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[54] GRINDING MACHINE

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[56]

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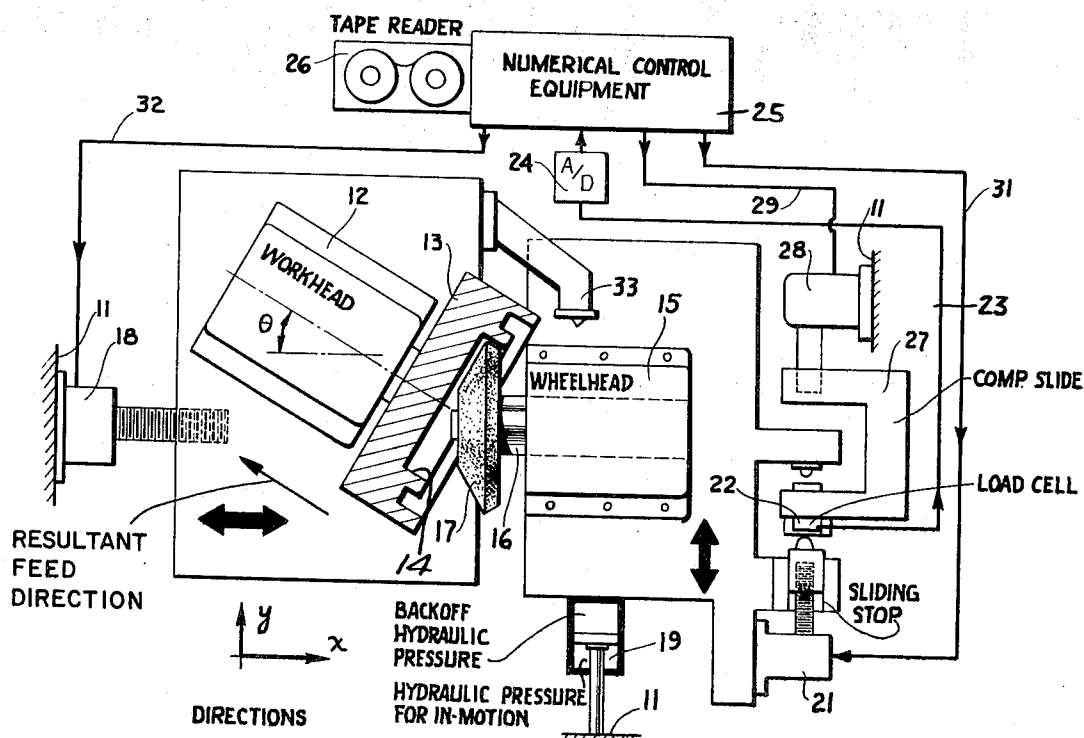
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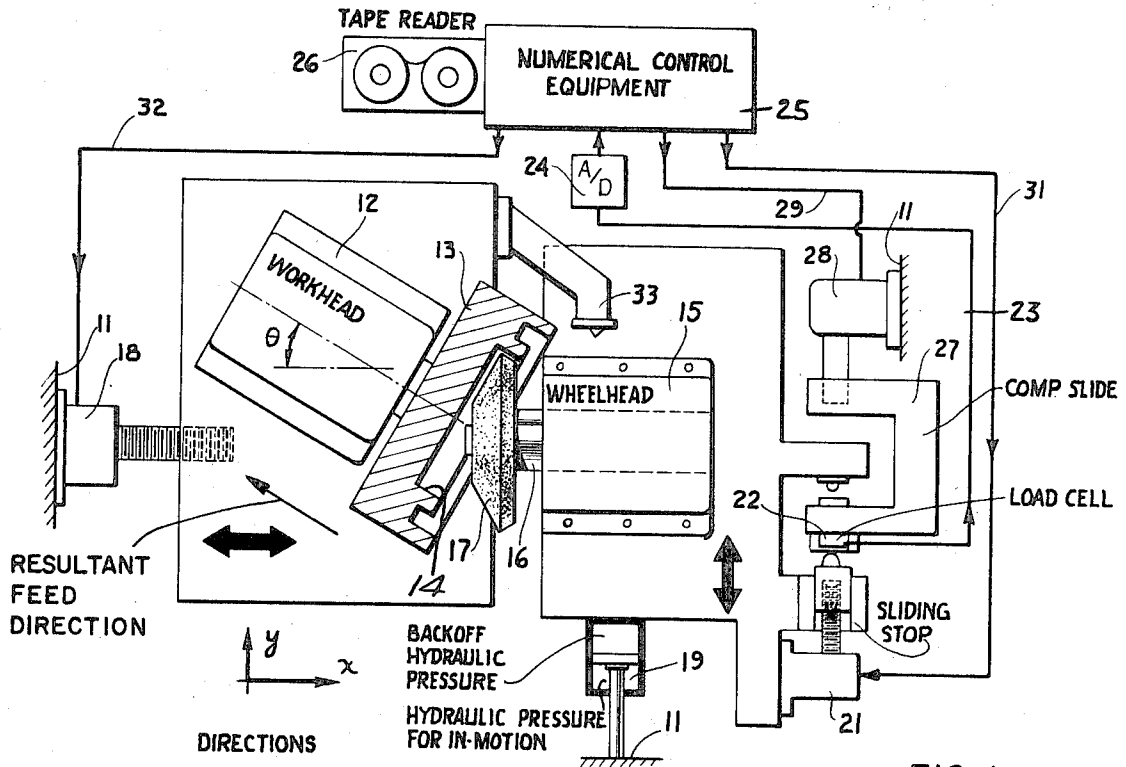
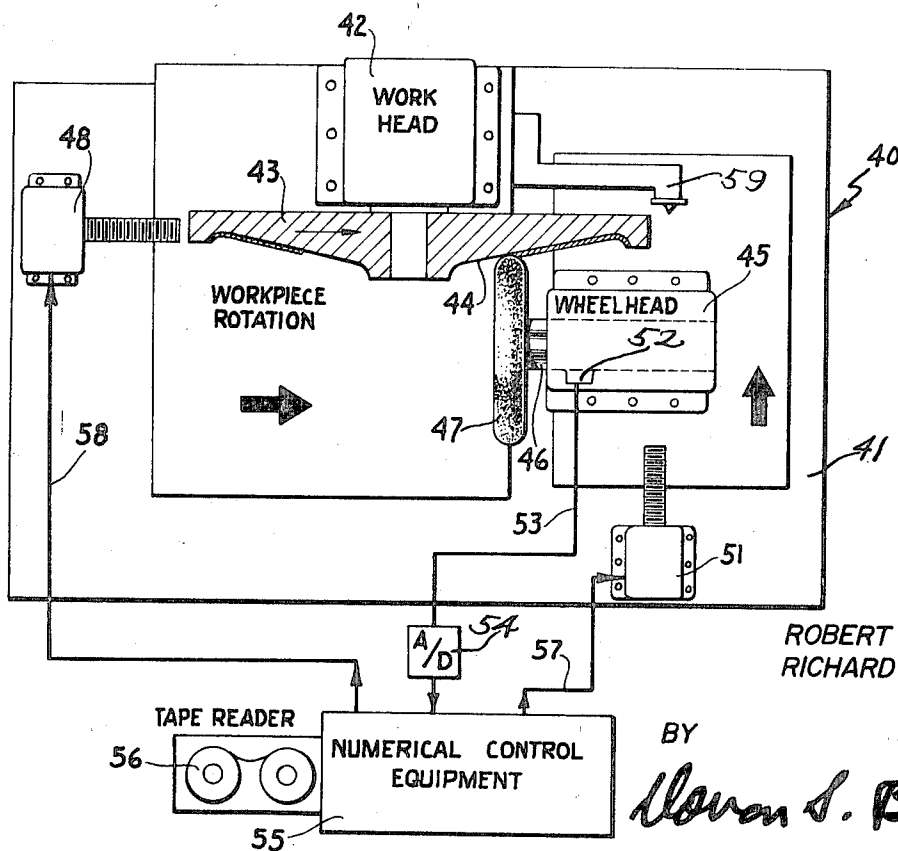
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ABSTRACT

This invention relates to a grinding machine and, more particularly, to apparatus for generating a surface of revolution by the abrasive process, wherein the feed is regulated to maintain the force between the abrasive wheel and the workpiece at a predetermined value.

4 Claims, 4 Drawing Figures

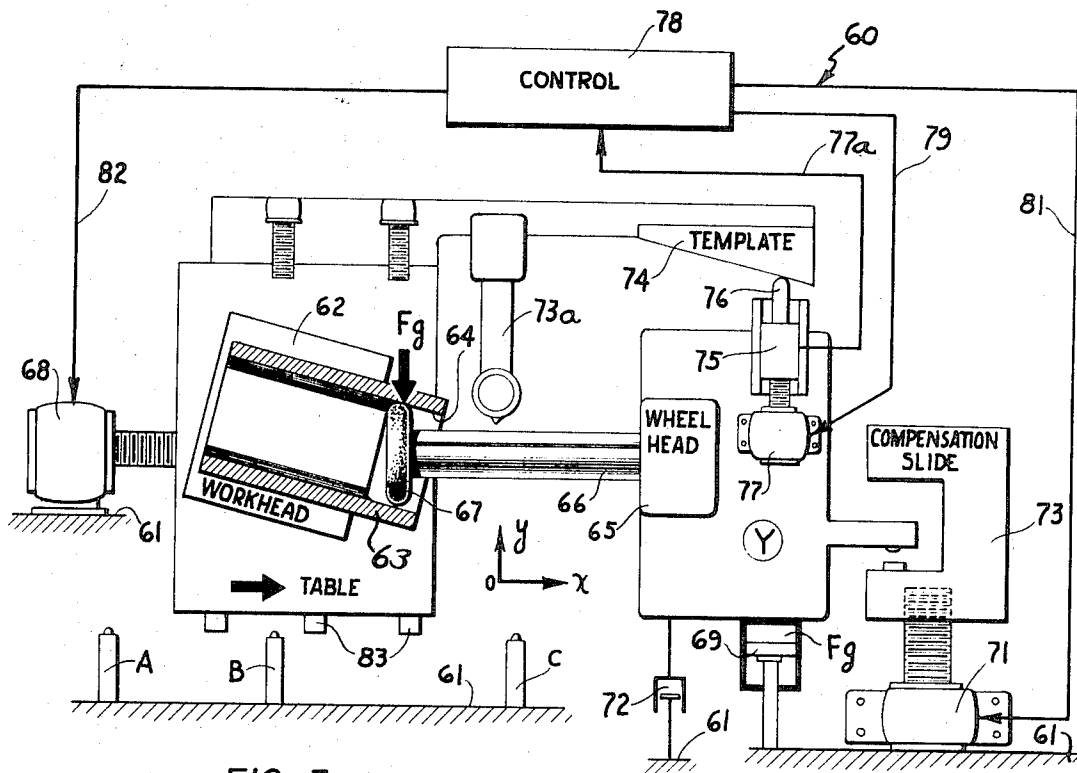
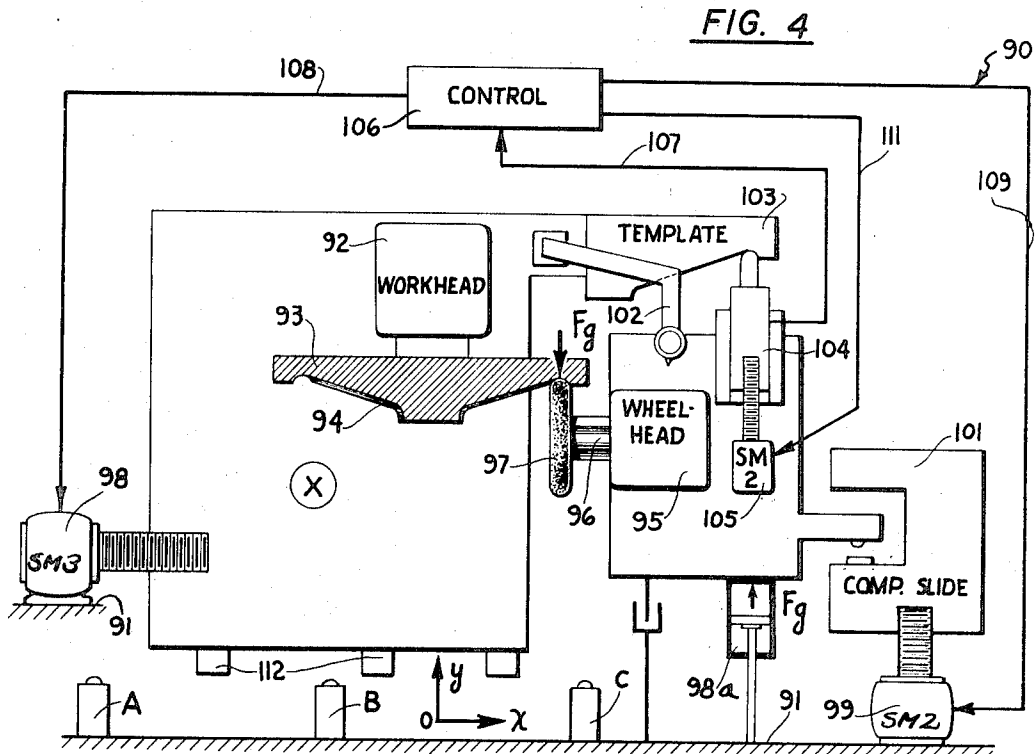




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GRINDING MACHINE

BACKGROUND OF THE INVENTION

In the art of grinding surfaces of revolution on a workpiece by the abrasive method, there are peculiar problems encountered when the generatrices of the surfaces of revolution extend considerable distances in the direction of the axis of the spindle on which the abrasive wheel is ground. This is particularly true when the wheel is mounted at the end of the cantilevered spindle, such as is used in internal grinding. The probability is quite high that the deflection in the spindle will differ from one part of the surface to another, not only because of inaccuracies in the previous machining operation, but also because of differences in hardness of the metal. A good example of a work in which this problem is encountered is in the grinding of deep holes. In such grinding, it is necessary that the spindle be extremely long in order to enter the hole. The diameter of the spindle must be somewhat less than the diameter of the hole and it is very likely that the last machining operation left a tapered hole when a cylindrical hole is desired. There is a strong possibility of a heat treatment having taken place which was more or less effective at one end of the hole than at the other, producing a substantial difference in grindability in the direction of the length of the hole. Another type of work which presents a similar problem is that of contour grinding where the abrasive wheel must be moved not only transversely of its spindle but also longitudinally relative to the work. These problems become almost insurmountable when one attempts to grind this type of surface under production conditions. 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 capable of generating surfaces of revolution accurately wherein the generatrices are extremely long.

Another object of this invention is the provision of a grinding machine capable of grinding a contoured surface despite differences in amount of material to be removed in different places due to inaccuracies in a preceding operation.

A further object of the present invention is the provision of a grinding machine which makes use of data processing techniques to regulate feed in two directions while maintaining the force constant at all times.

It is another object of the instant invention to provide a grinding machine for grinding long holes in one continuous long pass without time-consuming grinding-and-measuring techniques.

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 present invention consists of a grinding machine for generating on a workpiece a surface of revolution having generatrices that are relatively long in comparison with the active generator of the abrasive wheel. The machine is provided with a base on which is mounted a workhead for supporting the workpiece and rotating it about the axis of the surface of the revolution and the machine is also provided with a wheelhead in which the spindle, on which the abrasive wheel is mounted, is rotatably carried. A stepping motor is provided for bringing about movement between the workhead and the wheelhead longitudinally of the axis of the spindle and feed means is provided for regulating the movement between the workhead and the wheelhead transversely of the axis of the spindle. A sensor is provided for measuring the force between the abrasive wheel and the workpiece and generating a signal proportional thereto. A control is provided receiving the signal from the sensor and delivering command signals to the stepping motor and the feed means to cause the wheel to move over the workpiece in accordance with a predetermined pattern, while maintaining the force at a predetermined value.

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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 schematic view of a grinding machine embodying the principles of the present invention,

FIG. 2 is a schematic view of a modified form of the invention,

FIG. 3 is a schematic view of a still further variation of the present invention, and

FIG. 4 is a still further modification of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. 1, which best shows the general features of the invention, the grinding machine, indicated generally by the reference numeral 10, is shown as having a base 11 on which is mounted a workhead 12 for supporting a workpiece 13 having a surface of revolution 14 and rotating it about an axis. Also mounted on the base 11 is a wheelhead 15 rotatably carrying a spindle 16, on the other end of which is mounted an abrasive wheel 17. A stepping motor 18 is connected to the workhead 12 to bring about movement between the workhead and the wheelhead longitudinally of the axis of the wheel spindle 16. A feed means including a hydraulic cylinder 19 and a stepping motor 21 regulates the movement between the workhead 12 and the wheelhead 15 transversely of the axis of the spindle. A sensor consisting of a strain gage 22 is interposed between the wheelhead 15 and the base 11 to measure the force between the abrasive wheel 17 and the workpiece 13 during grinding. The strain gage 22 provides a voltage on a line 23 which is proportional to this force and the line transmits this signal through an analog-to-digital converter 24 to a control 25 including digital computing apparatus. A tape reader 26 is connected to the control 25 and carries data relative to the desired shape and size of the finished surface of revolution 14.

A compensation slide 27 is slidably mounted on the base 11 and is connected to a stepping motor 28. A line 29 extends from the control 25 to the stepping motor 28 for introducing to it pulses for controlling its motion. Similarly, a line 31 extends from the control 25 to the stepping motor 21 to control its motion. Furthermore, a line 32 extends from the control 25 to the stepping motor 18 to control its motion. A diamond dressing apparatus 33 is associated with the workhead 12 and is in a position to dress the abrasive wheel 17 on occasion.

The operation of the apparatus will now be readily understood in view of the above description. A surface of revolution 14 is inclined to the axis of the spindle 16. Motion in the X-direction can take place under the control of the stepping motor 18, while motion in the Y-direction is under the control of the hydraulic cylinder 19 and the stepping motor 21. Stepping motors 18 and 21 receive pulses from the control 25. The strain gage 22 senses the Y-component of grinding force (that is, the force perpendicular to the axis of the spindle 16). Depending on the orientation of the surface being ground, the normal force is at some angle to the force in the Y-direction. If the angle θ is the angle between the axis of the spindle and the line perpendicular to the surface being ground, then the Force in Y-direction is equal to $F \sin \theta$. The computing apparatus in the control 25 reads the various desired positions of the surface from the tape in the tape reader 26 and relays this information to the stepping motors 18 and 21. The speed of position change is dependent upon the force sensor, however; that is to say, the velocity of transverse along the programmed path W will be governed by the movement necessary to keep the grinding force $F \sin \theta$ at a constant value. Thus, since normal grinding force is constant and the velocity of grinding can be measured by the rate of pulses sent to the stepping motors, the wheel sharpness can also be obtained. The wheel sharpness is defined as the ratio of plunge grinding velocity divided by normal force intensity. With knowledge of the work rotational speed, control of the surface integrity of the workpiece can be assured.

FIG. 2 shows a variation in form of the invention. The grinding machine, indicated generally by the reference numeral 40, is shown as having a base 41 on which is mounted a workhead 42 carrying a workpiece 43 having a surface of revolution 44 to be finished. A wheelhead 45 is mounted on the base 41 and rotatably carries a spindle 46 with an abrasive wheel 47 mounted at its outer end. A stepping motor 48 extends between the base 41 and the workhead 42 to bring about movement parallel to the axis of the spindle 46, while a stepping motor 51 is connected between the base 41 and the wheelhead 45 to bring about motion perpendicular to the axis of the spindle. A load cell 52 is mounted on the spindle 46 to give an indication of the force between the wheel 47 and the workpiece 43 during grinding. A line 53 extends from the load cell 52 to an analog-to-digital converter 54 which, in turn, is connected to a control 55. A tape reader 56 carrying a program commensurate with the desired shape of the surface of revolution 44 is connected to the control 55.

The operation of the apparatus shown in FIG. 2 is similar to that of the apparatus shown in FIG. 1. A punched tape carried in the tape reader 56 carries the coordinates of the contour of the surface of revolution 44 to be produced. The rate that the grinding machine will traverse this desired path is governed by the wheel sharpness and the force between the wheel and the work. This force is measured by the load cell 52 which reads wheelhead spindle deflection. The numerical-control equipment forming the part of the control 55 sends the contour coordinates along lines 57 and 58 to the stepping motors 51 and 48, respectively, thus generating the contour of the surface of revolution. The grinding force is read by the load cell 52 and fed back to the control 55 through the analog-to-digital converter 54. This reading of force governs the rate of traverse along the path. If the force is higher than a predetermined amount, the rate of feed determined by the stepping motors 48 and 51 is slowed down. If the force is lower than the predetermined amount, the rate is increased. At the end of the grind, the table stepping motor 48 is reset to zero. The cross-slide motor 51 is reset to zero minus the compensation used to dress the grinding wheel by means of a dressing apparatus 59.

FIG. 3 shows another modification of the invention. The grinding machine, indicated generally by the reference numeral 60, is provided with a base 61 on which is slidably mounted a workhead 62 on which is mounted a workpiece 63 for rotation about the axis of its surface of revolution 64 which is to be formed. Also mounted on the base is a wheelhead 65 rotatably carrying a spindle 66 on the outer end of which is mounted an abrasive wheel 67. A stepping motor 68 extends between the base 61 and the workhead 62 to bring about motion parallel to the axis of the spindle 66. A crossfeed means consisting of a cylinder 69 and a stepping motor 71 serve to move the wheelhead 65 transversely of the axis of the spindle 66. A damper 72 is associated with the cylinder 69. A compensation slide 73 engaged by the stepping motor 71 is also associated with the wheelhead. A dressing apparatus 73a is mounted on the workhead table as is a control, such as a template 74, whose operative surface is shaped in the shape and size of the surface of revolution 64 which is to be formed on the workpiece 63. Mounted on the wheelhead is a sliding electrical position indicator 75 of the LVDT type which generates an electrical signal indicative of position of a plunger. The plunger 76 engages the surface of the template 74, while its back end is connected to a stepping motor 77, also mounted on the cross-slide of the wheelhead 65. A line 77a extends from the indicator 75 to a control 78 which contains computing equipment. A line 79 extends from the control 78 to the stepping motor 77 to move the plunger 76 of the indicator 75 toward and away from its neutral position. A line 81 extends from the control 78 to the stepping motor 71 to control the backoff position of the wheelhead 65 after dress. The line 82 extends from the control 78 to the stepping motor 68 to control motion of the workhead 62. The workhead 62 is provided with dogs 83 which engage suitable limit switches A, B, and C mounted on the base 61 to indicate workhead position.

The operation of the apparatus shown in FIG. 3 is similar to that described above for the other modifications of the invention. The workhead 62 moves in the X-direction (parallel to the axis of the spindle 66) until a dog 83 strikes the limit switch B. The wheelhead table 65 then begins to move under the impetus of the cylinder 69 until the abrasive wheel 67 makes engagement with the workpiece 63. The grinding wheel grinds until the plunger 76 of the indicator 75 contacts the surface of the template 74 and the contact increases until a set point of voltage is reached. When this voltage is reached, the control 78 commands the stepping motor 68 to move in the X-direction. If the grinding wheel can remove stock at the rate that the stepping motor 68 is dictating to it, the set point of the indicator 75 will remain constant. If the workhead table speed is too great, the workpiece 63 will cam the slide in the Y-direction causing the contact between template 74 and indicator 75 to recede. This lowers the output voltage appearing on the line 79 and causes the control 78 to indicate through the line 82 that the stepping motor 68 should slow down until the abrasive wheel can grind its way in the Y-direction. This continues until the set point is reached again. Grinding continues until the table hits the limit switch C ending the cycle. Stepping motor 68 retracts the workhead table and, after the table has been so retracted and dressing has taken place by means of the dressing apparatus 73, the stepping motor 71 retracts the compensation slide to zero minus the amount of compensation to be dressed from the wheel. The stepping motor 77 pulls the probe 76 back by the amount of compensation.

FIG. 4 shows a grinding machine 90 having a base 91 on which is mounted a workhead 92 carrying a workpiece 93 rotating it about the axis of a surface of revolution 94 which is to be formed. A wheelhead 95 is also carried on the base and rotatably carries a spindle 96 on which is mounted an abrasive wheel 97. A stepping motor 98 is connected between the base 91 and the workhead 92 to bring about motion parallel to the spindle axis. A feed means consisting of a cylinder 98a and a stepping motor 99 are connected between the base 91 and the wheelhead 95 to bring about cross-slide motion or motion perpendicular to the axis of the spindle 96. A stepping motor 99 is connected to a compensation slide 101 which is slidably carried by the base 91 and which contacts the wheelhead 95 on occasion for dressing the wheel, and determining the amount of retraction for dress on a dressing apparatus 102 attached to the table of the workhead 92.

Mounted on the workhead 92 is a template 103 whose operative surface is shaped in a manner similar to the surface of revolution 94 which is to be formed on the workpiece. The wheelhead carries an indicator 104 whose sliding member makes contact with the surface of the template 103 and the back end of which is engaged by a stepping motor 105. The indicator 104 is connected to a control 106 by means of a line 107. The control, on the other hand, sends command signals through a line 108 to the stepping motor 98, through a line 109 to the stepping motor 99, and through a line 111 to the stepping motor 105. The front of the workhead 92 is provided with cams 112 which engage limit switches A, B, and C on occasion.

The operation of the apparatus shown in FIG. 4 is similar to that described in connection with the other versions. The workhead 92 moves in the X-direction carrying the workpiece with it until the limit switch B is contacted. This begins the motion of the wheelhead 95 under the impetus of the cylinder 98a. Eventually, the wheel 97 engages the workpiece 93, grinds inwardly until the indicator 104 strikes the template 103 and builds up the voltage to a predetermined set point. Upon reaching the set point, the control 106 indicates to the stepping motor 98 that motion should begin. This starts moving the workhead 92 in the X-direction. If it is possible for the abrasive wheel 97 to remove stock from the workpiece at the rate that the stepping motor 98 is dictating to the workhead, the indicator 105 set point will remain constant. If the table speed in that direction is too great, the work will cam the slide

for the wheelhead in the rearward direction (against the direction indicated by the cylinder 98) and causes the indicator 104 to indicate a decreased voltage. This decreased output voltage makes itself felt through the line 107 to the control 106 and that control causes the stepping motor 98 to slow down until the abrasive wheel can grind its way in the Y-direction so that the set point of the indicator 104 is reached again. Grinding continues in this way until the workhead hits the switch C and terminates the cycle. The stepping motor 98 operates to reverse the table direction and remove the wheel from the workpiece. The stepping motor 99 is then retracted to zero minus the amount of compensation to be dressed from the wheel, so that, when the cylinder 98a retracts the wheelhead 95 back to contact with the compensation slide 101, the abrasive wheel 97 will be in the exact position to have the proper amount removed by the dressing apparatus 102. The stepping motor 105 also pulls the probe of the indicator 104 rearwardly by the amount of the compensation.

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 generating on a workpiece a surface of revolution having generatrices that are relatively long compared to the width of the grinding surface of the abrasive wheel used on the machine, comprising

- a. a base,
- b. a workhead for supporting the workpiece and rotating it about the axis of the surface of revolution,
- c. a wheelhead in which a spindle for carrying the abrasive wheel is rotatably mounted,
- d. an actuator, responsive to control signals, for bringing

about movement between the workhead and the wheelhead longitudinally of the axis of the said spindle,

- e. feed means for regulating the movement between the workhead and the wheelhead transversely of the axis of the spindle, the feed means including a hydraulic cylinder for producing a primary moving force and a stepping motor for producing a secondary regulation of the transverse movement,
 - f. a sensor for measuring the force of contact between the abrasive wheel and the workpiece during grinding and generating a signal proportional thereto,
 - g. a control receiving the signal from the sensor and delivering command signals to the actuator and to the feed means to cause the wheel to move over the workpiece in accordance with a predetermined pattern, while maintaining the force at a predetermined value.
2. A grinding machine as recited in claim 1, wherein the generatrices of the surface of revolution are inclined to both the longitudinal and the transverse directions.
3. A grinding machine as recited in claim 1, wherein the control includes computing apparatus which receives the said predetermined pattern in machine language.
4. A grinding machine for generating an internal surface of revolution on a workpiece, comprising
- a. a base on which are mounted a workhead and a wheelhead,
 - b. stepping motors for moving the workhead and wheelhead in directions extending longitudinally and transversely of a spindle carrying an abrasive wheel,
 - c. a control including data processing apparatus for controlling the introduction of electrical pulses to the motors to cause the abrasive wheel to move across the workpiece in a predetermined pattern while maintaining the force of contact between the wheel and the workpiece during grinding at a predetermined value.

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