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Suzuki

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[54] **MULTI-WHEEL GRINDING MACHINE**

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[52] **U.S. Cl.** **51/165.88**

[51] **Int. Cl.** **B24b 49/02**

[58] **Field of Search**...51/165.87, 165.88; 125/11 CD

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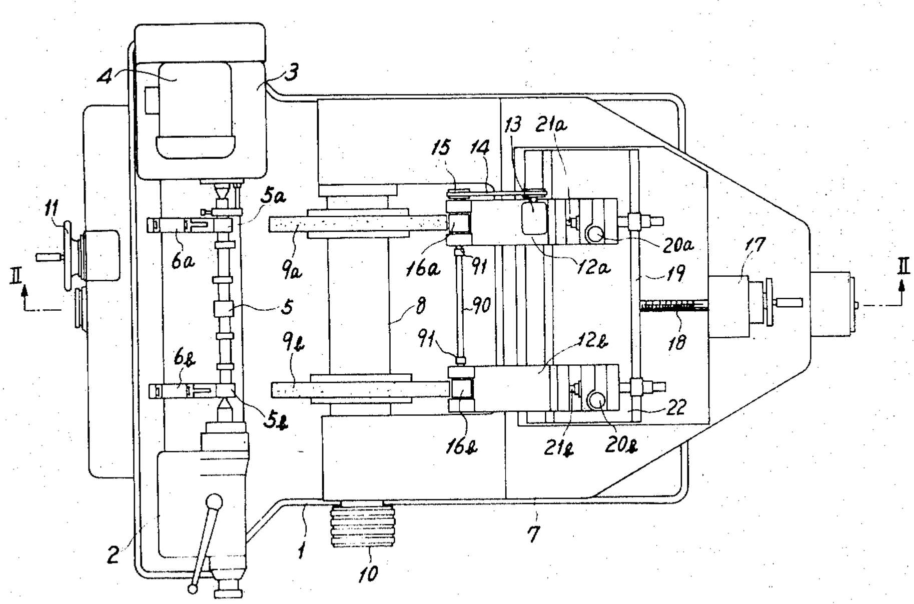
[57] **ABSTRACT**

A multi-wheel grinding machine is provided having a plurality of grinding wheels for simultaneously performing a grinding operation on a plurality of portions of a workpiece. A separate dressing head corresponding to each grinding wheel is provided for respectively dressing the several grinding wheels in a controlled manner. Thus, when a difference between the diameters of the respective portions being ground on the workpiece as sensed by automatic sizing devices provided for this purpose is determined to be outside a predetermined limit, the infeed movement of the wheel slide carrying the grinding wheels is stopped and the dressing heads are respectively advanced for dressing the grinding wheels unevenly to eliminate this difference, whereby the plurality of portions of the workpiece may be effectively ground to the same diameter.

10 Claims, 5 Drawing Figures



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SHEET 1 OF 4

Fig. 1

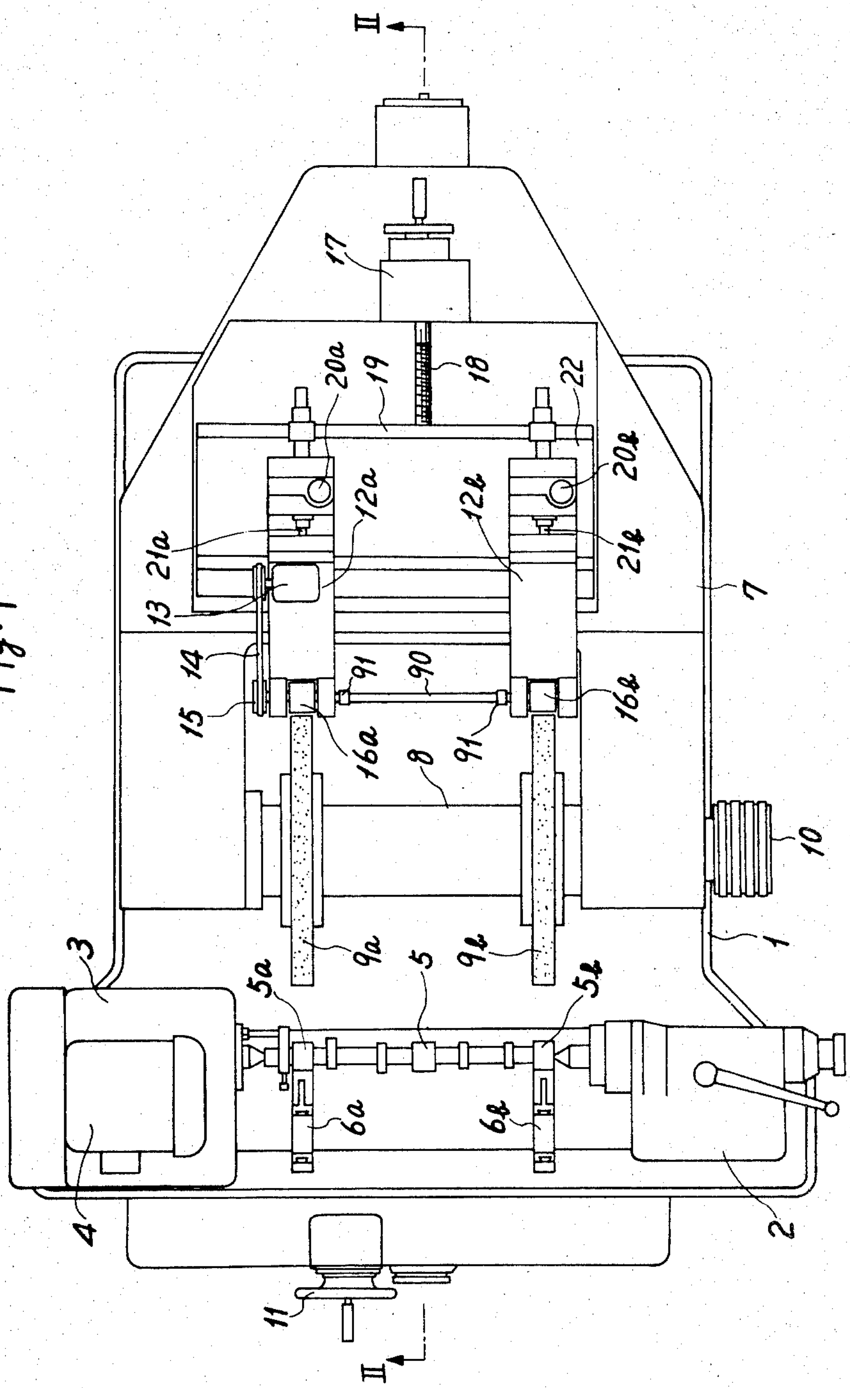

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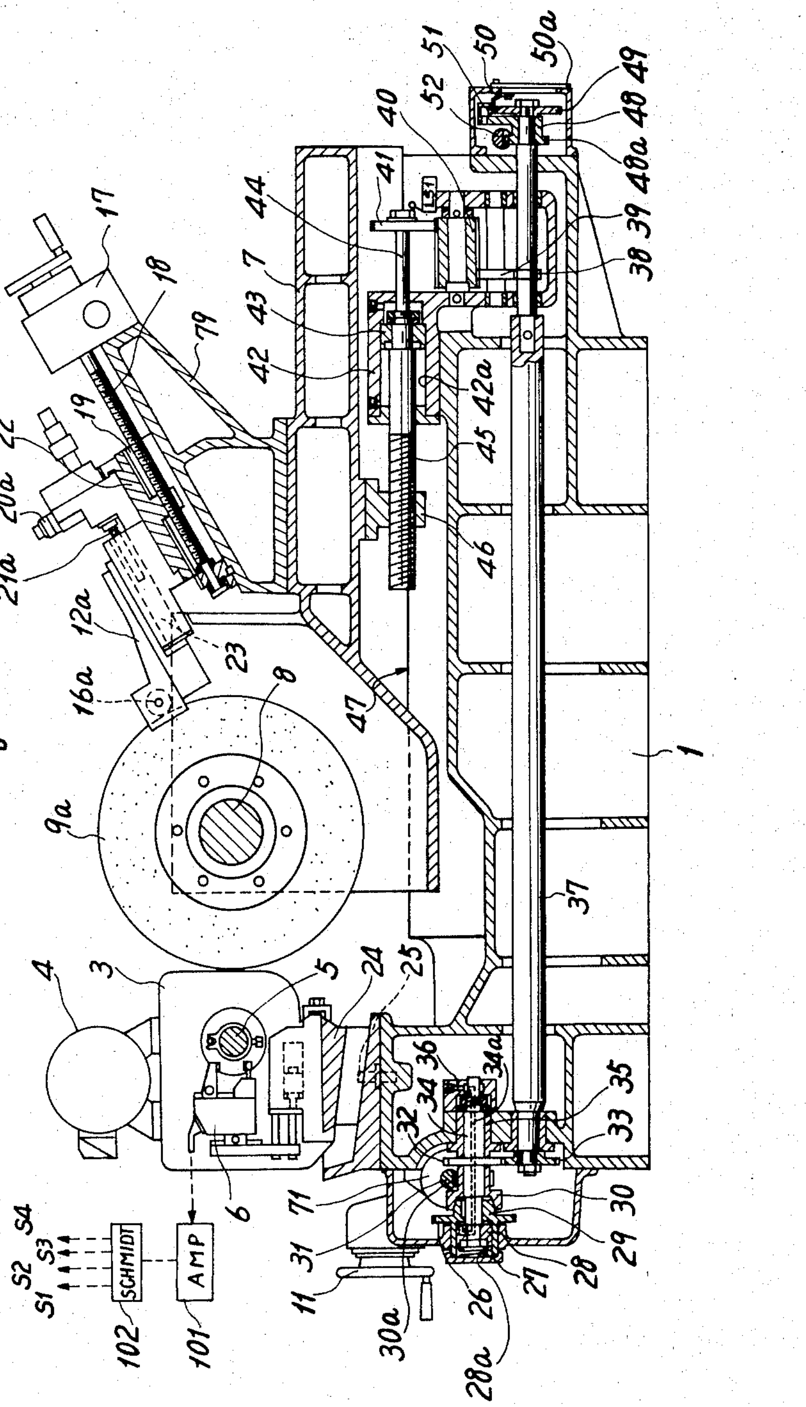
Fig. 2



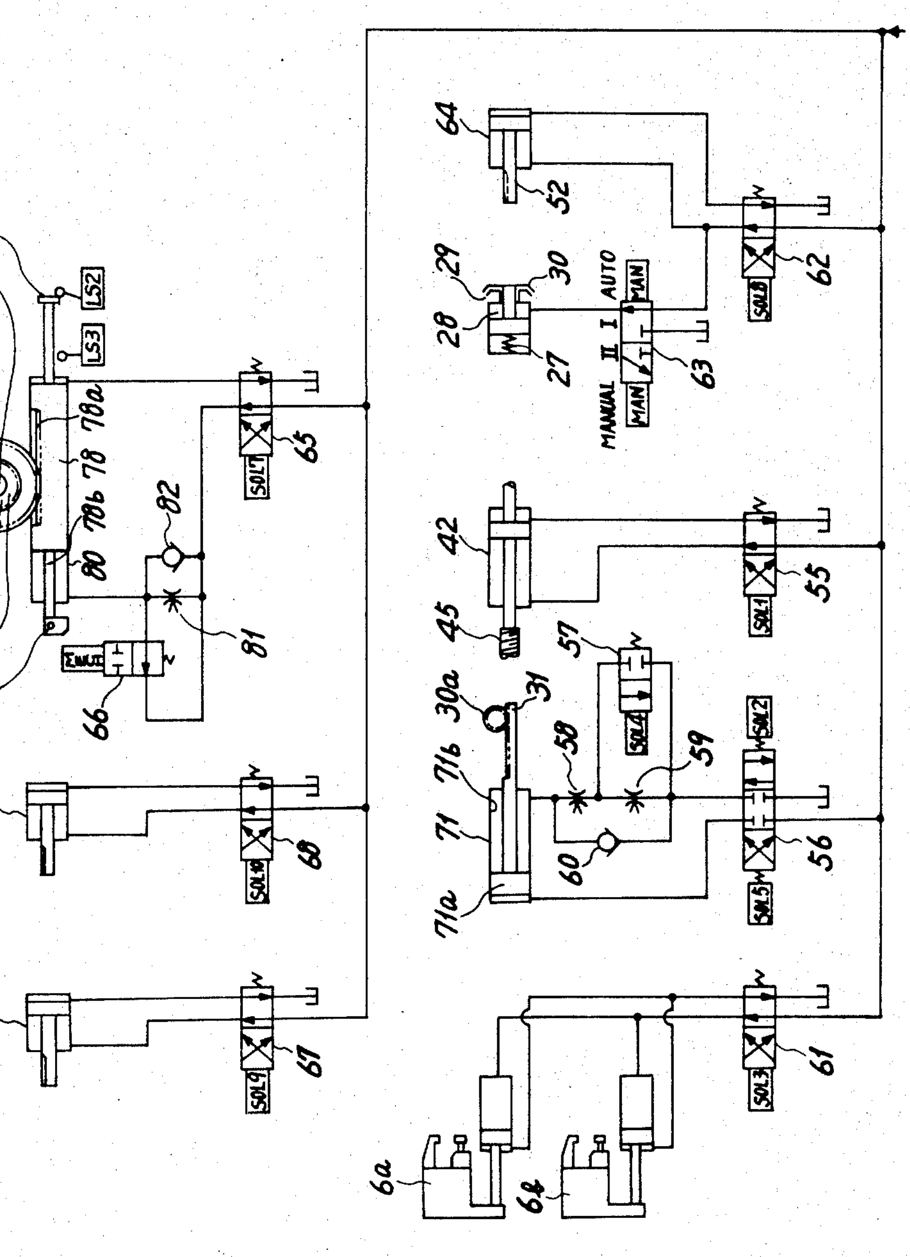

MANUAL
AUTO
MAN
MAN
LS2
LS3
SOL1
SOL2
SOL3
SOL5
SOL7
SOL8
SOL9
SOL10

Fig. 3

Fig. 5

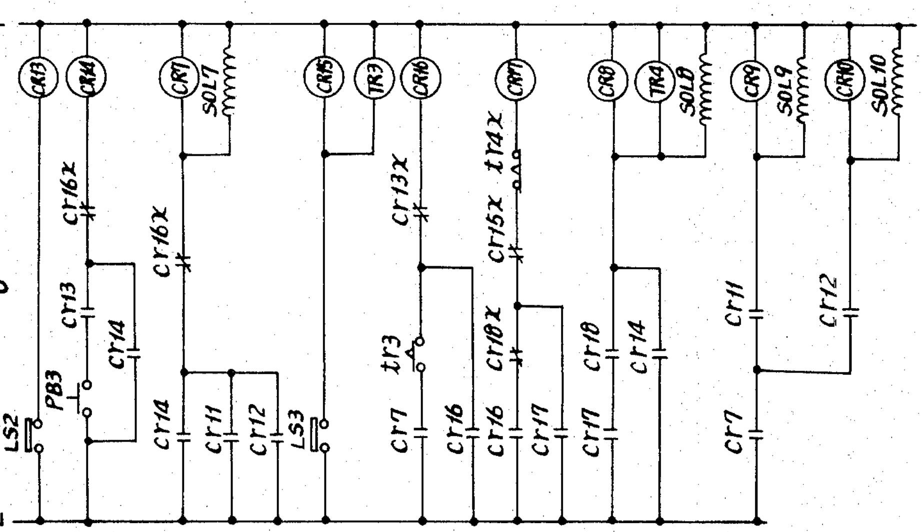
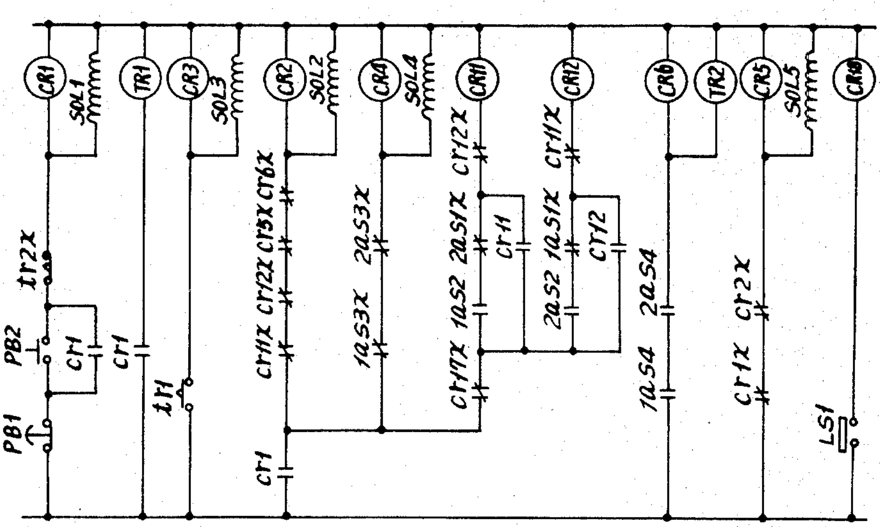

E
F
LS2
PB3
CR13
CR14
cr16x
cr13
cr14
CR7
SOL7
cr11
cr12
LS3
CR15
TR3
CR16
cr13x
tr3
cr7
cr16
CR17
tr4x
cr15x
cr18x
cr17
CR8
TR4
SOL8
cr18
CR9
SOL9
CR10
SOL10

Fig. 4


PB1
PB2
cr1
tr2x
CR1
SOL1
TR1
tr1
CR3
SOL3
CR2
SOL2
1aS3x
2aS3x
CR4
SOL4
cr17x
1aS2
2aS1x
cr12x
cr11
CR11
2aS2
1aS1x
cr11x
cr12
CR12
1aS4
2aS4
CR6
TR2
cr1x
cr2x
CR5
SOL5
LS1

MULTI-WHEEL GRINDING MACHINE

BACKGROUND OF THE INVENTION

The present invention relates to a grinding machine, and more particularly concerns an improved multi-wheel grinding machine which enables a plurality of portions on a workpiece to be simultaneously ground by multiple grinding wheels.

Multi-wheel grinding machines are known in the art, but when a grinding operation is carried out on a work-piece by such machines heretofore available, the several portions of the workpiece being ground by the several grinding wheels are provided with finished diameters which due to various causes are not the same. To keep this difference between the diameters of the ground portions within a required value, every diameter is measured after the grinding operation on the plural portions of the workpiece is completed. When the difference is not within the required value, the measuring apparatus produces a signal. However, in such cases when the difference is larger than that of the required value, the rejected workpiece should be abandoned according to the past practice, which of course is economically unfavorable although necessary for maintaining recognized quality standards. Thus, a preferable practice would be to measure the diameters of the portions which are being ground before the grinding operation has been completed and to keep the difference being produced therebetween within the required value during the completion of the grinding operation.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide an improved multi-wheel grinding machine which is operative to substantially eliminate any difference in diameters of the several portions of a work-piece being ground thereby during the grinding operation.

Another object of the present invention is to provide an improved grinding machine having a plurality of grinding wheels for simultaneously grinding a corresponding plurality of portions of a workpiece and being automatically operable during a grinding operation to provide each of the finished ground portions of the workpiece with the same diameter within a predetermined range of accuracy.

A still further object of this invention is to provide a multi-wheel grinding machine wherein a wheel slide carrying the grinding wheels is advanced to compensate for wear of the grinding wheels after the grinding operation is completed so that safety in operation and high machining accuracy are obtained.

The foregoing and other objects are attained by a grinding machine having a plurality of grinding wheels for simultaneously grinding a plurality of portions on a workpiece, a dressing head for each grinding wheel, and an automatic sizing apparatus for measuring the diameters of the workpiece portions being ground by the grinding wheels and responsive to detecting a difference in the diameters of the workpiece portions beyond a predetermined limit for stopping the feeding movement of a wheel slide carrying the grinding wheels and advancing the dressing heads in a controlled manner for dressing the grinding wheels unevenly so that the difference in the diameters is substantially eliminated and the workpiece portions are ground to approximately the same diameter.

BRIEF DESCRIPTION OF THE DRAWINGS

Various other objects, features and attendant advantages of the present invention will be more fully appreciated as the same becomes better understood from the following detailed description of a preferred embodiment, when considered in connection with the accompanying drawings, in which like reference numerals designate like or corresponding parts throughout the several figures, and wherein:

FIG. 1 is a plan view of a multi-wheel grinding machine formed according to the invention;

FIG. 2 is a cross-sectional view taken along the line II—II in FIG. 1;

FIG. 3 is a schematic illustration of a hydraulic circuit for actuating the multi-wheel grinding machine of FIGS. 1 and 2 to effect the various movements thereof; and

FIGS. 4 and 5, taken together, constitute a schematic illustration of an electric control circuit for controlling the hydraulic circuit shown in FIG. 3 for causing a grinding operation to be performed on a workpiece with the multi-wheel grinding machine of the invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Referring now to the drawings, and more particularly to FIGS. 1 and 2, a tailstock 2 and a headstock 3 for supporting a workpiece 5 therebetween are carried by a table 24 which is pivotally mounted on a base 1 about a pivot pin 25 secured thereto. A motor 4 for rotating the workpiece 5 is mounted on the headstock 3. Automatic sizing devices 6*a* and 6*b* also carried by the table 24 are arranged to engage the workpiece 5 at spaced portions 5*a* and 5*b* thereon which are to be ground by a pair of grinding wheels 9*a* and 9*b*.

A wheel slide 7 is slidably mounted on parallel slide ways 47 formed on the base 1 and carries a rotatable wheel spindle 8 which is rotated about a horizontal axis perpendicularly oriented relative to the path of movement of the wheel slide by a suitable motor, not shown, through a V-grooved pulley 10 and a plurality of V-belts coupled thereto. A plurality of grinding wheels, being shown in this embodiment as two in number, namely, the grinding wheels 9*a* and 9*b*, are fixedly mounted on the wheel spindle 8 at positions corresponding to the workpiece portions 5*a* and 5*b*.

A slide base 19 is mounted on a sloping surface of a pedestal 79 which is secured to the wheel slide 7 on the side of the grinding wheels 9*a* and 9*b* oppositely disposed from the workpiece 5. Slidably mounted on the slide base 19 is a slide 22 which carries a plurality of dressing heads corresponding in number to the grinding wheels, in this embodiment two dressing heads 12*a* and 12*b*. At the front ends of the dressing heads 12*a* and 12*b*, rotary dressers 16*a* and 16*b* are rotatably mounted and connected with each other by means of a spline shaft 90 and universal joints 91. A drive pulley 15 for the rotary dressers 16*a* and 16*b* is connected to the drive shaft of an electric motor 13 mounted on the dressing head 12*a* by a belt 14. The dressing heads 12*a* and 12*b* are slidably mounted through rams 23 on the slide 22 and are individually movable toward and away from the grinding wheels 9*a* and 9 *b* by respective ratchet mechanisms 20*a* and 20*b* through feed screws 21*a* and 21*b* and the rams 23 which are interengaged therewith. At the rear end of the pedestal 79, another ratchet mechanism 17 is provided for moving the slide 22 back and forth on the slide base 19 through the operation of a feed screw 18 which is threadably engaged with the slide 22. Therefore, the dressing heads 12*a* and 12*b* may be moved together by operating feed screw 18 to move the slide 22 and also individually through the operation of feed screws 21*a* and 21*b*.

A feed mechanism for the wheel slide 7 will now be described, still referring to FIGS. 1 and 2. A gear 26, which is keyed to a shaft 34 and operably connected to a hand wheel 11, is provided with an integral clutch element 29 which faces a complementary clutch element 30, loosely mounted on the shaft 34. The shaft 34 is supported by a bushing 35 fixedly mounted on the base 1. The gear 26 is further provided with a cylindrical hollow, or chamber, 28 in one end thereof which contains a slidable piston 28*a* and a spring 27 compressed between the piston end remote from the shaft 34 and a closure member secured to the open end of the chamber 28 for normally urging the clutch elements 29 and 30 away from each other and thereby maintaining the same in a disengaged state. When the clutch elements 29 and 30 are disengaged from each other, the shaft 34 may be rotated by the operator through the hand wheel 11, the gear 26 keyed thereto and intermediate connecting gears, not shown. On the other hand, when the clutch elements 29 and 30 are engaged with each other, the shaft 34 may be automatically rotated by a feeding actuator device 71, that is, the movement of a rack 31 formed on the piston rod of the feeding actuator 71 is transferred to the shaft 34 through a pinion 30*a* and the clutch elements 29 and 30. The rotation of the shaft 34 is further transferred to a transmission shaft 37 through gears 32 and 33 being respectively secured to the shaft 34 intermediate its ends and the front end of the transmission shaft 37. Engagement of the clutch 29 with the clutch element 30 may be effected by supplying pressurized fluid through an end radial port 36 and an axial bore 34*a* in the shaft 34 to the chamber 28 between the piston 28*a* and the clutch element 29 for urging the piston to further compress the spring 27 and the clutch 29 to be shifted toward the clutch element 30.

In the vicinity of the rear end of the transmission shaft 37, there is provided a gear 38 which meshingly engages an idler gear 39 which further engages an axially elongate gear member 40. The elongate gear 40 is rotatably supported in the base 1 and engages another gear 41 secured to the rear end of a feeding shaft 44 so that the shaft 44 may be rotated either manually through operation of hand wheel 11 or by the feeding actuator 71. At the rear portion of the base 1, a hydraulic actuator 42 is provided which comprises a cylindrical chamber 42*a*, a piston 43 slidably disposed therein and the feeding shaft 44. The piston 43 is rotatably mounted on the shaft 44 but is retained by conventional shoulders from any axial movement with respect to the shaft. A screw 45 is formed on the front end of the feeding shaft 44 where it engages a nut 46 secured to the underside of the wheel slide 7 for causing the same to be moved along the longitudinal axis of the shaft 44. Therefore, the wheel slide 7 may be moved at a rapid speed toward and from the workpiece 5 by the hydraulic actuator 42 and at a slower speed either manually through operation of the hand wheel 11 or by the feeding actuator 71 through the transmission shaft 37 and its associated mechanism.

At the rear end of the transmission shaft 37, there also is provided a compensating mechanism to compensate for any reduction of the grinding wheel diameter due to wear thereof and any dressing operation performed thereon. A rocking piece 48, which is rotatably mounted on the end of the transmission shaft 37 but is prevented from axial movement thereon, has a pinion 48*a* formed thereon which is engaged with a rack 52 formed on a piston rod of a compensating actuator 64, shown in FIG. 3. A ratchet pawl 51 is pivotally mounted on the rocking piece 48 and is engageable with a ratchet wheel 49 which is keyed to the shaft 37. Interposed between the ratchet pawl 51 and the ratchet wheel 49 is an arc-shaped plate member 50 which is secured to a housing 50*a* for the compensating mechanism.

The compensating actuator 64 for the compensating mechanism is actuated by pressurized fluid for turning the rocking piece 48 to thereby make the ratchet pawl 51 engage with the ratchet wheel 49. Thus, the transmission shaft 37 may be turned through a predetermined angle so that the wheel slide 7 may be shifted according to the reduction of the grinding wheel radius caused by normal wear thereof and any dressing operations performed thereon. The amount of compensation may be controlled by the arc-shaped plate 50. That is, the ratchet pawl 51 is positioned on the plate 50 at the start and therefore is not initially engaged with the ratchet wheel 49. When the rocking piece 48 is turned by the actuator 64, the ratchet pawl 51 slides on the plate 50 through a predetermined distance, and thereafter the pawl 51 becomes disengaged from the plate 50 so that it engages the ratchet wheel 49, whereby it is operative to rotate the ratchet wheel 49 therewith. Accordingly, by controlling the angular position of the plate 50, the distance through which the pawl 51 slides on the plate 50 may be changed and thus, the amount of rotation of the ratchet wheel 49 is changed, since the total amount of rotation of the rocking piece 48 is always the same. During the rotation of the transmission shaft 37 by the compensating mechanism, the clutch elements 29 and 30 are disengaged from each other and the wheel slide 7 is located in a retracted or an original position.

Referring now to FIG. 3 in conjunction with the grinding machine shown in FIGS. 1 and 2, the ratchet feeding mechanism 17 positioned at the rear of the pedestal 79 for moving the dressing head-supporting slide 22 thereon will now be described in detail. A rocking piece 77, which is rotatably mounted on one end of the feed screw shaft 18, meshingly engages a rack 78*a* formed on a piston 78 slidably disposed in a hydraulic actuator 80. A pair of ratchet pawls 73 and 75 are pivotally carried by the rocking piece 77, the ratchet pawl 73 being used for advancing the slide 22 and the ratchet pawl 75 being used for retracting the slide 22. A pair of ratchet wheels 72*a* and 72*b* are secured in side-by-side relation to the feed screw 18. A pair of arc-shaped plates 74 and 76 are respectively adjustably mounted on the interior of the feed mechanism housing between the ratchet wheel 72a and the ratchet pawl 73 and between the ratchet wheel 72b and the ratchet pawl 75. By leftward movement of the piston 78, as seen in FIG. 3, the rocking piece 77 is turned in a clockwise direction so that the ratchet pawl 73 slides over the arc-shaped plate 74 during a predetermined amount of such movement of the rocking piece 77, and thereafter becomes engaged with the ratchet wheel 72a, whereby the feeding screw connected therewith is turned so that the slide 22 and the dressing heads 12a and 12b disposed thereon are advanced toward the grinding wheels 9a and 9b. During this rotation of the rocking piece 77, also the pawl 75 rides onto the surface of the plate 76. By this advancement of the dressing heads 12a and 12b, a dressing operation of the grinding wheels 9a and 9b may be performed by the rotary dressers 16a and 16b. When the dressing operation is completed, the piston 78 is moved to the right for retracting the ratchet pawl 73 onto the plate 74, the pawl 73 at first freely riding over the wheel 72a during this counterclockwise rotation of the rocking piece 77. On the other hand, during the counterclockwise rotation of the rocking piece 77, the ratchet pawl 75 slides on the plate 76 for a predetermined distance and thereafter becomes engaged with the ratchet wheel 72b, so that the dressing heads 12a and 12b are retracted. Since the feed screw 18 is not rotated while the ratchet pawl 75 slides on the plate 76, the dressing heads 12a and 12b are disposed at an advanced position by a calibrated distance.

Referring now particularly to FIG. 3, there is shown a hydraulic control circuit for operating the multi-wheel grinding machine of the present invention which is described herein. A changeover valve 55 is provided for the hydraulic actuator 42, having an associated solenoid SOL 1 which is operative upon energization or de-energization to cause the wheel slide 7 to be moved toward or from the workpiece 5 at a high rate of speed. Another changeover valve 56 controls the supply of pressurized fluid to the hydraulic actuator 71 for providing automatic relatively slower feeding movement of the wheel slide 7. When a solenoid SOL 2 associated with the change over valve 56 is energized, fluid pressure moves a piston 71a of the hydraulic actuator 71 to the right, as viewed in FIG. 3, whereby an automatic infeed is imparted to the wheel slide 7 through rack 31 and pinion 30a as hereinbefore described, and when a solenoid SOL 5 associated therewith is energized, the wheel slide 7 is automatically retracted from the workpiece 5. Between the changeover valve 56 and a forward chamber 71b of the hydraulic actuator 71, there is provided a throttling circuit which comprises a rough feed throttle valve 58, a fine feed throttle valve 59 and a shut-off valve 57. The throttle valves 58 and 59 are provided in series with each other between the forward chamber 71b of the hydraulic actuator 71 and the changeover valve 56. The shut-off valve 57 and the throttle valve 59 are connected in parallel relation. When a solenoid SOL 4 is energized, the fluid in the forward chamber 71b is evacuated to a reservoir, not shown, through the rough throttle valve 58, the shut-off valve 57 and the changeover valve 56 so that the wheel slide 7 is advanced toward the workpiece 5 at a rough grinding speed. When the solenoid SOL 4 is de-energized, a fine grinding speed is imparted to the wheel slide 7, since the by-pass conduit through the shut-off valve 57 is closed and the evacuated fluid now passes through the fine throttle valve 59 which further restricts the fluid flow. Provided in parallel relation with the throttle valves 58 and 59 is a check valve 60 which enables the pressurized fluid to pass into the forward chamber 71b for retracting the piston 71a to its original position upon energization of solenoid SOL 5, but otherwise prevents fluid flow in an opposite direction therethrough such that evacuation of chamber 71b must take place through the throttle valves.

Numeral 61 indicates a changeover valve which is provided for causing engagement and disengagement of the automatic sizing devices 6a and 6b with workpiece 5.

Another changeover valve 62 controls the operation of the compensating actuator 64. When a solenoid SOL 8 associated with the changeover valve 62 is energized, a piston in the compensating actuator 64 is advanced in order to compensate for any diametric reduction of the grinding wheels 9a and 9b. Between the hydraulic actuator 28 and the changeover valve 62, there is provided a manual changeover valve 63 which controls the hydraulic actuator 28. When the manual changeover valve 63 is changed to "AUTO," that is, to a position indicated by I, the pressurized fluid is directed to the actuator 28 so as to engage the clutch elements 29 and 30 by moving the piston against the force of the compressed spring 27. When the solenoid SOL 8 is energized, that is, the compensating actuator 64 is actuated, a supply conduit to the actuator 28 is always connected to the reservoir through the manual changeover valve 63, whereby the piston therein is advanced by the compressed spring 27 to disengage the clutch elements 29 and 30 from each other. On the other hand, when the manual changeover valve 63 is changed to "-MANUAL," that is, to a position indicated by II, a supply conduit from the actuator 28 is directly connected to the reservoir through the manual changeover valve 63 for permitting evacuation of fluid from actuator 28 so that the clutch elements 29 and 30 are disengaged from each other by the action of spring 27.

A changeover valve 65 is provided for controlling the operation of the hydraulic actuator 80. When a solenoid SOL 7 is energized, the piston 78 is moved to the left as viewed in FIG. 3, and thus, the dressing heads 12a and 12b are advanced by means of the ratchet mechanism 17. Until engagement between a shut-off valve 66 and a dog 83 mounted on the piston rod 78b occurs, the dressing heads 12a and 12b are advanced at a rapid speed toward the grinding wheels 9a and 9b. Just before the rotary dressers 16a and 16b engage the grinding wheels 9a and 9b, the dog 83 engages the shut-off valve 66, whereby a by-pass conduit through shut-off valve 66 is closed and thus, the fluid being evacuated from the actuator 80 is throttled by a throttle valve 81 so that the rotary dressers 16a and 16b are advanced at a slow dressing speed into the grinding wheels 9a and 9b to perform the desired dressing operation thereon. When the piston 78 reaches the end of its stroke, a limit switch LS3 is actuated by a dog 84 secured thereto for de-energizing the solenoid SOL 7 so that the pressurized fluid will be supplied to the opposite chamber of the hydraulic actuator **80** through a check valve **82** which is interposed in parallel relation with the throttle valve **81**, and thus, the dressing heads **12***a* and **12***b* are retracted at a rapid speed. LS2 indicates another limit switch in line with LS3 which is provided to confirm the fact that the piston **78** has been fully retracted to the right end, or in other words, that the dressing heads **12***a* and **12***b* have been retracted to their original positions.

Changeover valves **67** and **68** are provided for hydraulic actuators **69** and **70**, respectively, comprising the ratchet mechanisms **20***a* and **20***b* for individually advancing the dressing heads **12***a* and **12***b*. When solenoids SOL **9** and SOL **10**, which are controlled by the signals supplied by the automatic sizing devices **6***a* and **6***b*, respectively, are energized, the dressing heads **12***a* and **12***b* are advanced toward the grinding wheels **9***a* and **9***b* by a predetermined short distance.

The signals supplied by the automatic sizing devices **6***a* and **6***b* are passed through an amplifier 101 to a Schmitt trigger circuit 102 which, in turn, provides signals S1, S2, S3 and S4 from each of the sizing devices. The signals S1, S2, S3 and S4 are respectively produced when the diameters of portions **5***a* and **5***b* on the workpiece **5** are ground to predetermined levels. For example, the signals S1 and S2 are produced for each of the workpiece portions at preselected diameter values thereon, and the difference between the signals S1 and S2 is equal to an established permissible tolerance between the finished diameters of the portions **5***a* and **5***b*. Accordingly, the fact that the signal S2 is produced by either one of the automatic sizing devices **6***a* and **6***b* when the signal S1 has not yet been produced by the other of the sizing devices means that the difference in the diameters of workpiece portions **5***a* and **5***b* at that point exceeds the allowed tolerance. The signal S3 is produced when the depth of the workpiece portion yet to be removed reaches a point that requires the feed speed of the wheel slide **7** to be changed from a rough grinding speed to a fine grinding speed, and the signal S4 is produced when the respective diameters of the portions **5***a* and **5***b* are ground to a finished diameter. The signals produced by the automatic sizing device **6***a* are indicated hereinafter by the reference characters 1S1, 1S2, 1S3 and 1S4, and the signals produced by the automatic sizing device **6***b* are indicated by 2S1, 2S2, 2S3 and 2S4. When the workpiece portions **5***a* and **5***b* are evenly ground, each pair of signals, for example, the signals 1S2 and 2S2, is produced by both automatic sizing devices at almost the same time. However, when the signal 2S1 has not been produced in spite of the fact that the signal 1S2 has already been produced, as indicated hereinbefore, the workpiece portions **5***a* and **5***b* are being unevenly ground such that the diameter of the portion **5***b* is larger than that of the portion **5***a*. When this fact is detected, the further advancement of the wheel slide **7** is ceased and the solenoid SOL 9 is energized to actuate the hydraulic actuator **69** by means of the changeover valve **67** so that the dressing head **12***a* corresponding to the grinding wheel **9***a* is advanced by means of the ratchet mechanism **20***a* to dress the grinding wheel **9***a*. When the signals 1S2 and 2S2 are not produced at the same time, either dressing head **12***a* or **12***b* is advanced for the purpose of compensation, and when the signals 1S2 and 2S2 are produced at the same time, the normal grinding operation cycle is continued.

Referring now to FIGS. **4** and **5**, the cycle of the grinding operation is described hereinafter. Symbols CR, SOL and TR are used to designate relay coils, solenoids and timer coils, respectively. Symbols as indicate contacts in the control circuit which are actuated by the signals S1, S2, S3 and S4. Symbols *cr* indicate contacts in the control circuit associated with the relay coils having the same number. Numerals **1** and **2** which appear at the head of the symbol as indicate the contacts operated by the signals which are supplied from the automatic sizing devices **6***a* and **6***b* respectively. The symbol *as* or *cr*, with the symbol *x* thereafter, represents a normally closed contact, while without the symbol *x*, a normally open contact is represented.

When the wheel slide **7** is located at the original or retracted position thereof, the relay coil CR5 and solenoid SOL5 are energized by normally closed coils *cr***1***x* and *cr***2***x*, and furthermore, the relay coils CR18 and CR13 are energized, since the limit switches LS1 and LS2 are actuated. In this situation, an operator of the machine herein disclosed pushes a button PB2 to permit energization of the relay coil CR1 and the solenoid SOL1 to thereby close contacts *cr***1**, whereby the relay coil CR1 is self held by means of the now closed associated contact *cr***1** disposed parallel to PB2. With the energization of the relay coil CR1 and the corresponding closure of contacts *cr***1**, timer coil TR1, relay coil CR2, solenoid SOL2, relay coil CR4 and the solenoid SOL4 are all energized, whereby the wheel slide **7** is advanced toward the workpiece **5** at a rapid speed by means of the hydraulic actuators **42** and **71**. After the wheel slide **7** is advanced through a predetermined distance, the feeding speed is changed to a rough grinding speed, since the hydraulic actuator **42** ceases its movement and the wheel slide **7** is advanced only by the actuator **71**. While a rough grinding operation is being performed on the workpiece **5**, the period determined by the timer coil TR1 elapses, causing contact *tr***1** to close to thereby energize the relay coil CR3 and the solenoid SOL3, whereby the automatic sizing devices **6***a* and **6***b* are advanced to engage the workpiece **5**. When the grinding operation is continued, the signals 1S1 and 2S1 are supplied by the automatic sizing devices **6***a* and **6***b* to open normally closed contacts **1***as***1***x* and **2***as***1***x*. Thereafter, the signals 1S2 and 2S2 are supplied to thereby close the normally open contacts **1***as***2** and **2***as***2**. When each pair of signals 1S1 and 2S1 and 1S2 and 2S2 is supplied at the same time, the relay coils CR11 and CR12 are not energized in spite of the closing of the contacts **1***as***2** and **2***as***2**. With further reduction in the diameter of the workpiece **5** by the grinding operation, the automatic sizing devices **6***a* and **6***b* supply the signals 1S3 and 2S3, whereby normally closed contacts **1***as***3***x* and **2***as***3***x* are opened to thereby de-energize the relay coil CR4 and solenoid SOL4. Accordingly, the by-pass through the shut-off valve **57** is closed so that a fine grinding speed is rendered to the wheel slide **7**. When the diameter of each of the portions **5***a* and **5***b* reaches a required or finished value, the automatic sizing devices **6***a* and **6***b* supply the sizing signals 1S4 and 2S4 which respectively are effective to close the contacts **1***as***4** and **2***as***4**. By closing the contacts **1***as***4** and **2***as***4**, the relay coil CR6 and timer coil TR2 are energized and thus, the contact *cr***6***x* associated with the relay coil CR6 and disposed in series with relay coil CR2 is opened, whereby the relay coil

CR2 and solenoid SOL2 are de-energized to stop the movement of the wheel slide 7. When the time determined by the timer coil TR2 is up, relay coil CR1 and solenoid SOL1 are de-energized through opening of contact *tr*2*x* and relay coil CR5 and solenoid SOL 5 are energized through now reclosed *cr*1*x* and *cr*2*x* resulting in a rapid return of the wheel slide 7 by the combined operation of the hydraulic actuators 42 and 71. Simultaneously, the automatic sizing devices 6*a* and 6*b* are retracted to the original positions thereof, since the relay coil CR3 and the solenoid SOL 3 are now de-energized, the timer coil TR 1 being de-energized when the relay coil TR1 is de-energized. When the wheel slide 7 is retracted to the original position, the limit switch LS1 is actuated, whereby the spindle motor 4 is stopped.

Thereafter, to perform a dressing operation, a button PB3 is pushed by an operator resulting in the energization of the relay coil CR14, since the relay coil CR13 has been energized by means of the limit switch LS2 to close contacts *cr*13. When the relay coil CR14 is energized, all of its associated contacts *cr*14 are closed to thereby energize a relay coil CR7 and the solenoid SOL 7, whereby the dressing heads 12*a* and 12*b* are advanced toward the grinding wheels 9*a* and 9*b* for the dressing operation by the rotary dressers 16*a* and 16*b* being rotated by the motor 13. Also, with the energization of the relay coil CR14, relay coil CR8, timer coil TR4 and solenoid SOL 8 are energized, and thus, the compensating actuator 64 is actuated to advance the wheel slide 7 to compensate for the reduced radius of the grinding wheels 9*a* and 9*b* due to wear thereof and the dressing operation performed thereon. It will be appreciated that, at this time the clutch elements 29 and 30 are disengaged from each other under the force of spring 27. At the end of advancement of the rotary dressers 16*a* and 16*b*, a limit switch LS3 is actuated by the dog 84 to thereby energize relay coil CR15 and timer coil TR3. After the spark-out operation which continues for a time determined by the timer coil TR3, *tr*3 closes so that the relay coil CR16 is energized, whereby contacts *cr*16*x* are opened and the relay coil CR14 is de-energized. By the de-energization of the relay coil CR14, the relay coil CR7 and the solenoid SOL 7 are also de-energized, contacts *cr*14 now being open again, so that the dressing apparatus is retracted at a rapid speed, and the limit switch LS3 is disengaged from the dog 84 to thereby de-energize the relay coils CR15, CR8 and solenoid SOL 8. By the de-energization of the solenoid SOL 8, the clutch elements 29 and 30 are re-engaged with each other by means of the fluid pressure-invoked movement of piston 28*a*. When the limit switch LS2 is actuated to confirm the full retraction of the dressing heads 12*a* and 12*b*, a relay coil CR13 is energized.

The grinding operation cycle, wherein a difference in size appears between the diameters of the portions 5*a* and 5*b* and the elimination of such difference is required, is described hereinafter.

As in the ordinary grinding operation, when the button PB2 is pushed, relay coil CR1, solenoid SOL 1, timer coil TR1, relay coil CR2, solenoid SOL 2, relay coil CR4, solenoid SOL 4 all are energized, and the wheel slide 7 is thereby advanced to perform a rough grinding operation on the workpiece 5. After the passage of a predetermined time established by the timer coil TR1, relay coil CR3 and solenoid SOL 3 are also energized so that the automatic sizing devices 6*a* and 6*b* are moved into engagement with the workpiece 5.

When a difference in diameter sizes in the workpiece portions 5*a* and 5*b* is produced by the rough grinding operation, the automatic sizing devices 6*a* and 6*b* do not produce signals simultaneously. For example, when the portion 5*a* is ground so that its diameter is smaller than that of the portion 5*b*, the sizing device 6*a* will produce the signal 1S2 before the sizing device 6*b* even produces the signal 2S1. To eliminate this difference, the diameter of the grinding wheel 9*a* is reduced by performing a dressing operation thereon. In this assumed situation, the contact 1*as*2 is closed, but the normally closed contact 2*as*1*x* is still closed, since the signal 2S1 has not issued. Accordingly the relay coil CR11 is energized, such that all the normally open and closed contacts *cr*11 and *cr*11*x*, respectively, associated therewith are reversed, whereby the relay coil CR2 and the solenoid SOL 2 are de-energized to stop the movement of the wheel slide 7 and at the same time, the relay coil CR7 and the solenoid SOL 7 are energized so that the slide 22 is advanced by means of the ratchet mechanism 17. Furthermore, the relay coil CR9 and the solenoid SOL 9 are now energized to advance the dressing head 12*a* with respect to the slide 22 so that the grinding wheel 9*a* may be dressed off by a larger amount than that of the grinding wheel 9*b*. Toward the end of the dressing operation, the limit switch LS3 is actuated to thereby energize the timer coil TR3 which sets up a dwelling time for the dressing heads 12*a* and 12*b*. When the set time is up, the relay coil CR16 is energized through the contact *tr*3 associated with the timer coil TR3 resulting in the de-energization of the relay coil CR7 and solenoid SOL 7 through normally closed contact *cr*16*x*, now being opened. By the de-energization of relay coil CR7 and solenoid SOL 7, the slide 22 is retracted and relay coil CR9 and solenoid SOL 9 are de-energized through the reopening of a contact *cr*7. When the dressing heads 12*a* and 12*b* are retracted by means of the ratchet mechanism 17, the limit switch LS3 is disengaged from the dog 84 to thereby de-energize the relay coil CR15. By the de-energization of the relay coil CR15, the relay coil CR17 is energized to thereby de-energize the relay coil CR11 and energize the relay coil CR2 and the solenoid SOL 2. By the energization of solenoid SOL 2, pressurized fluid is supplied to the actuator 71 in a direction to advance the wheel slide 7 toward the workpiece 5 again.

The automatic sizing device 6*b* produces the signals 2S1 and 2S2. By continuing the grinding operation, the signals 1S3 and 2S3 are simultaneously produced by the automatic sizing devices 6*a* and 6*b*, since the grinding wheels 9*a* and 9*b* are dressed up to grind the workpiece 5 into the same size. The signals 1S3 and 2S3 effect the de-energization of the relay coil CR4 and SOL 4 so that the infeed speed of the wheel slide 7 is changed from a rough grinding speed to a fine grinding speed. When the workpiece 5 is ground into the required diameter the sizing signals 1S4 and 2S4 are produced by the automatic sizing devices 6*a* and 6*b*, respectively.

By the signals **1S4** and **2S4**, the relay coil CR6 is energized and thus, relay coil CR2 and solenoid SOL **2** are de-energized to stop the movement of the wheel slide **7** and the timer coil TR2 is energized to make the wheel slide **7** stay at the same position to perform a spark-out operation. After the predetermined time, the wheel slide **7** is retracted in the usual manner according to an ordinary grinding operation. When the limit switch LS1 is actuated by the feeding shaft **44**, the relay coil CR**18** is energized to thereby energize the relay coil CR**8**, solenoid SOL **8** and timer coil TR4 through the now closed contacts *cr***17** and *cr***18**. Accordingly, the compensating actuator **64** is actuated to compensate for the diameter reduction of the grinding wheels **9***a* and **9***b*, that is to advance the wheel slide **7** by the amount which the radius of the grinding wheels has been reduced. The relay coils CR**17** and CR**8** and solenoid SOL **8** are de-energized after a time determined by the timer coil TR4.

It is to be appreciated that the situation where the diameter of the portion **5***a* is smaller than that of the portion **5***b* has been described, but in case of the opposite situation, the difference between the diameters of the portions **5***a* and **5***b* may also be eliminated in the same manner as described above.

As described above, when any significant difference is produced on the portions being machined, the difference is automatically detected and the grinding operation is automatically instantly halted. The grinding wheels are then unevenly dressed so that the difference is eliminated. Accordingly, the workpieces are not ruined and are machined with high machining accuracy, since the compensating operation is done during the grinding operation.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. It is to be understood, therefore, that within the scope of the appended claims the invention may be practiced otherwise than as specifically described herein.

What is claimed as new and desired to be secured by Letters Patent of The United States is:

1. A multi-wheel grinding machine comprising:

a base;

supporting means mounted on said base and adapted to rotatably support a workpiece having a plurality of portions thereon to be ground;

a plurality of automatic sizing devices operatively associated with said workpiece for measuring the diameters of said portions being ground;

a wheel slide slidably mounted on said base and having a plurality of grinding wheels;

first feeding means for moving said wheel slide toward and away from said workpiece to perform a grinding operation thereon with said grinding wheels;

a dresser slide slidably mounted on said wheel slide;

a plurality of dressing means slidably mounted on said dresser slide for dressing said grinding wheels;

second feeding means mounted on said wheel slide and connected to said dresser slide for moving said dresser slide toward and away from said grinding wheels to perform dressing operations thereon;

a plurality of third feeding means mounted on said dresser slide for moving said plurality of dressing means toward and away from said grinding wheels; and

a control system operably connected to said first, second and third feeding means for halting the movement of said first feeding means and actuating said second and third feeding means to dress said grinding wheels unevenly when a difference between output values of said sizing devices corresponding to the diameters of said workpiece portions being ground is detected to be beyond a predetermined value, and for advancing said wheel slide again following a dressing operation, whereby said workpiece portions are ground to substantially predetermined dimensions.

2. A multi-wheel grinding machine as claimed in claim **1**, wherein said first feeding means is provided with compensating means for compensating any diameter reduction of said grinding wheels by advancing the same, comprising:

a shaft connected to said first feeding means;

a ratchet wheel secured to said shaft;

a ratchet pawl engageable with said ratchet wheel; and

a hydraulic actuator for rotating said ratchet wheel through said ratchet pawl.

3. A multi-wheel grinding machine as claimed in claim **2**, wherein said control system is operable to actuate said compensating means and said second feeding means at the same time to dress said grinding wheels when said wheel slide is retracted to an original position thereof.

4. A multi-wheel grinding machine comprising:

a base;

a table mounted on said base;

head stock and foot stock means mounted on said table for supporting a workpiece therebetween having at least two portions to be ground;

a pair of automatic sizing devices mounted on said table and operable to measure the diameters of said two portions;

a wheel slide slidably mounted on said base and supporting at least a pair of rotatable grinding wheels;

first feeding means for moving said wheel slide toward and from said workpiece to perform a grinding operation thereon with said grinding wheels;

a dresser slide slidably mounted on said wheel slide;

at least a pair of dressing means slidably mounted on said dresser slide for dressing said grinding wheels;

second feeding means mounted on said wheel slide and connected to said dresser slide for moving said dresser slide toward and from said at least a pair of grinding wheels to perform dressing operations thereon;

at least a pair of third feeding means mounted on said dresser slide for individually moving said at least a pair of dressing means toward and from said grinding wheels; and

a control system operably connected to said first, second and third feeding means for halting the movement of said first feeding means and actuating said second and third feeding means to dress said grinding wheels unevenly when a difference between output values of said sizing devices corresponding to diameters of said workpiece portions being ground is detected to be beyond a predetermined value, and for advancing said wheel slide again following a dressing operation, whereby said workpiece portions are ground to substantially predetermined dimensions.

5. A multi-wheel grinding machine as set forth in claim **1**, wherein said control system comprises a plurality of switching means respectively capable of generating a series of signals in response to said output values of said sizing devices, and said control system is responsive to said series of signals for halting the movement of said first feeding means and advancing said dressing means to dress said grinding wheels unevenly when said signals are produced in a manner of an out-of-predetermined sequence.

6. A multi-wheel grinding machine as set forth in claim **5**, wherein said switching means are capable of respectively generating first and second signals when said workpiece portions are respectively ground to a predetermined first dimension and thereafter a predetermined second dimension, said first and second signals being for serving to halt the movement of said first feeding means and to actuate said second and third feeding means so as to perform a dressing operation on said grinding wheels unevenly when said second signal has been generated from one of said switching means before said first signal is generated from another of said switching means, whereby said workpiece portions are ground to substantially an equal diameter.

7. A multi-wheel grinding machine as set forth in claim **6**, wherein said plurality of switching means generate third and fourth signals according to the decrease of diameters of said workpiece portions being ground, said third signal being for serving to decrease the infeed speed of said wheel slide and said fourth signal being for serving to stop the infeed movement of said wheel slide.

8. A multi-wheel grinding machine as set forth in claim **4**, wherein said control system comprises a pair of switching means respectively capable of generating a series of signals in response to said output values of said sizing devices, and said control system being responsive to said series of signals for halting the movement of said first feeding means and advancing said dressing means to dress said grinding wheels unevenly when said signals are produced in a manner of an out-of-predetermined sequence.

9. A multi-wheel grinding machine as set forth in claim **8**, wherein each of said pair of switching means is capable of generating first and second signals when said pair of workpiece portions are respectively ground to a predetermined first dimension and thereafter a predetermined second dimension, said first and second signals being for serving to halt the movement of said first feeding means and to actuate said second and third feeding means so as to perform a dressing operation on said grinding wheels unevenly when said second signal has been generated from one of said switching means before said first signal is generated from the other of said switching means.

10. A multi-wheel grinding machine as set forth in claim **9**, wherein each of said pair of switching means generates third and fourth signals according to the decrease of diameters of the said two portions being ground, said third signal being for serving to decrease the infeed speed of said wheel slide and said fourth signal being for serving to stop the infeed movement of said wheel slide.

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