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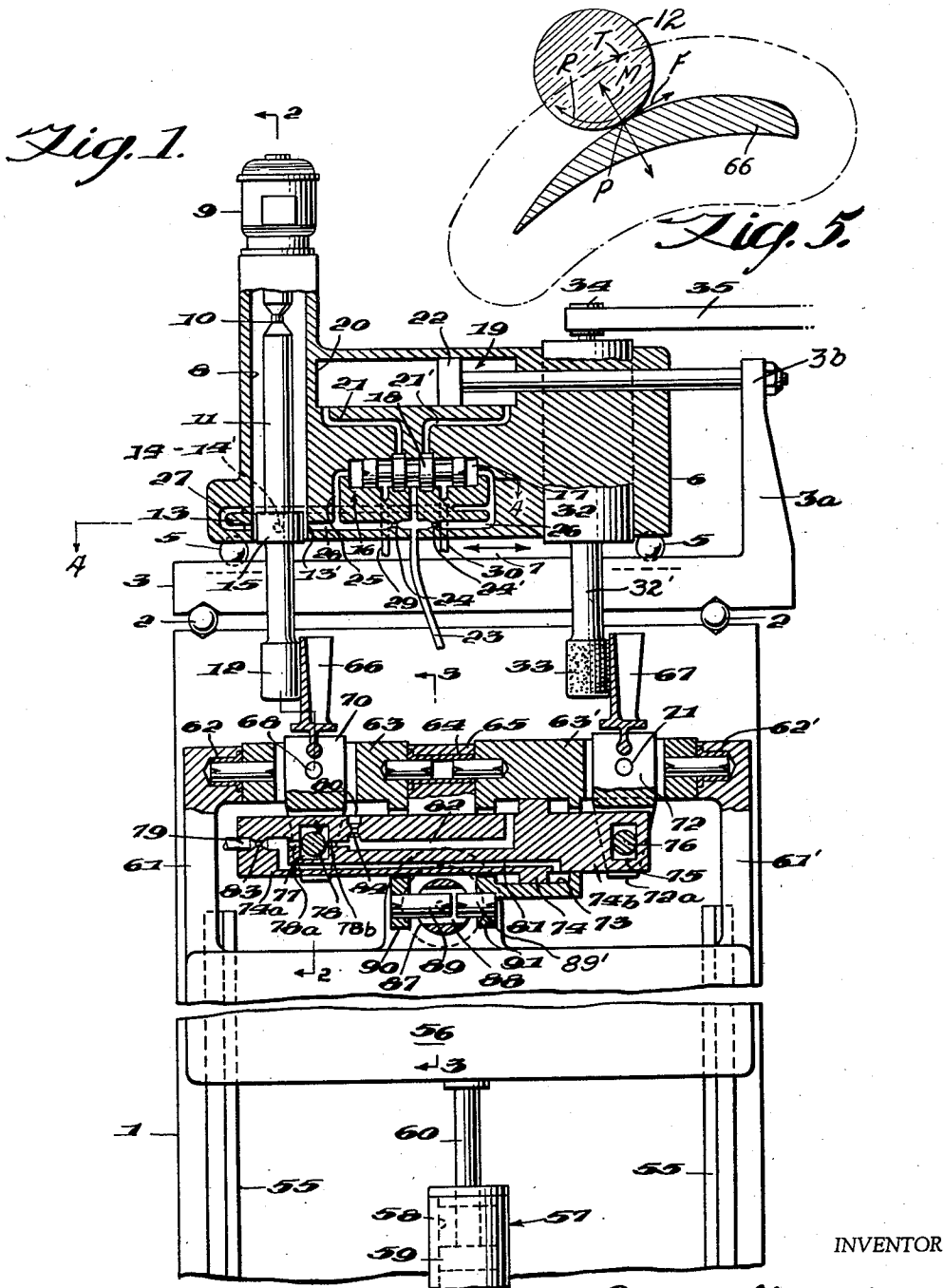
R. CHIAPPULINI

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AUTOMATIC COPYING MILLING AND GRINDING MACHINE

Filed June 4, 1951

2 Sheets-Sheet 1



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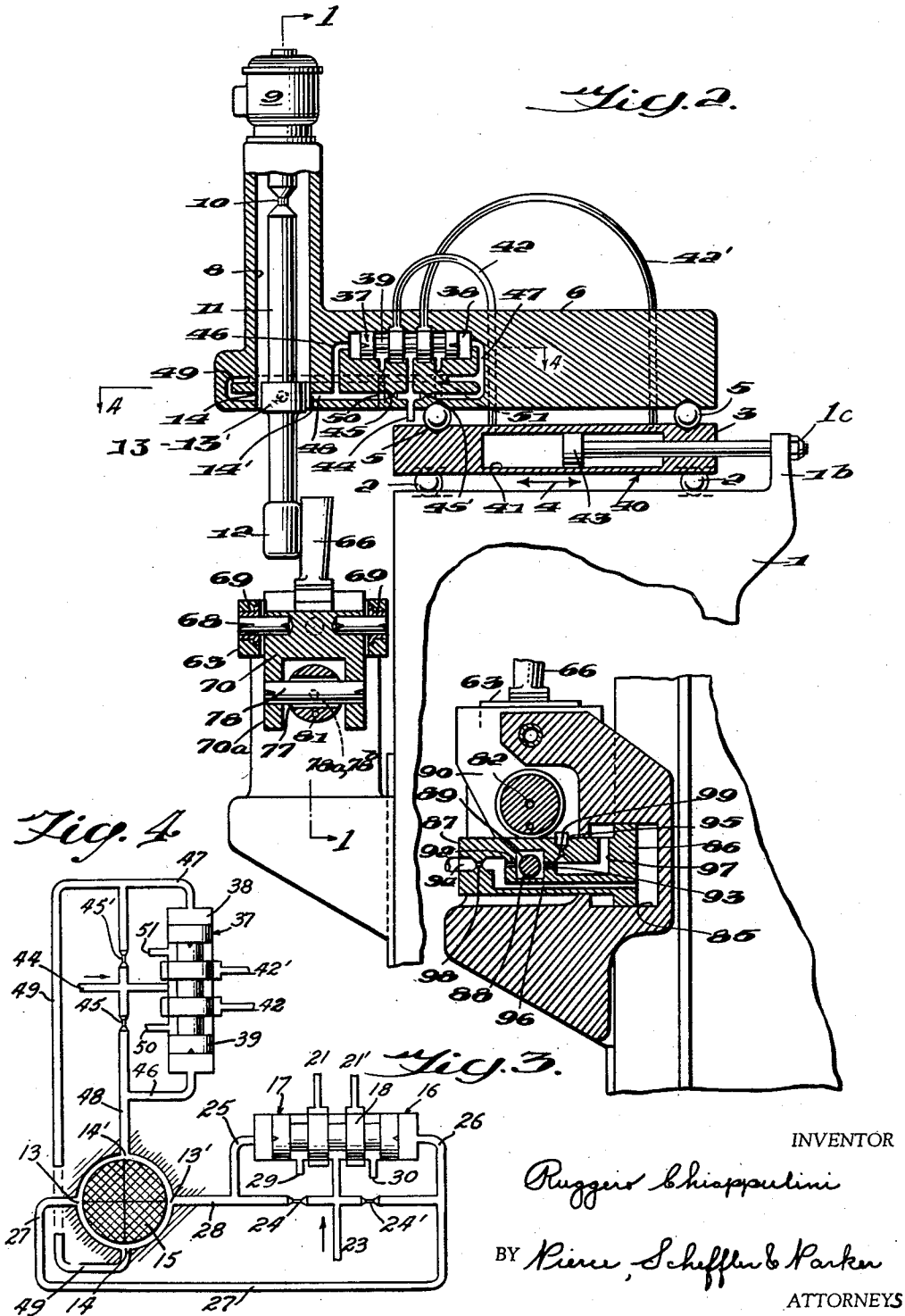
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UNITED STATES PATENT OFFICE

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AUTOMATIC COPYING MILLING AND GRINDING MACHINE

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6 Claims. (Cl. 51—100)

1

The present invention relates to copying machines such as grinders, millers, and the like wherein a feeler is caused to travel along the surface of a pattern fashioned to the desired finished contour of a blank and the feeler motion is translated into corresponding motion of a tool used to work the surface of the blank to agree with that of the pattern. This technique is particularly useful in finishing curved surfaces such as propeller and turbine blades.

Various types of transmissions are already known for making the tool follow or track the feeler movement such as mechanical, pneumatic and hydraulic. The mechanical type is not too practical since a complicated system of rods is required, the error in transmission is appreciable and the cost is high. In pneumatic systems the transmission error is likewise appreciable due to the high elasticity of the gas medium employed thus leading to copying distortion. A hydraulic transmission system has less error but in previously known copying machines, particularly those used in working the complexly curved surfaces of blades for turbo-machines such as steam or gas turbines and axial flow type air compressors, conical or greatly convex tools had to be used. These tools permit only a limited output because the limited length of the contact line with the metal blank being worked due to their complex shape necessitates small lateral advances, particularly in the finishing work. Moreover because of the shape of the metal blank the thickness of the tool spindle must be decreased to a minimum which either limits the number of different shapes capable of being processed or results in substantial copying error caused by flexing of the spindle.

This invention also concerns a copying machine wherein motion of the feeler is converted into corresponding motion of the tool by hydraulic follow-up mechanism but which suffers from none of the disadvantages inherent in the prior art machines. In particular the improved operating characteristics result from applicant's improved wobbler type of mount for the pattern and metal blank which permits these two elements to execute identical wobbler movements about the junction point of mutually perpendicular intersecting axes, use of geometrically identical feeler and tools constituted either by cylinders uniform in diameter throughout their length or slightly convex with the largest diameter at the middle such as in a barrel, and wherein the pattern is attracted magnetically to the surface of the magnetic feeler. The wobbler type of mount

2

permits simultaneous identical wobble motions of the pattern and metal blank about two mutually perpendicular axes, and the magnetic attraction between pattern and feeler causes the latter to cling to the former as it is caused to advance circumferentially of the pattern.

The slightly convex to cylindrical characteristic of the magnetic feeler provides a well distributed, constantly effective magnetic attractive force between the feeler and pattern. If the advance of the pattern and metal blank in the direction of the feeler and tool axes, respectively are set in the proper ratio to the profile circumferential advance of the feeler and tool, then a completely smooth worked surface (milled or ground for example) can be achieved. The matched wobble movements of the pattern and metal blank not only enable the feeler and tool to maintain constant long line contacts with the pattern and metal blank, respectively, as distinguished from a spotwise contact between such elements but also enable use of strong shafts for the comparatively large diametered feelers and tools which continuously force lateral deviations upon the pattern and metal blank.

In the accompanying drawings which illustrate a preferred embodiment of the invention as applied to a copying type grinding machine; Fig. 1 is a front view of the improved machine partly in elevation and partly in section on line 1—1 of Fig. 2; Fig. 2 is a vertical section taken on line 2—2 of Fig. 1; Fig. 3 is vertical section taken on line 3—3 of Fig. 1; Fig. 4 is a view in plan on lines 4—4 of Figs. 1 and 2 showing the pilot valve assemblies incorporated in the machine; and Fig. 5 is a diagrammatic view illustrating the cooperative relationship between the magnetic feeler and pattern.

With reference now to the drawings, the general frame of the machine is designated by numeral 1. Mounted upon the frame by spaced ball type rollers 2 is a slide 3, having a direction of motion indicated by the double arrow 4 in Fig. 2. Mounted upon slide 3 by spaced ball type rollers 5 is a second slide 6 having a direction of motion indicated by the double arrow 7 in Fig. 1. Motions of the two slides 3 and 6 are thus rectilinear and mutually perpendicular.

Slide 6 includes at one side thereof a vertical bore 8 atop which is a motor 9 that drives, through a flexible connection 10, a vertically disposed spindle 11. The flexible connection 10 is incorporated to enable spindle 11 to be moved out of the normally vertical spindle axis. The lower end of spindle 11 terminates in a cylinder

like feeler 12. In the drawing, feeler 12 is of uniform diameter throughout its length and therefore truly cylindrical. However if desired the spindle surface can be given a slightly convex curvature intermediate its ends in a longitudinal direction much in the way a barrel is constructed.

At the lower part of the bore 3 in slide 5 are arranged two pairs of mutually perpendicular ports 13—13' and 14—14' which in cooperation with an enlarged cylindrical portion 15 on spindle 11 function as a hydraulic control for a pilot valve assembly 16 built into the body of slide 6. Valve assembly 16 includes a horizontally disposed cylinder 17, piston 18 and a system of ports so arranged that displacement of spindle 11 in one direction or the other in the plane of the drawing Fig. 1 causes the pilot piston 18 to move in the same direction.

Disposed above the pilot valve assembly 16 is a power motor 19 of the double action hydraulic expansible chamber type. Motor 19 includes a cylinder 20 with hydraulic conduits 21, 21' leading from opposite ends thereof into the pilot valve assembly 16 and a stationary piston 22 extending outwardly of the body of slide 6 to a fixed anchor point 23 at the upper end of a vertically arranged arm 3a on slide 3. Hydraulic fluid is supplied at constant pressure from a pump, not illustrated, to the pilot valve assembly 16 through inlet conduit 23. The fluid is directed through throttling orifices 24, 24' into bores 25, 25' to opposite ends of pilot cylinder 17 and also through bores 27, 28 to ports 13, 13' at spindle 11. Return conduits 29, 30 lead from the pilot valve cylinder 17 to the low pressure sump of the hydraulic system which has been omitted for the sake of simplicity. Thus when spindle 11 moves to the right for example, a pressure differential in the pilot valve 16 is established causing more of the hydraulic fluid to enter the left end of cylinder 17 moving piston 18 to the right sufficiently to uncover and expose bore 21' to the high pressure fluid in pilot valve 16 and simultaneously open conduit 21 to the low pressure return line 29. Hydraulic fluid flows into that portion of the motor cylinder 20 to the right side of piston 22 causing the slide 6 to also move to the right in a horizontal plane. A similar sequence of events effecting displacement of slide 6 to the left will take place should spindle 11 move to the left from vertical as viewed in Fig. 1. Thus any displacement of spindle 11 in the plane of the drawing, Fig. 1 from vertical results in a like and simultaneous horizontal rectilinear displacement of slide 6 on slide 3.

Also mounted within slide 6 for rotation in a vertical plane is a quill, i. e. a sleeve or bushing wherein the tool spindle is lodged in such manner, for example by means of ball bearings, that it can rotate freely, terminating at its lower end in a tool 33, which as previously explained is a grinder in the illustrated embodiment, of the same size and shape as the feeler 12. A drive pulley 34 is disposed at the upper end of spindle 32' and the illustrated drive means for spindle 32' is a belt 35 running over pulley 34. This type of drive is illustrative only and it will be obvious that other types of drives such as an electric motor can be substituted for the particular type illustrated. So also with the drive for spindle 11. Spindles 11 and 32' are parallel and the feeler 12 and tool 33 are located at like elevations.

With reference now to Fig. 2, provision is made

for displacing slide 3 horizontally on frame 1 in the direction of double arrow 4 in response to lateral displacements of feeler 12 left and right from the vertical position in the plane of the drawing Fig. 2. This plane is of course normal to the plane of the drawing Fig. 1. For this purpose a second pilot valve assembly 37 also built into the body of slide 6 is provided and includes a horizontally disposed cylinder 38, piston 39 and a system of ports so arranged that displacement of spindle 11 in one direction or the other in the plane of the drawing Fig. 2 causes pilot piston 39 to move in the same direction.

Disposed below slide 6 in the body of slide 3 is a power motor 40 of the double action hydraulic expansible chamber type including a cylinder 41 with hydraulic conduits 42, 42' leading from opposite ends thereof into the pilot valve assembly 37, and a stationary piston 43 extending outwardly of the body of slide 3 to a fixed anchor point 4c on an upstanding arm 4b of frame 1. Hydraulic fluid is supplied at constant pressure from the pump, not illustrated, to pilot valve assembly 37 through inlet conduit 44. The fluid is directed through throttling orifices 45, 45' into bores 46, 47 to opposite ends of pilot cylinder 38 and also through bores 48, 49 to ports 14, 14' at spindle 11, which as previously explained are mutually perpendicular to ports 13, 13'. Return conduits 50, 51 lead from pilot valve cylinder 38 to the low pressure sump of the hydraulic system. Thus when spindle 11 moves to the right with reference to Fig. 2 for example, a pressure differential is established in the pilot valve assembly 37 causing hydraulic fluid to enter the left end of cylinder 38 moving piston 39 to the right sufficiently to uncover and expose conduit 42' to the high pressure fluid in pilot valve assembly 37 and simultaneously connect conduit 42 with the low pressure fluid return conduit 50. Hydraulic fluid flows into that portion of motor cylinder 41 to the right side of piston 43 causing slide 3 to also move rectilinearly to the right in a horizontal plane. A similar sequence of events effecting displacement of slide 3 to the left will take place should spindle 11 move to the left from vertical as viewed in Fig. 2. Thus any displacement of spindle 11 from vertical in the plane of drawing Fig. 2 results in a like and simultaneous horizontal displacement of slide 3 on frame 1.

It will now be seen that any displacement of spindle 11 in any direction from vertical is resolved into two mutually perpendicular rectilinear vectors in a horizontal plane which through the two hydraulic systems described controlling movement of slides 3 and 6 are employed to effect a corresponding displacement of the tool 33. Tool 33 therefore faithfully tracks all displacements of feeler 12 as the latter rolls around the periphery of the pattern 65.

Frame 1 includes rails 55 at each side thereof guiding a platform 56 for controlled movement in a vertical plane, the power for lifting the platform being provided by a hydraulic motor 57 of the expansible chamber type including a cylinder 58 and piston 59, the piston rod 60 being secured to the underside of platform 56.

Upstanding at each side of platform 56 are arms 61, 61' in which are formed journals 62, 62' for mounting the spindled outer ends of coaxially arranged carriers 63, 63' for rotation about a horizontal axis. The inner spindled ends of the carriers are supported in a common journal 64 formed in another arm 65 upstanding upon platform 56.

5

Mounted upon carriers 63, 63' respectively are the pattern 66 and metal blank 67 to be finished. Pattern 66 is made magnetically attractive to feeler 12 such as by making the latter of magnetized material to assure constant surface contact therebetween, and blank 67 occupies the same position with respect to tool 33 as pattern 66 does with respect to feeler 12. Both pattern 66 and blank 67, in the illustrated example a turbine blade, are so supported as to enable both to execute like movements simultaneously about two mutually perpendicular horizontal axes, one of which is the common axis of carriers 63, 63' and the other an axis normal to and which intersects the axis of such carriers. A shaft 68 extending transverse to the axis of carrier 63 and supported in journals 69 on carrier 63 allows pivotal motion of the pattern mount 70 and hence also pattern 66 about the axis of shaft 68 in the plane of drawing Fig. 1. A similar shaft 71 extending transverse to the axis of carrier 63' and also supported in journals, not shown, on carrier 63' allows like pivotal motion of the metal blank mount 72 and hence also blank 67 about the axis of shaft 71.

As shown in Fig. 5, the magnetic attractive force M between the magnetic feeler 12 and pattern 66 develops, due to friction, a tangential force F in the point of contact P between their respective peripheries. Due to rotation of the feeler 12 in the direction R, a rolling motion of the feeler 12 along orbit T around the profile of the pattern 66 takes place providing the frictional force F is greater than the required controlling force of the hydraulic follower system 12, 15, 13, 13', 14 and 14'. Thus the feeler 12 rolls around the pattern and will not skid on its surface. Feeler 12 and pattern 66, while thus always clinging together, are able to transmit their motions to the tool 33 and work blank 67 respectively.

Structurally integral with the carrier 63' is the cylinder 73 of a double acting hydraulic motor. Piston 74 of this motor includes two rod portions 74a, 74b extending in opposite directions through the end walls of cylinder 73. Part 74b is provided with a transverse rectangular aperture 75 through which extends a cross pin 76 that bridges a yoke 72a depending from the main body of blank mount 72. The diameter of pin 76 is substantially the same as the width of aperture 75. Part 74a of the piston rod also is provided with a rectangular transverse aperture 77 through which extends a cross pin 78 bridging a yoke 70a depending from the main body of pattern mount 70. As will be seen clearly from Fig. 1, cross pin 78 in conjunction with the set of ports 78a, 78b and in cooperation with the throttling orifices 83, 84 functions as a direct pilot valve controlling pressure and flow of hydraulic fluid entering through fluid inlets 79, 80 and bores 81, 82 in piston 74 leading to opposite ends of cylinder 73. Throttling orifices 83, 84 are placed in the fluid inlets 79, 80. Thus any pivotal movement of the pattern mount 70 about the axis of shaft 68 is reflected in a like movement of cross pin valve 78 which establishes an unbalanced fluid pressure condition at opposite sides of piston 74 in cylinder 73 causing displacement of piston 74 in the same direction of movement as cross pin 78. This effects a corresponding displacement of cross pin 76 and like angular displacement of the metal blank mount 72 and blank 67 about the axis of shaft 71.

Provision is also made for translating any

6

pivotal movement of the pattern 66 and its mount 70 about the axis of the carriers 63, into a like pivotal movement of the metal blank 67 and its mount 72 about the axis of carrier 63'.

With particular reference now to Figs. 1 and 3, the organization for effecting this result is comprised of still another hydraulic motor of the double acting expansion chamber type including a cylinder 85 supported horizontally upon platform 56 perpendicular to the common axis of carriers 63, 63' and a piston 86. As seen in Fig. 3, the piston rod 87 projects forwardly and includes a transverse rectangular aperture 88 through which extends a cross pin 89 serving as a pilot valve and which latter is secured between ears 90, 91 depending respectively from the inner ends of carriers 63, 63', the ears also being apertured to pass piston rod 74a. Cross pin 89 in conjunction with ports 92, 93 and in cooperation with the throttling orifices 98, 99 functions as a direct pilot valve and controls pressure and flow of hydraulic fluid entering through fluid inlets 94, 95 and bores 96, 97 in piston rod 87 leading to opposite ends of cylinder 85. As with the other motors, throttling orifices 98, 99 are placed in the fluid inlets 94, 95.

Thus any pivotal movement of the pattern mount 70 and hence also the carrier 63 about the carrier axis is reflected in a like movement of cross pin 89 which then establishes an unbalanced fluid pressure condition at opposite sides of piston 86 in cylinder 85 causing displacement of piston 86 in the same direction. Movement of piston 86 is transmitted through piston rod 87 and pin 89' to ear 91 and hence provides power for rotating carrier 63' about its axis and hence also metal blank 67 to agree with the rotational displacement of carrier 63 and pattern 66.

From the foregoing description it will now be evident that any angular displacement of the pattern 66 about either of its two mutually perpendicular intersecting axes of rotation, namely the axes of carrier 63 and cross pin 68 results in a like angular displacement of the metal blank 67 powered by the pistons 74 and 86 of the two expansion motors. The pattern 66 and metal blank always remain parallel.

If it is desired to reduce sliding friction in the pilot valves, to thereby effect an even greater accuracy in copying, the valve parts such as pistons 18 and 38, etc. may be made to rotate about their axis as is already known.

I claim:

1. In an automatic copying machine the combination comprising parallel arranged pattern and work blank mounts each pivotally supported for pivotal movement about two mutually perpendicular intersecting axes whereby each mount is capable of a wobble movement about the junction of such axes, means controlled by and actuated in accordance with all wobble movements of said pattern mount for transmitting all wobble movements of said pattern mount to said work blank mount whereby to maintain said mounts in constant parallel relation, parallel arranged rotatable feeler and tool spindles, the axis of rotation of said tool spindle being fixed and said feeler spindle being flexible about its axis of rotation, geometrically identical feeler and tool members carried respectively by the corresponding spindles and which have a rounded surface contour, said feeler member being positioned to establish a rolling contact with the surface of a pattern secured to said pattern

mount, said pattern and feeler member being magnetically attractive to one another, and the work blank being adapted to be secured to its mount parallel to said pattern to establish contact with the surface of said tool, and means controlled by and actuated in accordance with all movements of said feeler spindle for transmitting all movements of said feeler spindle to said tool spindle whereby to maintain said tool spindle in constant parallel relation with said feeler spindle.

2. In an automatic copying machine, the combination comprising parallel arranged rotatable feeler and tool spindles, geometrically identical feeler and tool members carried respectively by the corresponding spindles and which have a rounded surface contour, the axis of rotation of said tool spindle being fixed and said feeler spindle including a flexible connection permitting deviation of the same and hence said feeler from its normal axis of rotation, power drive means controlled by and actuated upon deviation of said feeler spindle from its normal axis of rotation for causing said tool spindle to follow and duplicate the deviation of said feeler spindle thereby remaining parallel to the same, pattern and work blank mounts each pivotally supported for pivotal movement about two mutually perpendicular intersecting axes whereby each mount is capable of a wobble movement about the junction of such axes, power drives individual to each said axis of movement and controlled by pivotal movement of said pattern mount for causing the said mount for said work blank to follow and duplicate pivotal movement of said pattern mount, said feeler member being positioned to establish a rolling contact with the surface of a pattern secured to said pattern mount said pattern and feeler member being magnetically attractive to each other and the work blank being secured to its mount parallel to said pattern to establish contact with the rotatable surface of said tool.

3. An automatic copying machine as defined in claim 2 wherein the said power drive means for said tool spindle and the power drives for said work blank mount are constituted by double acting hydraulic motors of the expansible chamber type.

4. An automatic copying machine as defined in claim 2 wherein the power drive means for said tool spindle is constituted by double acting hydraulic motor means of the expansible chamber type, and said motor means is controlled by a pilot valve assembly including a valve cylinder and a piston slidable in the same.

5. In an automatic copying machine, the combination comprising a frame, a first slide carried by and displaceable rectilinearly upon said frame, a second slide carried by and displaceable rectilinearly upon said first slide in a direction normal to the direction of displacement of said first slide, rotatable feeler and tool spindles carried by said second slide in spaced parallel relation with their respective axes of rotation arranged perpendicular to the plane of displacement of said second slide, geometrically identical feeler and tool members carried respectively by said feeler and

tool spindles and which have a rounded surface contour, the axis of rotation of said tool spindle being fixed and said feeler spindle including a flexible connection permitting deviation of the same and hence said feeler from its normal axis of rotation, power drive means for each of said slides controlled by said deviation of said feeler spindle for causing said slides to follow and duplicate displacement of said feeler; pattern and work blank mounts, each of said mounts being supported pivotally for pivotal movement about two mutually perpendicular intersecting axes whereby each mount is capable of a wobble movement about the junction of such axes, linkage means connecting said pattern mount with said work blank mount in each of its two axes of pivotal movement, each said linkage means including power drive means controlled by pivotal movement of said pattern mount for causing the mount for said work blank to follow and duplicate the movement of said pattern mount, said feeler member being positioned to establish a rolling contact with the surface of a pattern secured to said pattern mount said pattern and feeler member being magnetically attractive to each other and the work blank being positionable upon its mount parallel to said pattern to establish contact with the rotatable surface of said tool.

6. In an automatic copying machine the combination comprising parallel arranged pattern and work blank mounts, means supporting each of said mounts in spaced relation for wobble movement about a fixed point, means controlled by and actuated in accordance with all wobble movements of said pattern mount for transmitting all wobble movements of said pattern mount to said work blank mount whereby to maintain said mounts in constant parallel relation, parallel arranged rotatable feeler and tool spindles, geometrically identical feeler and tool members carried respectively by the corresponding spindles and which have a rounded surface contour, said feeler member being positioned to establish a rolling contact with the surface of a pattern secured to said pattern mount, said feeler member and pattern being attractive magnetically to each other, and said work blank being adapted to be secured to its mount parallel to said pattern to establish contact with the surface of said tool, and means controlled by and actuated in accordance with all movements of said feeler spindle for transmitting all movements of said feeler spindle to said tool spindle whereby to maintain said tool spindle in constant parallel relation with said feeler spindle.

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