinbefore. It is to be here noted that the tube T10 can be cut off a little further than the tube T11 by means of the "overlap" control provided by the variable resistor KK—LL in the circuit line L55. This provides for obtaining a slow down of the motor SM without braking in order to care for weak signals.

When the tube T11 conducts it gives the same effect on the motor SM as if the "speed setting" were very suddenly adjusted for a lower speed. Shortly after tube T11 begins to conduct current the tube T10 also begins to conduct, with the result that the inverter tubes T1 and T2 are phased on and the motor is instantly braked to a low speed as explained hereinbefore.

Instantly that motion of the magnet GM of signal generator G stops and the signal disappears, the electronic network instantly restores the normal conditions for operation of motor SM at maximum speed, and the motor rapidly accelerates to and remains in operation at that speed until a signal is again generated by motion of the magnet GM of the signal generator G.

Sensitivity control

The slow-down control by the network of the motor SM is effected by adjustment of the variable resistor or potentiometer PP—QQ in the grid control circuit line in the plate circuit line L41 of the pentode tube T13, to which the grid control circuits of tubes T11 and T10 are connected by line L49. The signal pick-up can be desensitized to the extent where there would be established in effect a limiting minimum to the effective control voltage generated by the signal generator G. By increasing the effective slow-down effect the sensitivity of the control can be increased to thereby lower appreciably the required voltage. The slow-down control can therefore be adjusted to operate under a desired range of voltages of the generated signal, and, if desired or found expedient, can be adjusted and set for operation only above a limited minimum voltage.

Motor and solenoid power circuits

In this example, three-phase, 440-volt, A.-C. current is supplied to the machine from any suitable power source (not shown) by the power lines L1, L2, and L3 as shown in Fig. 17.

Lines L1 and L3 lead to the primary windings of the main power or anode transformer 1PT, from the secondary of which current is supplied for the electronic network of Fig. 16 and for the machine motor and solenoid control circuits of Fig. 18 to be hereinafter described. There is thus supplied to the primary of transformer 1PT a 440-volt single phase 60-cycle A.-C. current. The motor CM for driving the cutter spindle 21 is of the alternating type and, in the present instance, may be considered to have a one-half (½) H. P. rating. Motor CM is supplied with three-phase 440-volt A.-C. current direct from power lines L1, L2 and L3 by circuit lines PL1, PL2 and PL3.

The rapid traverse motor is also that of the alternating current type and, in this example, may be assumed to have a one-half (½) H. P. rating. Motor RTM is supplied with three-phase 440-volt A.-C. current direct from lines L1, L2 and L3, by the circuit lines PL4, PL5 and PL6.

The motors CM and RTM are controlled by magnetic solenoid actuated normally open contactor units in their respective power circuits, such units being in turn controlled from a control circuit of lower voltage, in this example 110-volt, supplied from a portion of the secondary winding of the power input transformer 1PT.

The power supply circuit to cutter spindle drive motor CM includes in the circuit lines PL1, PL2 and PL3 thereof, the sets of normally open contractors 1MC of a solenoid actuated contractor unit 1M (see Fig. 21), as will be clear from the circuit diagram of Fig. 20.

The power circuit to motor RTM includes in the circuit lines PL4, PL5 and PL6 thereof, the sets of normally open contactors 2FC of a magnetic solenoid actuated contactor unit 2F (see Fig. 18).

Subsidiary circuit lines PL7, PL8, PL9 are connected between lines PL4—PL5; PL5—PL4; and across contactors 2FC in line PL6, respectively. The sets of normally open contactors 2RC of a solenoid actuated contactor unit 2R (see Fig. 18) are connected in circuit lines PL7, PL8 and PL9, respectively. These sets of contactors 2FC and 2RC are mechanically and electrically interlocked, the electrical interlock being obtained through the sets of normally closed contactors 2FC' and 2RC' in the control circuit lines of Fig. 18, as will be hereinafter explained.

Rapid traverse, feed, and air cylinder actuating solenoids

The rapid traverse clutch actuating solenoid RTS, the feed clutch actuating solenoid FS, and the "pull back" air cylinder solenoid AS, in this example, are each constituted by a 440-volt, 60-cycle, A.-C., single phase unit, and each is operated through the medium of electrical relays in the control circuits of Fig. 18.

Single phase, 440-volt, 60-cycle, A.-C. current is supplied to these solenoid units directly from lines L1 and L3 of the power input circuit by circuit lines connected across lines L1 and L3 ahead of the power transformer 1PT, as shown by Fig. 17. The power circuit for solenoid RTS comprises the circuit lines PL10 and PL11 connected through the solenoid; the power circuit for solenoid FS comprises circuit lines PL12 and PL13 connected through the solenoid; and the power circuit for solenoid AS comprises the circuit line PL14 connected to lines PL12 and PL13 across solenoid FS.

The solenoid RTS is controlled by a magnet actuated relay unit 3CR (see Fig. 18) having sets of normally open contactors 3CR' connected in circuit lines PL10 and PL11.

The solenoid FS is controlled by a magnet actuated relay 2CR (see Fig. 18) having sets of normally open contactors 2CR' connected in the circuit lines PL12 and PL13, respectively.

In this example the solenoid AS is also controlled in its operation by the sets of contactors 2CR' which control the solenoid FS.

110-volt control circuit

A circuit is provided which is supplied from the 440-volt power circuit of Fig. 17 with a lower voltage, in this instance 110-volts, for effecting operation of the circuit controlling contactors in the power circuits to the motors CM and RTM and to the solenoid units RTS, FS and AS, as well as for supplying 110-volt current as the primary voltage for various of the filament and power transformers in the electronic network as hereinbefore identified in connection with the preceding description of Fig. 17.

Referring to Fig. 17, in connection with Fig. 18, this 110-volt control circuit includes the circuit lines 1X3 and 1X5 which are tapped into the secondary winding of power transformer 1PT at points to supply thereacross, single phase, 110-volt, 60-cycle A.-C. current. A master switch control circuit line CL2 is connected across circuit lines 1X3 and 1X5 and includes therein a set of normally open contacts 1T therein. A magnet actuated relay unit 1CR is connected in circuit line CL2 and includes a set of normally open contacts 1CR' connected in a circuit line CL3 across contacts 1T, a set of normally open contacts 1CR' in current supply line 1X3; and a set of normally open contacts 1CR' in the circuit line L20 to the shunt field SMF of motor SM, as will be clear by reference to the electronic network diagram of Fig. 16. When relay contacts 1CR' in line 1X3 are open, the current is completely cut off from the control circuits and is also cut off to the shunt field of motor SM.

A control circuit for the contactor unit 1M is provided by circuit line CL4 connected across supply lines 1X3 and 1X5. This circuit line CL4 includes therein the normally closed traverse return limit switch unit 8 for momentary opening near the end of the rapid traverse return cycle as referred to hereinbefore. Control circuit CL4 also includes therein "Start" and "Stop" sets of contacts 5' and 6' which are of the manually operated push button type, the push button 5 of which is located on the centralized push button station 4 positioned on the upper side of the work spindle head 16 of the machine, as will be clear by reference to Fig. 1.

A control circuit line CL5 is connected across supply lines 1X3 and 1X5 and includes therein a solenoid actuated timing relay unit 2T. Unit 2T includes a set of normally open contacts 2T(1) and a set of normally open contacts 2T(2) connected in control circuits to be referred to herebelow. The set of contacts 2T(2) are set to close at the end of the time cycle provided for by the timing relay unit 2T. The set of contacts 2T(1) are adjustable and are set to close at a predetermined point in the time cycle of 2T(2), that is, 2T(1) closes prior to the closing of 2T(2). For example, a typical time cycle may be a closing of 2T(2) fifteen (15) seconds after the energization of the relay unit 2T, with contacts 2T(1) set to close at any time interval less than the fifteen (15) second cycle of 2T(2).

There is also connected in circuit line CL5, the feed limit switch unit 9 which is normally open but which is closed by the feed stop rod 90 on the saddle and carriage unit 18—19 at the end of the feed cycle. Feed limit switch 9 is connected in control circuit line CL5 between the relay unit 2T of the supply line 1X3.

A circuit line CL6 is connected across supply lines 1X3 and 1X5 and includes therein the actuating solenoid of a relay unit 2CR. Relay unit 2CR includes the set of normally open contacts 2CR' connected in circuit line CL6 between 2CR and supply lines 1X3 and 1X5, and the sets of normally open contacts 2CR' connected in the power circuit lines PL12 and PL13, respectively, for the feed solenoid FS.

A control circuit line CL7 is connected across supply lines 1X3 and 1X5 and includes therein the actuating magnet of a relay 2R. Relay 2R has three (3) sets of normally open contacts 2RC which are connected in power circuit lines PL7, PL8 and PL9, respectively, of the power circuits to rapid traverse motor RTM, and a set of normally closed contacts 2RC′ connected in the control circuit line CL8.

Circuit line CL8 is connected between circuit line CL4 and circuit line CL7, being connected to line CL4 at a point between the "Start" and "Stop" contacts 5′ and 6′ and to circuit line CL7 between relay unit magnet 2R and supply line 1X5. In this circuit line CL8 there is connected; the actuating magnet of a contactor unit 2F between circuit line CL7 and the set of normally closed contacts 2RC′; a set of contacts 27′ of a rapid traverse control switch unit between contact set 2RC′ and supply line 1X3; and a set of normally open contacts 1MC of contactor unit 1M between supply line 1X3 and control circuit line CL4.

An interlock control circuit line CL9 is connected between supply line 1X5 and control circuit line CL5, being connected into the latter between the feed limit switch unit 9 and timing relay 2T. Circuit line CL9 includes therein the actuating magnet of a relay unit 3CR. Relay unit 3CR includes sets of normally open contacts 3CR′ connected in the power circuit lines PL10 and PL11, respectively, through the rapid traverse clutch sloenoid RTS. A normally open interlock line switch 10 is connected in circuit line CL9 between relay magnet 3CR and line CL5, and the set of timing contacts 2T(2) of the timing relay 2T is connected in line CL9 between 3CR and the interlock limit switch 10.

A control circuit line CL10 is connected across supply lines 1X3 and 1X5 and includes therein the actuating magnet of a contactor unit 3M. Between the magnet of 3M and supply line 1X3, there is connected in line CL10 a set of "Start" contacts 205 and a set of "Stop" contacts 206 which constitute a push button actuated switch unit having the control button 205′ and 106′ located at the switch button switch station 4 (see Fig. 1). The "Start" switch contacts 205 are connected in line CL10 between supply line 1X3 and the "Stop" contacts 206. A shunt line CL11 is connected between supply line 1X3 and the line CL10 across the "Start" contacts 205.

The contactor unit 3M includes three (3) sets of normally open contacts 3MC. One set of contacts 3MC is connected in the shunt line CL11 across "Start" contacts 205; another set of contacts 3MC is connected in the direct current supply circuit line L14 of the electronic network; and another set of contacts 3MC is connected in the circuit line L39 of the electronic network.

The contactor unit 1M includes in addition to the normally open sets of contactors 1MC in the power lines PL1, PL2 and PL3 to the cutter spindle motor CM, a set of normally open contacts 1MC in the supply line 1X3 between control circuit lines CL8 and CL5 (see Fig. 18), and another set of normally open contacts 1MC in the line CL8 between supply line 1X3 and the point of connection of line CL8 into the control circuit line CL4.

A circuit line CL12 is connected to line CL7 between contacts 2T(1) and contacts 26′, and extends to and is connected into line CL6 between contacts 2CR′ and the solenoid of the contactsor unit 2CR in order to close the circuit through 2CR when the timing contacts 2T(1) close.

An operating cycle

With a machine organization of the present example an efficient, semi-automatic operating cycle may be performed as follows:

In carrying out this cycle, it is assumed that the saddle and cross feed carriage unit 18—19 has been projected upwardly to position with the tracer roller T engaged with master cam M and the cutter C positioned for machining engagement with a work piece W to be machined out into the finished article, in this instance of a turbine blade WT.

The operator then closes the master control circuit CL2 by closing the master control switch 1T which energizes relay 1CR and closes supply lines 1X3 and 1X5. Operation of the cutter spindle motor CM is then started by pressing the button 5 to close the control circuit CL4. Closing of this circuit actuates the contactor unit 1M to close the sets of contacts 1MC in the power circuit lines PL1, PL2, and PL3 to motor CM. At the same time, the sets of contacts 1MC in the line CLS and in the supply line 1X3, respectively, are closed, thus setting up the remainder of the control circuits for conditioning for operation.

The operator then presses the start button 205 and thereby closes the control circuit CL10 and energizes the contactor unit 3M. Energization of this unit results in closing the set of normally open contactors 3MC in shunt line CL11 and the sets of contacts 3MC in the direct current supply lines L14 and L39 of the controlling electronic network to the work spindle drive motor SM (see Fig. 16). Thus motor SM starts operating to revolve the work piece W. At this time, clutch solenoid FS is de-energized and the slip clutch FC is in position with feed screw F out of driven engagement with the feed train gear. And, as the rapid traverse clutch RTC is de-energized, the feed screw F is then out of driven connection with both the work spindle motor SM and the rapid traverse motor RTM.

The operator next moves the master control lever 26A of the air cylinder control valve unit 26, to the position which sets the valve unit 26 so as to open air cylinder 25 for unrestricted exhaust to atmosphere with the cross feed carriage 19 and tracer roller T thus yieldingly maintained in engagement with and under the control of the pattern surface *m* of the master cam M.

Engagement of clutch FC with the feed gear train, which latter is being driven from motor SM, results in driving the feed screw F from motor SM, so that the saddle and carriage unit 18—19 then starts on its power driven feed to the left to carry out a machining cycle. As soon as the tracer roller T is fed across the dwell *sd* and engages the pattern surface *m* of cam M, the rotary, circular cutter C begins its machining engagement with the work piece W. Due to the 1:1 reproduction ratio between the movements of the tracer roller T under the control of the master cam M, and the cutter C, the cutter C will make one (1) machining pass around the work piece W for each revolution of the master cam and the work piece. The rate of linear feed of the saddle and carriage unit with tracer roller T and cutter C along the master cam and the work piece, is correlated with the rate of rotation of the cam and the work piece, so that, the cutter C and the tracer T will, in the present example, feed axially along the work piece W and the master cam M in thousandths of an inch per revolution of the work piece.

As the feed and machining cycle progresses, the radial movements of the cutter C "in" or "out" relative to the rotating work piece W is under the complete control of the contours radially of the pattern surface *m* of the master cam

M, while the rate of rotation of the work piece W and the rate of linear feed of the tracer roller T and cutter C axially along cam M and the work piece W are controlled through slow down and acceleration of the work spindle and feed drive motor SM by the action of the signal generator and pickup G and the associated motor speed control and braking electronic network. Thus, the rate of movement of the surface or contour of the work piece W past the point of effective cutting or material removing contact between the surface of the work piece and the circular, rotary cutter C, is maintained substantially constants throughout the machining cycle as the cutter C makes its machining passes around and as it is fed axially along the revolving work piece. Whenever the cutter C, cross feed carriage 19 and permanent magnet GM are at rest at any point along the path of cross feed radially relative to the work piece, there is no signal generated by the signal generator G and the motor controlling network is conditioned for maximum speed of operation for the speed setting for which the network has been adjusted. Whenever there is movement of cutter C, cross feed carriage 19 and magnet GM from any at rest position in either direction along the radial path of cross feed as dictated by the master cam M, a signal is generated by the generator G and is imposed upon the motor controlling network to effect a slow down and braking of the motor SM, so that, the speed of rotation of work piece W and of linear feed of the saddle and carriage unit 18—19 is reduced in direct proportion to the motor speed reduction. And the magnitude of the speed reduction imposed on motor SM is in direct ratio to the velocity of cutter C, carriage 19 and magnet GM, due to the fact that the magnitude of the signal generated and imposed on the controlling network by the generator G will be in direct proportion to the rate of speed or velocity of the movement in either direction of magnet GM relative to the coil GC.

Feed of tracer roller T and cutter C axially along the master cam and the work piece and cross feed of the tracer roller T and cutter C radially relative to the cam and work piece, continues under the direct control and dictation of the master cam M for the length of the work piece to be machined as determined by each particular work piece and cam combination. Just in advance of the end of the machining cycle, the feed stop rod 90 on saddle 18 engages the feed limit switch unit 9 to close the contacts thereof and close the control circuit line CL5. This energizes the timing relay 2T and sets the timing cycle provided for by the timing contacts 2T(1) and 2T(2) of that relay. The feed continues until feed stop rod 90 engages the abutment stop 92 so that further movement in a feed direction of saddle 18 is arrested.

During the timing cycle which is determined by the timing adjustment of timing contacts 2T(2), the timing contacts 2T(1) close to close the circuit line CL–6 and energize the relay 2CR, so that the sets of normally open contacts 2CR' are closed in the control circuit line CL6 and in the power circuit lines PL12 and PL13 of the feed clutch solenoid FS. Closing of the circuit through feed solenoid FS energizes that solenoid and effects actuation of clutch FC to the left of rock shaft 60 in a clockwise direction to draw control rod 62 to the left.

When the timing contacts 2T(1) close to close line CL6, they also close at the same time the control circuit line CL7, the rapid traverse motor reversing switch 26'—27' being in the position closing line CL7 as shown in Fig. 21. With line CL7 closed, relay unit 2R is energized and its sets of contacts 2RC are closed to close the power circuit lines PL7, PL8 and PL9 to the rapid traverse motor RTM. Thus, motor RTM is put into operation at the point in the cycle between closing of the first set of timing contacts 2T(1) and the relay 2T.

The closing of the power circuit lines PL12 and PL13 through solenoid FS energizes that solenoid to actuate the operating mechanism for slip clutch FC to disengage that clutch from driven connection with the feed train gear to thus stop the drive of feed screw F from the motor SM. Simultaneously with the closing of relay contacts 2CR' to close the circuit through solenoid FS, the power circuit PL14 through solenoid AS is closed to effect energization of that solenoid. Energization of solenoid AS effects operation of the air control valve unit 26 to retract or "pull back" the cross feed carriage to a position with the tracer roller T and cutter C clear of master cam M and the machined work piece W, in preparation for the rapid traverse cycle.

The energization of solenoids FS and AS as referred to above, takes place just prior to the closing automatically of the timing contacts 2T(2) of timing relay 2T and effects closing of the normally open contacts of switch 10 and thus completes the closing of the circuit line CL9 to energize relay 3CR. Energization of relay 3CR effects closing of the contacts 3CR' in the power circuit lines PL10 and PL11 through the rapid traverse clutch actuating solenoid RTS, to thus energize solenoid RTS and thereby effect engagement of rapid traverse clutch RTC. The engagement of clutch RTC by closing of solenoid RTS will result in driving feed screw F in a direction to move the saddle and carriage unit 18—19 to the right at a rapid traverse rate. As solenoid AS had previously operated control valve unit 26 to effect operation of the air cylinder 25 to retract cross feed carriage 19, rapid traverse movement to the right of the saddle and carriage unit is carried out with the carriage in retracted position so as to return the unit to position for starting the next machining cycle.

As the saddle and carriage unit approaches the end of the rapid traverse return, the rapid traverse clutch RTC is disengaged automatically to thus arrest rapid traverse movement of the saddle and carriage unit. After disengagement of clutch RTC, the unit then coasts and comes to a stop in position for the next machining cycle. Near the end of the rapid traverse return movement of the saddle and carriage unit 18—19, the return limit switch 8 is operated to momentarily open the normally closed contacts of the switch connected in the control circuit line CL4. Opening of the contacts of switch 8 causes de-energization of contactor unit 1M and results in opening the contacts 1MC in the supply circuit line 1X3, circuit line CL8, and the power circuit lines PL1, PL2 and PL3 of the cutter spindle motor CM. Thus, operation of motor CM is stopped and with the supply circuit line 1X3 opened, contactor unit 3M is de-energized which opens the sets of contacts 3MC in the lines L14 and L39 of the electronic network (see Fig. 16) to thus stop operation of the work spindle drive motor SM. The momentary opening of the normally closed return limit switch 8 stops operation of all motors and cuts off all the electrical instrumentalities at the end of the rapid traverse cycle.

The invention is not limited or restricted in its adaptations and applications to use of rotary cutting or material removing tools, but contemplates and intends the utilization of tools or material removing means of the fixed types; nor is it limited or restricted to the use of work piece material removing means of the cutter types, as it is adapted to the use of such means of the grinding or abrasive surface types. Similarly, an organization of the invention may be utilized for contour surface polishing or buffing where material removal is a secondary or incidental function, as well as for those operations where material removal is very small but a primary function to meet very fine tolerances.

It is recognized that the control system of my present invention for controlling the rate of rotation of a member, exemplified by the work piece of the present example, in direct proportion to the velocity of movement of another member or element, such as the tool of the present machine, is capable of other adaptations and uses than with the particular machine organization and combination here presented, and it is not intended by the present disclosure of a specific adaptation and application of such control system to thereby limit and restrict its adaptation and use.

It will also be evident that various changes, modifications, substitutions, adaptations and eliminations may be resorted to without departing from the broad spirit and scope of my invention, and hence, I do not intend to limit my invention in all respects to the exact and specific disclosure hereof, except as may be required by intended limitations thereto appearing in the claims hereto appended.

What I claim is:

1. In combination, a rotary work holder; an electric motor for rotating said work holder; an electronic control network including, a power circuit to said motor, grid controlled gaseous electron tubes, and control circuits for said tubes for effecting operation thereof to control the current delivered to said motor by said power circuit; a tool holder mounted for cross feeding movements toward and from said work holder; means for effecting cross feeding movements of said tool holder; a signal generator adapted to be actuated to generate and impose signals on said network in the form of electrical impulses of varying magnitudes to effect control of said tubes to reduce the current delivered to said motor in direct proportion to the magnitude of the generated signal, said generator being adapted to generate said signals only during actuation thereof; and said generator being operatively coupled with said tool holder for operation during cross feeding movements of the latter in either direction from any position thereof to generate signals of a magnitude in direct proportion to the velocity of the cross feeding movement of said tool holder.

2. In combination, a rotary work holder; an electric motor for rotating said work holder; an electronic control network including, a power circuit to said motor, grid controlled gaseous electron tubes, and control circuits for said tubes for effecting control of the current delivered to said motor by said power circuit; a tool holder mounted for cross feeding movements toward and from said work holder; a signal generator for generating and imposing a signal on said network for effecting control of said tubes to reduce the current delivered to said motor to thereby reduce the speed of rotation of said work holder; said generator being operatively associated with said tool holder for signal generating operation by cross feeding movements in either direction of said tool holder; and an inverter comprising grid controlled gaseous electron tubes electrically connected with said motor for converting to alternating current, the direct current generated by coasting of said motor upon reduction in speed thereof.

3. In combination, a rotary work holder; an electric motor for rotating said holder, said motor including an armature; an electronic control network including, a power circuit to said motor, grid controlled gaseous electron tubes, and control circuits for said tubes for effecting control of the current delivered to said motor by said power circuit; a tool holder mounted for cross feeding movements toward and from said work holder; a signal generator for generating and imposing a signal in the form of an electrical impulse upon said network for effecting control of said tubes to reduce the current delivered to said motor to thereby reduce the speed of rotation of said work holder; said electronic net work including, an inverter comprising grid controlled gaseous electron tubes and associated circuits electrically connected with the armature of said motor for converting to alternating current the direct current generated by coasting of said armature upon reduction in the speed of operation thereof by reduction of current supplied thereto by said power circuit.

4. In combination, a rotary work holder; an electric motor of the direct current, shunt wound type for rotating said work holder, said motor including a rotary armature and armature windings thereon; an electronic control network including, an alternating current power circuit to said network, grid controlled gaseous electron tubes for rectifying to direct current the alternating current delivered thereto from said power circuit, a direct current supply circuit from said tubes to said motor, and control circuits for said tubes for effecting control by said tubes of the current delivered therefrom to said motor by said direct current supply circuit; a tool holder mounted for cross feeding movements toward and from said work holder; a signal generator connected in the control circuits for said electron tubes for generating and imposing thereon a signal in the form of an electrical impulse for effecting control of said tubes to reduce the supply of direct current delivered to said motor to thereby reduce the speed of rotation of said work holder; said generator being operatively coupled with and being adapted to be actuated by cross feeding movements in either direction of said tool holder to generate and impose a signal on said electron tubes to effect a reduction in the rate of rotation of said work holder; and said electronic network including an inverter for converting direct current to alternating current comprising grid controlled gaseous electron tubes electrically connected with the windings of said motor armature for receiving therefrom direct current generated by coasting of said motor armature upon a reduction in the supply of direct power current delivered thereto, and an electric circuit connecting the output side of said inverter with said alternating current power supply line for feeding back into said line the converted direct current delivered from said inverter.

5. In combination, a rotary work holder; an electric motor of the direct current type for rotating said work holder, said motor including a rotary armature having armature windings thereon; a rectifier for converting alternating current to direct current; an alternating current power circuit to said rectifier; a direct current power circuit from the output side of said rectifier to said motor; means for setting said circuits to limit the operation of said motor for a predetermined maximum rate of rotation of said work holder; control means associated with said rectifier and being operable to vary the amount of direct current supplied from the rectifier to said motor; a tool holder mounted for cross feeding movements toward and from said work holder; and means coupled with said tool holder and being adapted to be actuated thereby to operate said control means to effect a reduction of the amount of direct current delivered to said motor by cross feeding movements of said tool holder, of a magnitude in direct proportion to the velocity of cross feeding movement of said tool holder.

6. In combination, a rotary work holder, an electric motor for rotating said work holder, a power circuit to said motor, a tool holder mounted for cross feeding movements toward and from said work holder, control means electrically connected in the power circuit of said motor and being operable to control the speed of operation of said motor to vary the rate of rotation thereby of said work holder, said control means being operatively associated with said tool holder and being adapted to be actuated upon cross feeding movements thereof in either direction to control the operation of said motor to effect a reduction in the rate of rotation of said work holder, and means operatively associated with said motor and with said control means and being operable by the operation of said control means to brake the motor by absorbing the kinetic energy of the coasting motor following reduction in the rate of rotation thereof.

7. In combination, a rotary work holder, an electric motor for rotating said work holder, a power supply circuit to said motor, a tool holder mounted for cross feeding movements toward and from said work holder, control means electrically connected in the power circuit of said motor to vary the rate of rotation thereby of said work holder, said control means being operatively associated with said tool holder and being adapted to be actuated by cross feeding movements thereof in either direction to control the operation of said motor to effect a reduction in the rate of rotation of said work holder of a magnitude directly proportional to the velocity of cross feeding movement of the tool holder, and means for braking automatically the coasting of the motor resulting from a reduction in the speed of operation thereof by said control means.

8. In combination, a rotary work holder; an electric motor of the direct current type for rotating said work holder; an electronic control network including, an alternating current power circuit to said network, grid controlled gaseous electron tubes for rectifying alternating current from said power circuit to direct current, a direct current supply circuit from said tubes to said motor, and control circuits for said tubes for effecting control thereof to control the amount of current delivered therefrom to said motor; a tool holder mounted for cross feeding movements toward and from said work holder; a signal generator operable to generate a signal in the form of an electrical impulse of a magnitude in direct proportion to the rate of operation of said generator; said signal generator being connected with said electronic control network for imposing on the control circuits to said tubes a signal adapted to effect functioning of said tubes to reduce the amount of direct current delivered to said motor to thereby effect a reduction in the speed of rotation of said work holder of a magnitude in direct proportion to the magnitude of the generated signal; and said signal generator being operatively coupled with said tool holder and being adapted to be actuated by cross feeding movements of said tool holder in either direction to generate a signal of a magnitude in direct proportion to the velocity of cross feeding movement of said tool holder.

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