

Uhtenwoldt

[11] 3,796,012

[45] Mar. 12, 1974

[54] GRINDING MACHINE WITH CONTROLLED GRINDING FORCE

3,553,903	1/1971	Christie.....	51/165.9
3,604,160	9/1971	Ware.....	51/103 R
3,618,269	11/1971	Robillard et al.....	51/165.9
3,702,043	11/1972	Welbourn et al.....	51/165.77 X

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[57] ABSTRACT

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[58] **Field of Search**..... 51/165.77, 165.9, 165.92,
51/165.93

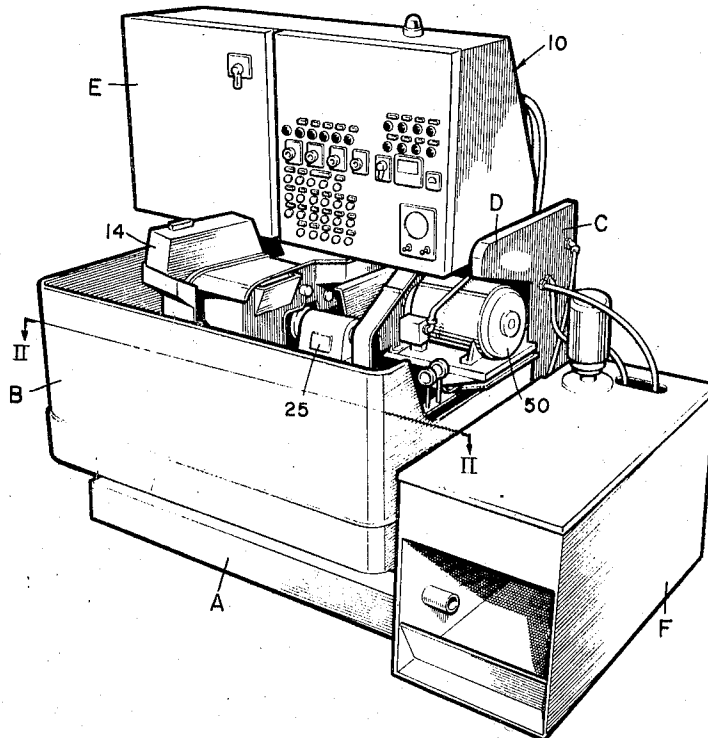
A grinding machine in which the grinding cycle is controlled by a signal from a transducer mounted in the workpiece support and capable of measuring substantially the entire grinding force.

[56] **References Cited**

UNITED STATES PATENTS

3,534,509	10/1970	Hatstat et al.	51/165.91
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4 Claims, 6 Drawing Figures



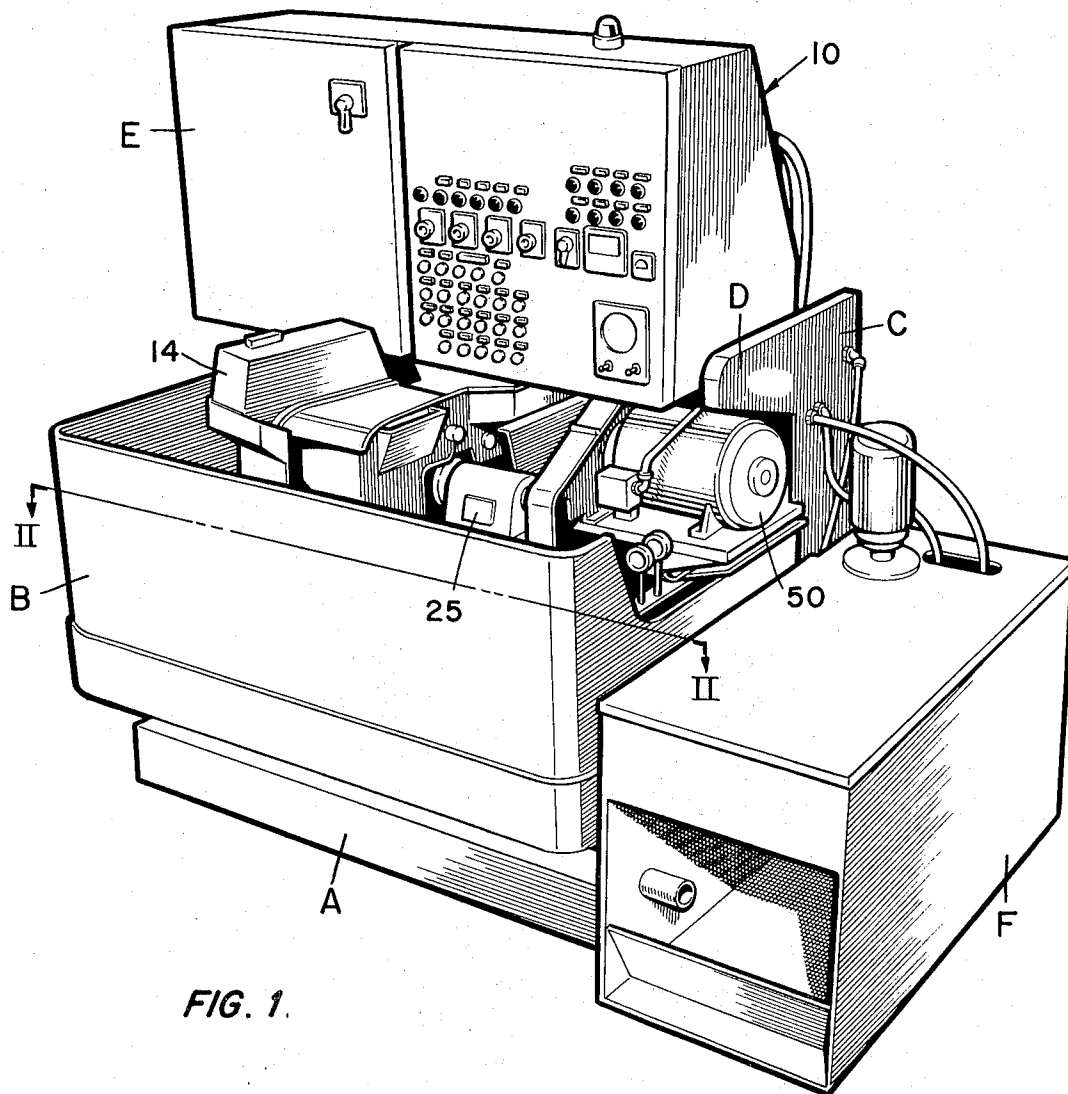
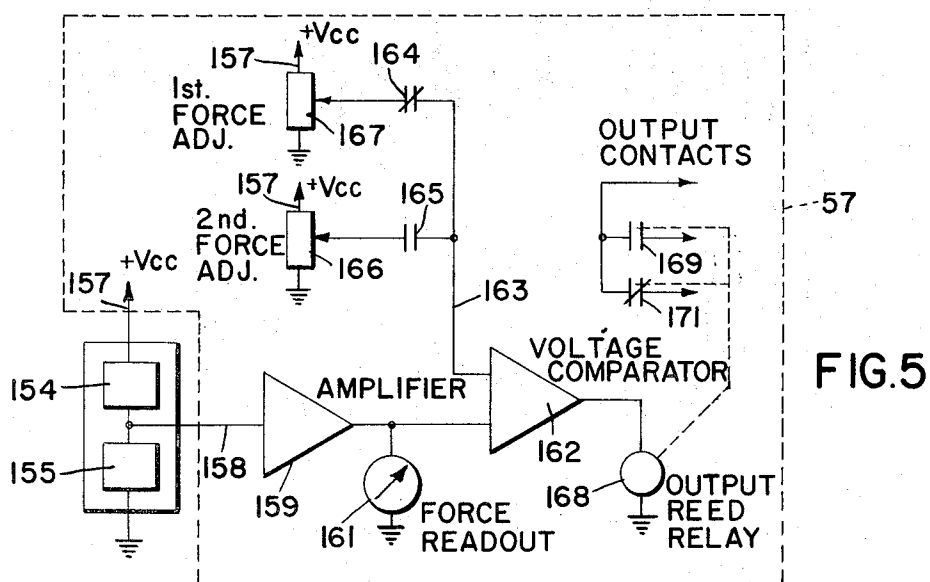
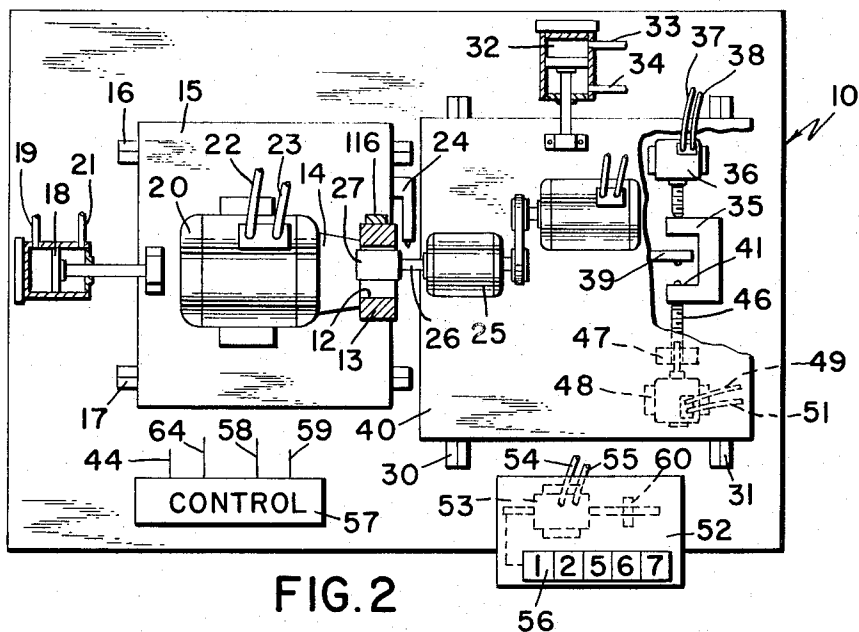


FIG. 1.



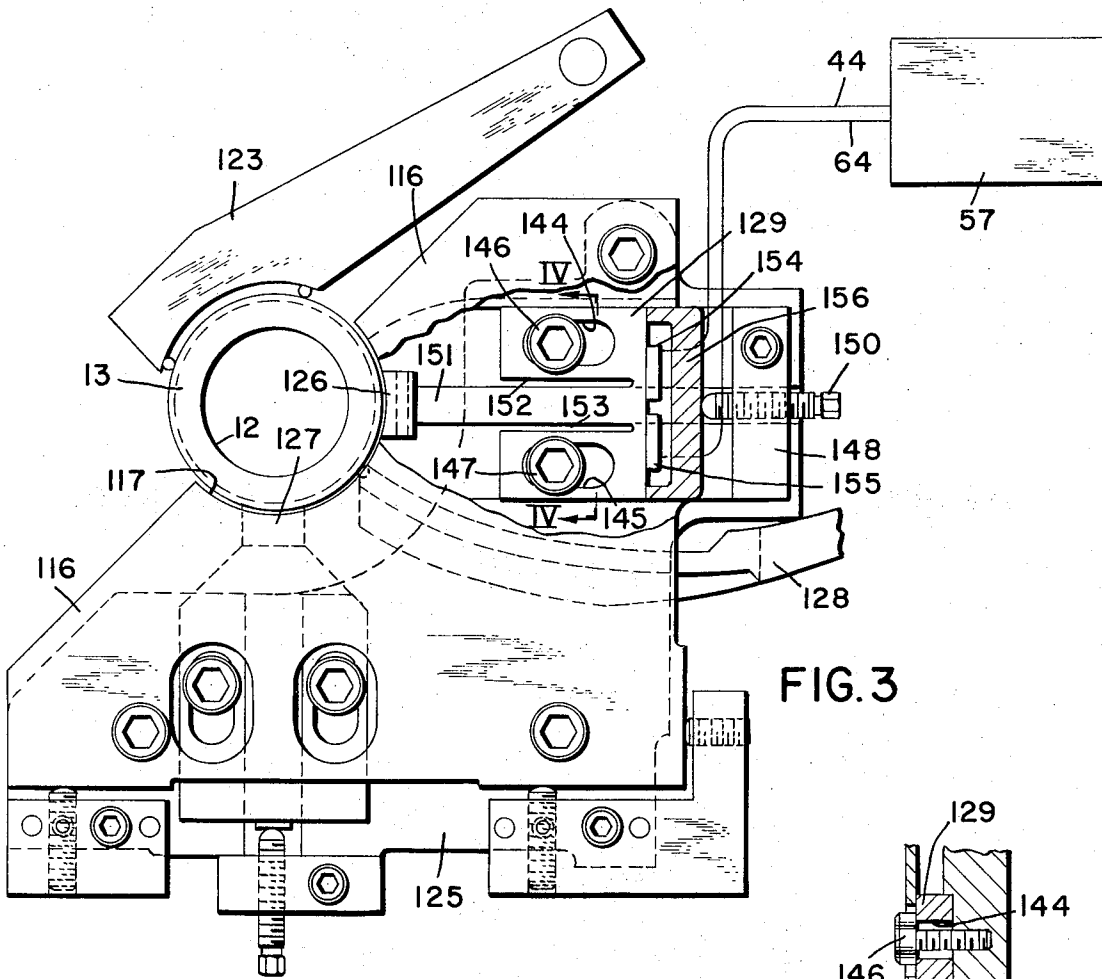


FIG. 3

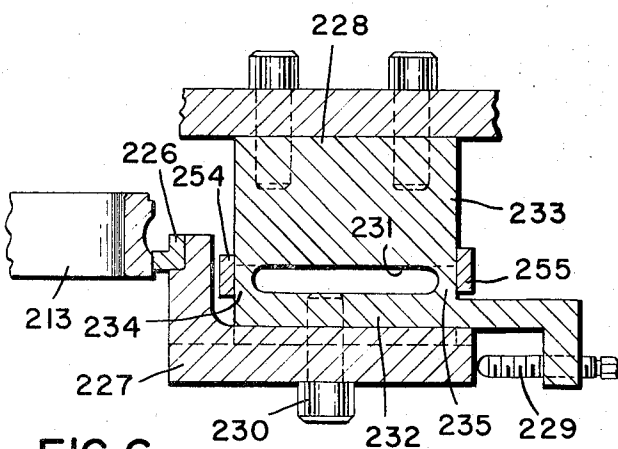


FIG. 6

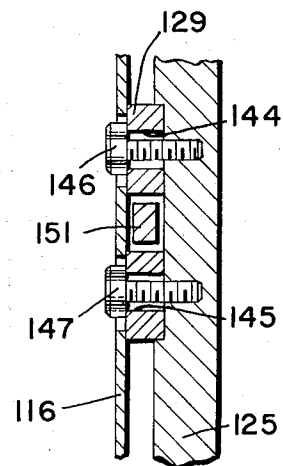


FIG. 4

GRINDING MACHINE WITH CONTROLLED GRINDING FORCE

BACKGROUND OF THE INVENTION

In the operation of modern grinding machines, it has been found desirable to use the so-called "controlled force" method of grinding. In this method, the movement of the abrasive wheel relative to the workpiece surface to be finished is controlled so that the force remains at a predetermined value and the feed or relative movement between the wheel and the workpiece may vary unpredictably. The original methods of producing controlled force in a grinding machine was by introducing a known hydraulic pressure into a main feed cylinder. Since this feed cylinder operated directly on the grinding machine element being fed (either the wheelhead or the workhead), the grinding force could not exceed the force produced by this cylinder. However, attempts to regulate the grinding force by regulating this hydraulic pressure have not been successful, especially where small tolerances in the grinding force are desired. Such situations exist, particularly, in the finish grinding portion of the grinding cycle, but they are also important in rough grinding because, if the rough grinding portion of the cycle does not produce a surface which is accurate both as to size and geometry, then accurate grinding force in the finish portion of the cycle is not possible. Many methods of regulating the grinding force have been suggested, one of them by a direct measurement of the deflection of the grinding spindle, as shown in the U.S. Pat. of Hahn, No. 3,555,741 which issued on Jan. 19, 1971. Another method of measuring grinding force that has been suggested is that a force transducer be placed in the dress compensation slide of a grinding machine; this method is shown in the U.S. Pat. of Robillard, No. 3,601,930 which issued on Aug. 31, 1971 and the patent application of Robillard et al. Ser. No. 846,901, filed Aug. 1, 1969, now U.S. Pat. No. 3,618,269 which issued on Nov. 9, 1971. Both methods lack applicability to all types of grinding and represent values of the grinding force taken at points quite remote from the actual grinding interface. In these previous constructions, the friction in the slide and the friction of hydraulic fluid in the lines effect any measurement of the grinding force for control purposes. These and other difficulties experienced with the prior art devices have been obviated in a novel manner by the present invention.

It is, therefore, an outstanding object of the invention to provide a grinding machine having a means for accurately determining the grinding force and using it to maintain the face at a predetermined value.

Another object of this invention is the provision of a grinding machine in which an accurate determination of grinding force is used for regulating the grinding cycle.

A further object of the present invention is the provision of a grinding machine having a method for controlling the grinding cycle making use of a measurement of grinding force taken close to the actual grinding interface.

It is another object of the instant invention to provide a grinding machine having a means for measuring grinding force which is simple in construction and which has no fine parts to become clogged, inaccurate, or inoperative.

With these and other objects in view, as will be apparent to those skilled in the art, the invention resides in the combination of parts set forth in the specification and covered by the claims appended hereto.

SUMMARY OF THE INVENTION

In general, the invention consists of a grinding machine for forming a surface of revolution on a workpiece, wherein the machine has a base, has a workhead mounted on the base for supporting the workpiece for rotation about the axis of the surface of revolution, and has a wheelhead mounted on the base and rotatably supporting a spindle on which an abrasive wheel is mounted. The workhead includes a support which engages the workpiece and which receives substantially the entire grinding force. Feed means is provided for bringing about relative movement between the wheelhead and the workhead to cause the wheel to engage the workpiece for a grinding operation. A transducer is mounted on the support and generates a signal indicative of the force between the wheel and the workpiece. A control is provided for receiving a signal from the transducer and transmitting a command signal to the feed means to adjust the movement to maintain the said force at a predetermined value.

More specifically, the support is provided with a resilient element that distorts slightly under the grinding force. The transducer is a strain gage and is mounted on the resilient element.

BRIEF DESCRIPTION OF THE DRAWINGS

The character of the invention, however, may be best understood by reference to one of its structural forms, as illustrated by the accompanying drawings, in which:

FIG. 1 is a perspective view of a grinding machine embodying the principles of the present invention,

FIG. 2 is a somewhat schematic plan view of the grinding machine taken along the line II—II of FIG. 1 and showing the major elements and the manner in which they are controlled,

FIG. 3 is an elevational view of a portion of the machine taken along the line III—III of FIG. 2,

FIG. 4 is a sectional view of the machine taken along the line IV—IV of FIG. 3,

FIG. 5 is an electrical schematic diagram of a portion of the machine controls, and

FIG. 6 is a horizontal sectional view of a modification of the grinding machine.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. 1, which best shows the general features of the invention, it can be seen that the grinding machine, indicated generally by the reference numeral 10, is of the type shown and described in the patent of Hohler et al., No. 3,197,921 which issued on Aug. 3, 1965. It is provided with a lower base A on which is mounted a workhead 14 and a wheelhead 25. Around the front of the base extends a splash guard B which is readily removable. Extending upwardly from the rear of the base A is a superstructure C having two arms similar to the arm D which extend forwardly from the ends of the base. Mounted between the arms is a control cabinet E. At one end of the machine is located a coolant tank F receiving coolant returned from the machine through a pipe G. This view also shows a drive motor 50 for the wheelhead 25.

FIG. 2 is approximately a horizontal view through the machine taken on the line II—II of FIG. 1. It shows somewhat schematically the base A on which is mounted the workhead 14. The workhead 14 is of the magnetic type shown and described in the U.S. Pat. of Yingst, No. 2,933,862 issued on Apr. 26, 1960. The workhead is constructed to support and rotate a workpiece 13 which has a surface of revolution 12 to be generated by the use of the abrasive process. The workhead is mounted on a table 15 which is mounted on the base 11 by means of ways 16 and 17 for movement in the direction of the axis of the surface of revolution 12 under the impetus of hydraulic cylinder 18. The cylinder is connected by conduits 19 and 21 to suitable valving and source of pressure fluid in the usual way to produce reciprocation during the grinding cycle. The workhead 14 contains a suitable motor 20 driven by electrical power supplied through the lines 22 and 23. Mounted on the table 15 is a diamond dressing apparatus 24.

Also mounted on the base 11 is a wheelhead 25 rotatably carrying a spindle 26 which has mounted at its outboard end an abrasive wheel 27. The wheelhead 25 is connected to the electric motor 50 for driving the spindle and wheel, the motor being supplied with electrical power through the lines 28 and 29. The wheelhead is mounted on a table 40 which is slidable on ways 30 and 31 transversely of the axis of the spindle 26 and of the axis of the surface of revolution 12. The motion is brought about by a main feed cylinder 32 which is connected by conduits 33 and 34 to the usual valves and source of pressure fluid. Slidably carried on top of the base under the table 40 is a compensation slide 35 which is capable of being moved back and forth transversely of the axis of the spindle 26 by means of a stepping motor 36 operated by electrical pulses received on lines 37 and 38. The table 40 is provided with a horn 39 which, on occasion, acts as a stop in combination with a notch 41 in the compensation slide 35. Pressing against the front of the slide 35 is a contact shaft 46 threadedly engaged with a nut 47 fastened to the underside of the table 40. The shaft 46 is rotated on occasion by means of a feed stepping motor 48 which receives pulses through lines 49 and 51. Mounted on the base is a recording means 52 for totalizing compensation movements in connection with a particular abrasive wheel 27. This recording means is of the type shown and described in the U.S. Pat. application of Robillard, Ser. No. 720,912, filed Apr. 12, 1968, now Pat. No. 3,561,168 which issued on Feb. 9, 1971. It contains a stepping motor 53 receiving actuating pulses through lines 54 and 55, these being the same groups of pulses received by the stepping motor 36 through the lines 37 and 38. The stepping motor 53 is connected to operate a mechanical counter 56 giving a visual indication of the amount of the wheel which has been removed by compensation movements and dressing operations by the dressing apparatus 24. The stepping motor 53 also operates the slide contact 60 of a potentiometer, so that the output voltage of the potentiometer is always an indication of the amount of material which has been removed from the wheel in the same manner as the visual counter 56.

Finally, mounted on the base 11 is a control 57 which receives signals on the lines 44 and 64 from a transducer (which will be described more fully hereinafter) and which also receives signals on the lines 58 and 59

originating in the potentiometer in the recording means 52. The output signals from the control operate the cylinder 18 and the cylinder 32 through suitable hydraulic valving, as is well known in the art. It also serves to transmit pulses to the feed stepping motor 48 and the compensation stepping motor 36.

Referring to FIG. 3, it can be seen that the workpiece 13 is supported in suitable shoes in the manner shown and described in the U.S. Pat. of Ware, No. 3,604,160 which issued on Sept. 14, 1971. The workpiece is shown as the inner race of a ball bearing. It is supported on its outer periphery which carries the ball groove, and the surface of revolution 12 which is to be finished in on the interior. The support means is indicated by the reference numeral 116 and consists of a plate 125 which may be fastened to the workhead 14 and which extends around a substantial portion of the workpiece. The plate carries a support shoe 126 which contacts the workpiece at the so-called "three o'clock" position, that is, directly in line with the grinding pressure of the abrasive wheel on the inner bore 12 of the workpiece. Also carried by the plate is a support shoe 127 which contacts the workpiece at the "six o'clock" position. A pivoted locating arm 123 positions the workpiece during loading in the shoes 126, 127. A pivoted ejector finger 128 operates on occasion for unloading on the portion of the workpiece lying between the shoes 126 and 127. A support element 129 for the shoe 126 is provided with two elongated apertures 144 and 145 by which it is adjustably attached to the plate 125 by means of bolts 146 and 147. An abutment 148 extends from the support plate 125 and is provided with an adjusting screw 150 threadedly mounted thereon. Overlying the shoes is a magnetic flux guide element 116 in the form of a suitable plate which has an arcuate edge 117 which lies closely adjacent the outer periphery of the workpiece 13 to provide a small air gap. The location of the plate 116 is determined by screws located in the plate 125 and pressing against it and is locked in place by bolts extending into the plate 125. FIG. 4 shows particularly well the relationship of the plate 116 to the mounting plate 125 and the support element 129.

The supporting shoe 126 is mounted on a long arm 151 which is separated from the rest of the support element 129 by slots 152 and 153. The back surface of the support element 129 separated from the arm 151 has mounted on it two transducers 154 and 155 which are connected by lines 44 and 64 to the control 57. A bridge 156 operates to transfer the pressure from the adjusting screw 150 to the outer edges of the support element 129. The back edge of the element between the slots 152 and 153, on the one hand, and the main body of the support element 129 acts as a diaphragm on which the transducers 154 and 155 are mounted.

FIG. 5 shows the general electrical arrangement of the apparatus. The transducers 154 and 155 are connected in series from ground to a high voltage connection 157. They are connected by a line 158 leading to the control 57 and the input of an amplifier 159. The output of the amplifier is connected to a gage 161 and to a voltage comparator 162. This voltage comparator also receives a voltage through a line 163 which is connected to the output side of machine contacts 164 and 165. The normally-open contact 165 is connected to the center tap of a potentiometer 166 whose ends are connected to ground, on the one hand, and to the high

voltage connection 157 on the other hand. The other side of the machine contact 164, which is normally closed, is connected to the center tap of a potentiometer 167, one end of which is connected to ground, and the other end of which is connected to the high voltage connection 157. The output of the voltage comparator 162 is connected through a coil of a relay 168 whose contacts 169 and 171 are normally-open and normally-closed, respectively. These contacts enter into the regulation of the grinding cycle in the well-known manner to increase and decrease the parameters effecting grinding force, particularly in the manner shown and described in the U.S. Pat. of Robillard, No. 3,601,930 which issued on Aug. 31, 1971.

FIG. 6 shows another method of attaching the transducers to the shoe. In the drawing, the workpiece 213 is shown as supported on a shoe 226 which is mounted on the end of an L-shaped arm 227 which is slidably mounted on a block 228. A set screw 229 provides for adjustment and the arm is locked in a position of adjustment by a bolt 230 extending into the block. The block 228 is provided with an elongated slot or passage 231 extending through it which divides the block into two portions 232 and 233. The portion 232 is the portion to which the arm 227 and the shoe 226 are mounted, while the other portion 233 is fastened to a fixed portion of the grinding machine. The slot 231 defines, therefore, two diaphragms 234 and 235 on the outer surfaces of which are mounted transducers 254 and 255, respectively.

The operation of the apparatus will now be clearly understood, in view of the above description. As the grinding forces increase and decrease, this fact results in the generation of a suitable voltage on the outputs of the strain gages 154 and 155. This voltage which is indicative of grinding force is presented to the control 157 is amplified and is compared with a reference voltage. As is shown in FIG. 5, the reference voltage may be changed, if more than one level of force is desirable, the change taking place when the cross-feed of the machine operates machine contacts 165 or 164. In any case, an imbalance in the voltages is indicated on the output of the voltage comparator 162 and this operates the relay 168 and sets up the operation of the contacts 169 and 171. These contacts operate in the well-known manner to increase and decrease the flow of fluid to the feed cylinder 32 to return the force to the predetermined amount at that particular part of the grinding cycle.

It is obvious that minor changes may be made in the form and construction of the invention without departing from the material spirit thereof. It is not, however, desired to confine the invention to the exact form herein shown and described, but it is desired to include

all such as properly come within the scope claimed.

The invention having been thus described, what is claimed as new and desired to secure by Letters Patent is:

1. A grinding machine for forming a surface of revolution on a workpiece, comprising

- a. a base,
- b. a workhead mounted on the base for supporting the workpiece for rotation about the axis of the surface of revolution, the workhead including a support which engages the workpiece and which receives substantially the entire grinding force, the said support being provided with a flexible element that distorts slightly under the grinding force,
- c. a wheelhead mounted on the base and rotatably supporting a spindle on which an abrasive wheel is mounted,
- d. feed means for bringing about relative movement between the wheelhead and the workhead to cause the wheel to engage the workpiece for a grinding operation,
- e. a transducer mounted on the said support and generating a signal indicative of the force between the wheel and the workpiece, the transducer being a strain gage and being mounted on the flexible element, and
- f. a control receiving a signal from the transducer and transmitting a command signal to the feed means to adjust the said movement to maintain the said force at a predetermined value, the support consisting of a hardened-metal shoe mounted on one end of an arm, the other end of the arm being connected by two relatively flexible elements to support elements that are fixed to the workhead, the flexible elements extending from the end of the arm and each having a strain gage mounted on its surface.

2. A grinding machine as recited in claim 1, wherein the flexible elements extend in opposite directions from the end of the arm.

3. A grinding machine as recited in claim 1, wherein the support consists of a hardened-metal shoe mounted on one end of an elongated arm, spaced points on the arm being connected by two flexible elements to a block fixedly mounted on the workhead, the flexible elements extending in the same direction away from the arm and each having a strain gage mounted on its surface.

4. A grinding machine is recited in claim 3, wherein the arm is L-shaped and the flexible elements extend from one leg, while the shoe is mounted at the outer end of the other leg.

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