

Oct. 27, 1964

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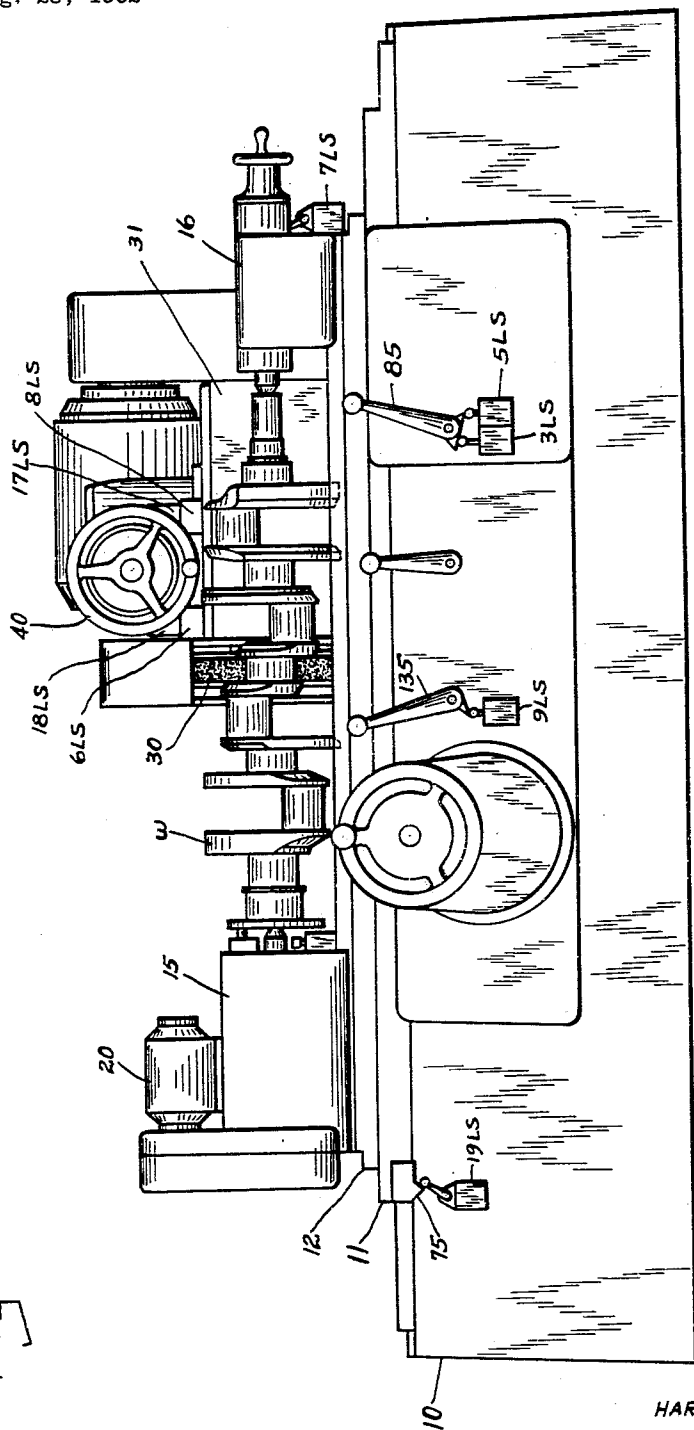
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APPARATUS FOR GRINDING FLEXIBLE WORKPIECES

Filed Aug. 23, 1962

5 Sheets-Sheet 1

Fig 1



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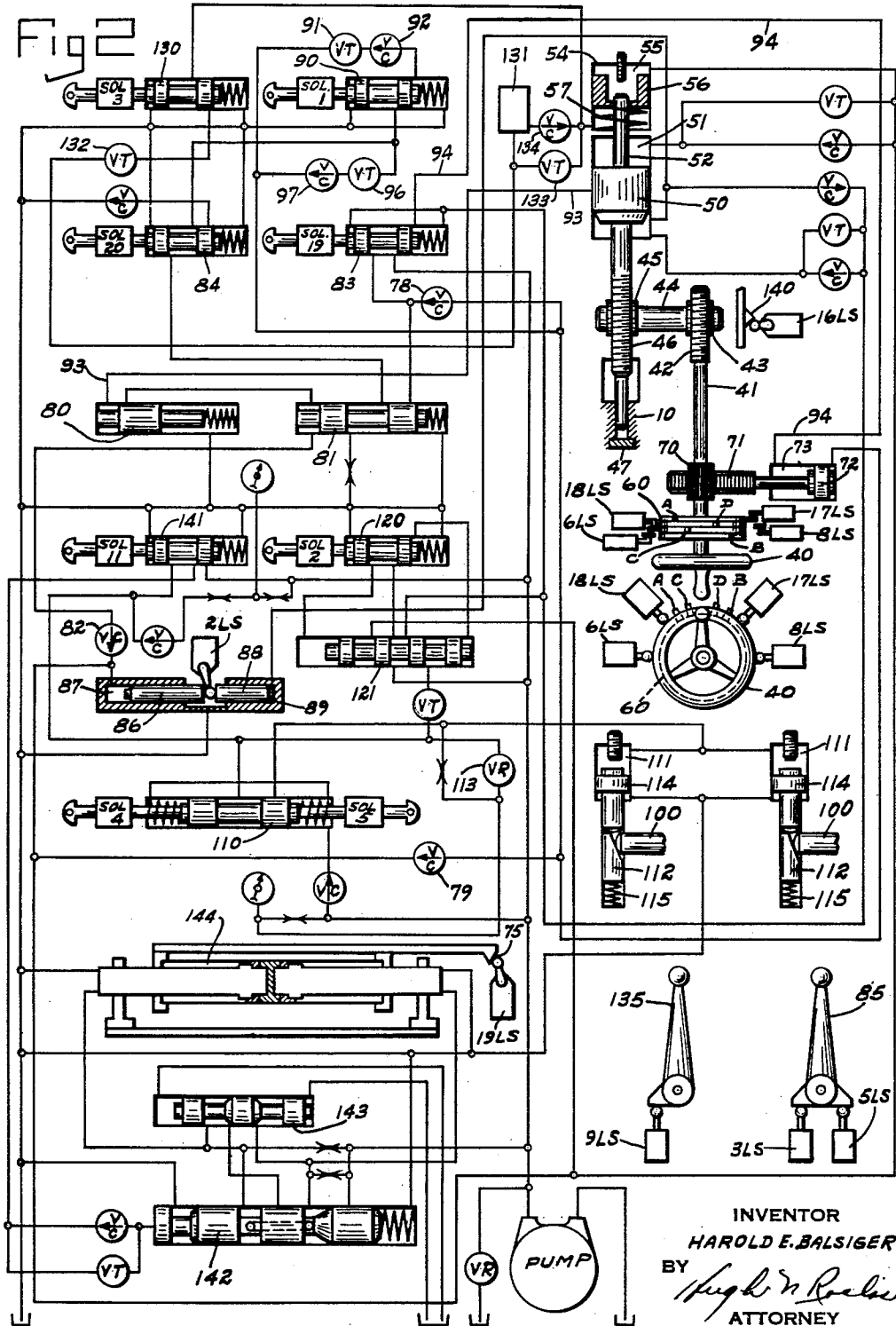
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APPARATUS FOR GRINDING FLEXIBLE WORKPIECES

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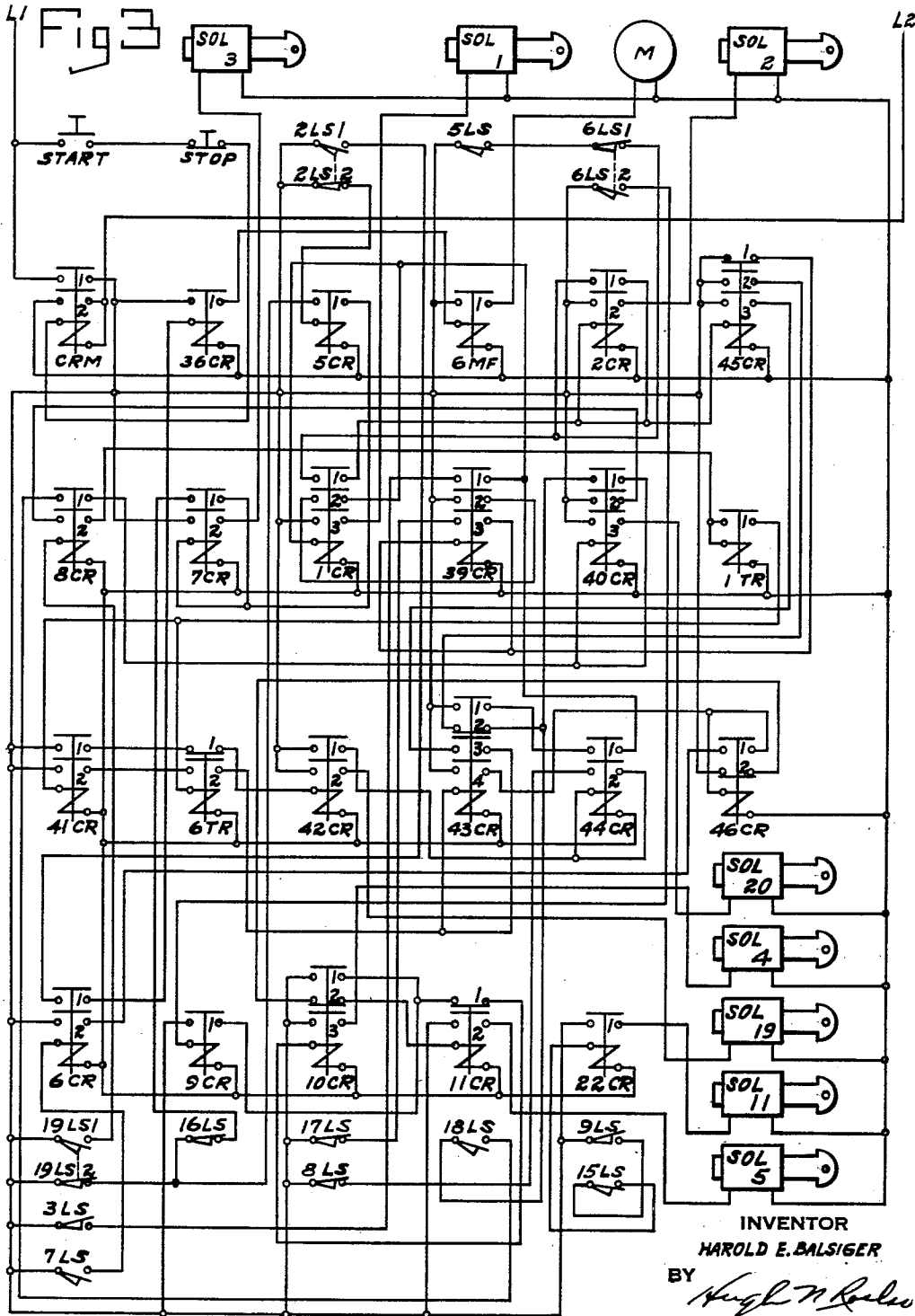
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APPARATUS FOR GRINDING FLEXIBLE WORKPIECES

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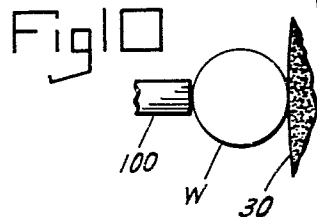
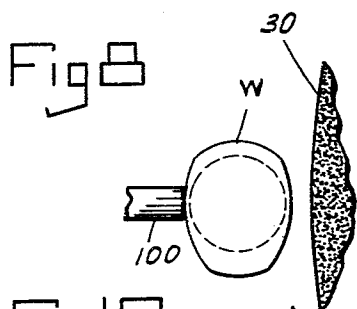
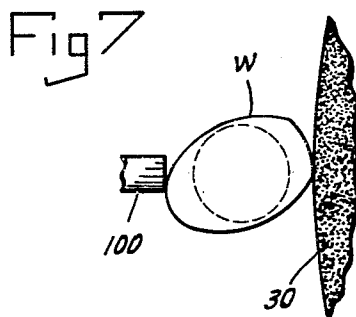
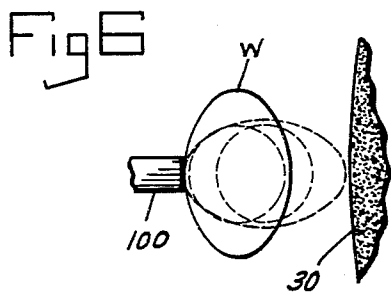
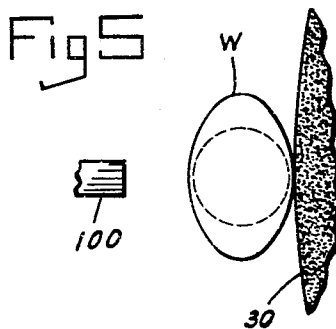
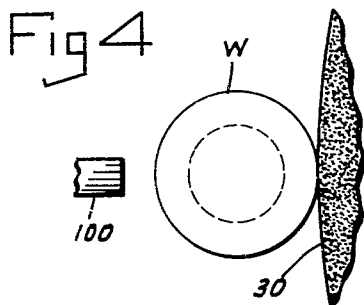
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APPARATUS FOR GRINDING FLEXIBLE WORKPIECES

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5 Sheets-Sheet 4



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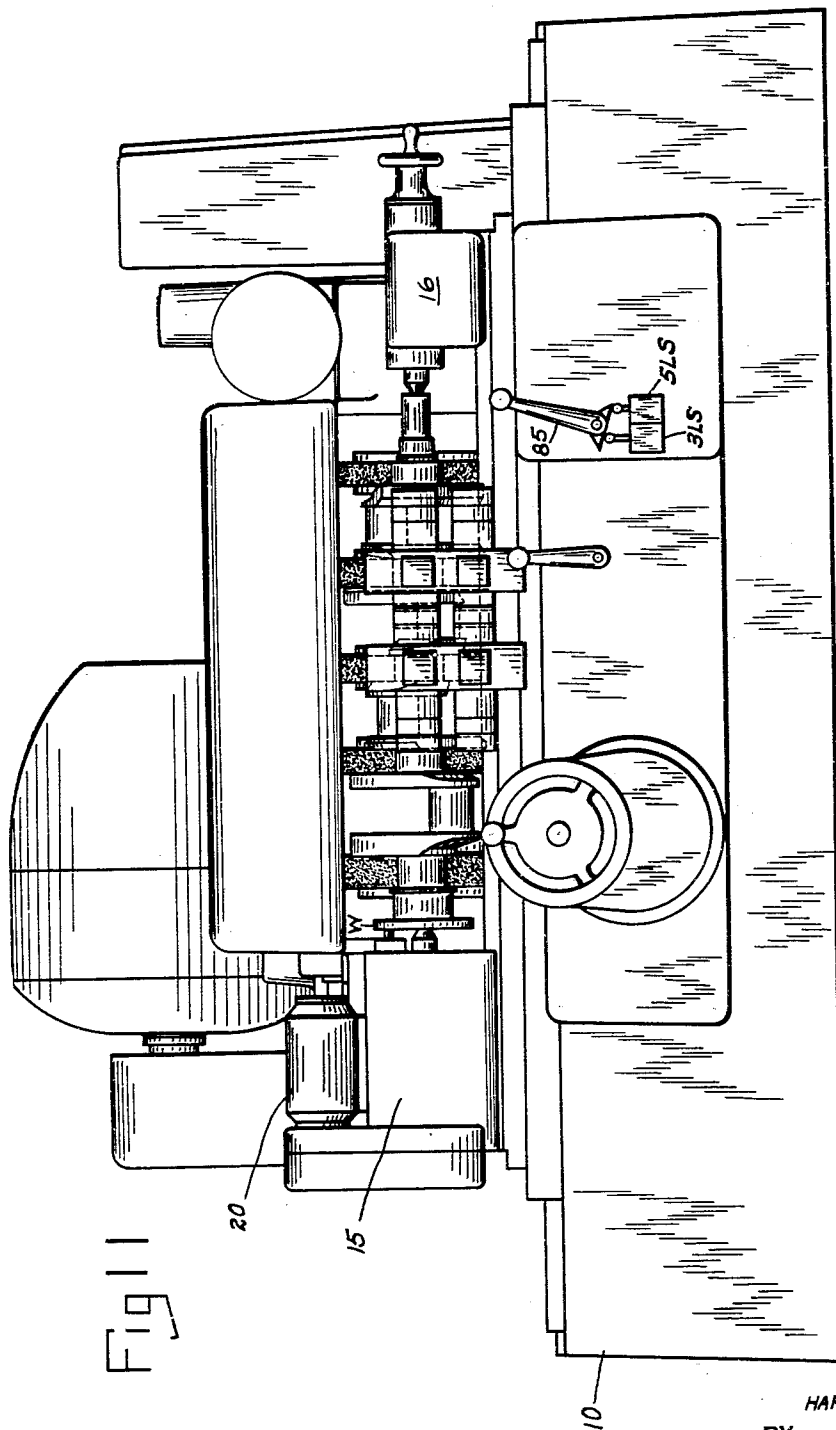
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APPARATUS FOR GRINDING FLEXIBLE WORKPIECES

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5 Sheets-Sheet 5



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3,153,884

APPARATUS FOR GRINDING FLEXIBLE WORKPIECES

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Filed Aug. 23, 1962, Ser. No. 219,013
10 Claims. (Cl. 51-165)

The present invention relates to grinding machines for grinding axially spaced portions of a workpiece, particularly where the workpiece is a crankshaft.

Because of the nature of the crankshaft, certain portions offer more resistance to the feeding thrust of the grinding wheel in one angular position than in another. Some bearings may require a different grinding procedure than others. This may be true whether the portion is a crankpin or a line bearing. For the purpose of illustrating, this invention is described in connection with the grinding of line bearings in both single and multiple wheel machines.

For example, the center main bearing is subject to variable deflection different from the end main bearing. Furthermore, the center main or thrust bearing is subject to greater deflection in one angular position than in another angular position 90° removed. When the grinding operation begins, the work is not supported by a work rest until the entire surface of the bearing has been subjected to the grinding operation.

During this portion of the grinding operation, because the bearing and shaft offer greater resistance to the grinding feed in one angular position, there will be a greater change in diameter of the bearing in this position and a lesser change in diameter of the bearing in the angular position in which the shaft offers less resistance to the grinding feed.

By the time the entire bearing surface has been touched by the grinding wheel, this variable thickness of the unsupported shaft results in a journal which is substantially elliptical in shape, but symmetrical with the axis of rotation of the shaft. At this point, according to the present invention, the grinding wheel is retracted and a work rest is applied to the bearing being ground. The wheel is again advanced, but slow down prior to engagement of the work occurs before the wheel advances far enough to engage the major radius of the elliptical-shaped portions of the workpiece. The grinding operation will then proceed at a grinding rate during which the wheel will grind *only* the points of major radius until they have been reduced to the same dimension as the minor radius. The feed may then be continued or reduced to a slower grinding rate which will continue to a point where a feed completion signal will either retract the grinding wheel, or advance the wheel in a suitable manner for a precision finishing or sizing operation. Thereafter, the grinding wheel is retracted either manually or by a timer or by a sizing device. On a crankshaft end bearing which is not affected as much by the variable stiffness of the shaft, a more or less conventional feed cycle is used.

Where crankshafts are made in large quantities, all the main bearings may be ground on a multiple wheel machine using a procedure similar to that described above in connection with the center main bearing. Whether the main bearings are ground one at a time or all at one time, it is important that they all rotate about the same axis which is the axis of rotation of the headstock when they have all been ground to the desired size. Otherwise, some or all of the bearings will move in an orbital path similar to that of a crankpin. This is accomplished in part by adjusting the rest or rests so that when the shoe is in advanced position, it is spaced from the axis of

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rotation of the headstock by an amount equal to the finished radius of the portion which it supports.

Each portion of the shaft will deflect to a different extent and the major diameter of the non-cylindrical contour of the bearings will occur at different angles and by different amounts. After the preliminary grinding operation, the multiple wheel support will be retracted and steady rests applied to one, two or more of the bearings being ground. When the wheels engage the various portions of the workpiece, they will grind only on the major diameters regardless of their angular relation to one another until said diameters have been reduced to the same dimension as the minor diameter after which stock removal will occur at substantially the same rate on all bearings until final size is reached.

It is, therefore, an object of the present invention to grind a bearing or bearings of a crankshaft not only round, but also concentric with its true axis which is also the axis of rotation of the crankshaft. True axis may be defined as the axis about which the bearing will rotate when not influenced by radial forces including gravity. The true axis is also the axis of rotation of the headstock spindle.

Another object is to provide means for grinding the portions of the workpiece of greater radius before contacting the portions of lesser radius until all portions have been reduced to the same dimension as the lesser radius at which time the workpiece is round and rotating about its true axis.

Another object is to provide means for retracting the grinding wheel and work rest after a preliminary grinding operation to apply a radial support to the workpiece and then advance said grinding wheel to complete the grinding operation.

Another object is to provide one type of feed cycle for grinding a bearing in one longitudinal position on a crankshaft and another type of feed cycle for grinding a bearing in another longitudinal position on said crankshaft.

Another object is to provide a feed cycle which will be applicable to the grinding of a single bearing or to the simultaneous grinding of a plurality of bearings having a common axis of rotation.

Another object is to provide feed control means which are determined by the longitudinal position of the work carriage.

Another object is to provide means whereby the longitudinal position of the work carriage determines the nature of the feed cycle on the portion of the workpiece which is in grinding position.

Another object is to provide means to co-ordinate the operation of the work rest, feed mechanism, and traverse mechanism in accordance with the requirements of a particular feed cycle.

Another object is to provide a machine having at least two automatic grinding cycles and means for selecting the grinding cycle for each portion of the workpiece.

FIG. 1 is a front elevation of a grinding machine arranged to grind the line bearings of a crankshaft.

FIG. 2 is a hydraulic circuit.

FIG. 3 is an electrical circuit.

FIG. 4 shows an unground center main bearing of a crankshaft about to be subjected to a preliminary grinding operation without a work rest.

FIG. 5 shows the workpiece after the preliminary grinding operation

FIG. 6 shows the workpiece supported by the work rest for the second approach of the grinding wheel.

FIG. 7 shows the workpiece with one portion of the major diameter after it has passed the grinding wheel.

FIG. 8 shows the workpiece still in process of reducing the major diameter.

FIG. 9 shows the workpiece with the major diameter reduced to the same dimension as the minor diameter.

FIG. 10 shows the workpiece reduced to final size.

FIG. 11 is a front elevation of a multiple wheel grinding machine.

Numerals 10 indicates the bed of a grinding machine. Work carriage 11 is slidably mounted on bed 10. Swivel table 12 is mounted on carriage 11. Workpiece W is rotatably supported on swivel table 12 by headstock 15 and footstock 16. Workpiece W is rotated by motor 20 operable through conventional driving means.

Grinding wheel 30 is rotatably mounted on grinding wheel support 31 which, in turn, is slidably mounted on bed 10. Wheel support 31 may be advanced and retracted manually with relation to workpiece W by means of hand wheel 40, hand wheel shaft 41, worm gear 42, worm wheel 43, shaft 44 and worm wheel 45 which engages feed screw 46. The relation between feed screw 46 and worm wheel 45 may be either that of a screw and nut or a rack and pinion. One end of feed screw 46 is slidably mounted in bed 10 and arranged to engage stop member 47. The other end of feed screw 46 is mounted in piston 50 which, in turn, is slidably supported in cylinder 51.

Tail rod 52 extends through the head end of cylinder 51 into a dash pot cylinder 55 and is connected to dash pot piston 56 by means of a conventional lost motion arrangement (not shown). Spring 57 in the lower portion of cylinder 55 serves to reset piston 56 at the end of a grinding cycle. Cylinder 55 is connected to a reservoir 131 by throttle valve 133 and check valve 134.

Cam ring 60 is mounted on shaft 41 to rotate with hand wheel 40. Cams A, B, C and D on cam ring 60 are arranged to actuate limit switches 6LS, 8LS, 17LS and 18LS as will be described later.

Power means for rotating shaft 41 for a rough grinding operation consists of pinion 70 on shaft 41 and rack 71 in engagement with pinion 70. Shaft 41 may be rotated in a clockwise direction by endwise movement of rack 71 from right to left. Rack 71 is connected to piston 72 in cylinder 73.

In order to permit rotation of hand wheel 40 without being limited by the rack and pinion, hand wheel 40 is connected to pinion 70 by means of a clutch arrangement as shown in co-pending application, Serial No. 211,937, filed July 16, 1962.

Operation

At the beginning of the cycle after starting the machine, the following circuits are closed:

Limit switch contact 2LS2 to energize relay 5CR.

For grinding the center main bearing or thrust bearing, limit switch contact 19LS1 is closed, completing a circuit to energize relay 8CR.

Normally closed relay contact 45CR1 completes a circuit to energize relay 39CR which is held through relay contact 39CR3 and feed slow down limit switch 17LS.

A circuit is completed through normally closed relay contacts 46CR2 and 10CR2 to energize work rest reset relay 11CR.

Limit switch contact 19LS1 is closed by cam 75 on carriage 11, when said carriage is in position to place the center main bearing in line with grinding wheel 30. Since this is the first operation, workpiece W is placed in the machine with carriage 11 in this position.

Footstock 16 is actuated manually to engage and support workpiece W. The movement of footstock 16 actuates footstock limit switch 7LS to complete a circuit to energize relay 6CR.

Relay contact 6CR1 closes to start work drive motor 20 when limit switch 2LS is closed by pressure from cylinder 51. Limit switch 2LS is shifted to the right by pressure from the head end of cylinder 51 on switch actuating piston 86 in cylinder 87.

Limit switch 2LS is shifted in the opposite direction

by a smaller piston 88 in cylinder 89 connected to the rod end of cylinder 51.

The feed movement is started by manually closing wheelbase limit switch 3LS by means of infeed lever 85 and relay contact 39CR1 to complete a circuit to energize fast feed relay 1CR. Relay contact 1CR2 is a holding contact in the circuit with previously closed relay contact 39CR2. Relay contact 1CR3 closes to energize fast feed solenoid 1.

Solenoid 1 shifts fast feed valve 90 to the right to direct fluid under pressure to throttle valve 91 and check valve 92 to the head end of fast feed cylinder 73. However, no fluid under pressure is available for cylinder 73 until rapid infeed pilot valve 80 is shifted to the right by pressure from port 93 of rapid feed cylinder 51 at the end of the rapid feed movement.

Relay contact 1CR1 completes a circuit which includes normally closed wheel support out limit switch 5LS and normally closed feed completion limit switch contact 6LS1 to energize infeed relay 2CR. Relay contact 2CR1 is a holding contact. Relay contact 2CR2 closes to energize infeed solenoid 2, shifting infeed pilot valve 80 to the right and directing fluid to the right hand end of infeed reversing valve 81 which, in turn, directs fluid under pressure through check valve 82 to the head end of rapid feed cylinder 51.

Rapid feed piston 50 advances wheel support 31 rapidly toward workpiece W until it picks up dash pot 54 to reduce the rapid feed rate for side wall grinding as determined by side wall throttle valve 133. Side wall grinding continues to a positive stop or stop member 47.

At the end of the rapid feed movement, port 93 in cylinder 51 is opened by piston 50 and fluid under pressure is directed to shift pilot valve 80 to the right. This movement of valve 80 directs fluid to shift reversing valve 81 to the right and also to continue on through check valve 82 to actuate pressure operated limit switch 2LS. Limit switch contact 2LS1 closes to energize relay 36CR. Limit switch contact 2LS2 opens to deenergize relay 5CR.

Relay contact 36CR1 closes to energize work drive motor relay 6MF and closes relay contact 6MF1 to start motor 20.

Relay contact 5CR1 opens in the circuit to dash pot relay 7CR which is not deenergized at this time because it is held by dash pot limit switch 16LS and relay contact 7CR1.

When reversing valve 81 is shifted to the right, it directs fluid under pressure from fast feed reset valve 83 through feed stop valve 84 to the head end of fast feed cylinder 73 as will be described.

Advancing wheel support 31 also closes wheel support "in" limit switch 3LS to complete a circuit through relay contact 39CR1 to energize fast feed relay 1CR. Relay contact 1CR1 closes in the circuit to infeed relay 2CR. Relay contact 1CR2 closes in the circuit with relay contact 39CR2 to hold relay 1CR. Relay contact 1CR3 closes to energize fast feed solenoid 1.

When stop member 47 is reached, pressure from the head end of rapid feed cylinder 51 is applied to the pilot valve 80 which directs fluid under pressure from fast feed reset valve 83 through feed stop valve 84 to fast feed valve 90 which is held in right hand position by previously energized fast feed solenoid 1 and directs fluid through fast feed throttle valve 91 to the head end of fast feed cylinder 73 to resume the advance of wheel support 31 by means of fast feed piston 72 for a rough grinding operation.

Piston 72 operates through a feed hand wheel mechanism until the #1 feed slow down limit switch 17LS is actuated by cam A on hand wheel shaft 41. FIG. 4 shows the workpiece W before the preliminary grinding operation. Limit switch 17LS opens the circuit through relay holding contact 39CR3 to deenergize relay 39CR.

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Relay contact 39CR1 opens to deenergize fast feed relay 1CR and fast feed solenoid 1. Valve 90 returns to left hand position, directing fluid under pressure through slow feed throttle valve 96 and check valve 97 to reduce the rate of movement of fast feed piston 72.

The feed continues at this reduced rate until cam C on shaft 41 actuates feed stop limit switch 18LS which closes to complete a circuit which includes relay contact 45CR2, normally closed relay contact 43CR2, and relay contact 8CR1, to energize feed stop relay 40CR. Relay contact 40CR1 provides a holding circuit around relay contact 8CR1 and limit switch 18LS. Relay contact 40CR2 closes to complete a circuit through relay contact 8CR2 to energize timer clutch relay 1TR.

After a round out period, during which the grinding operation continues without any feed movement, relay contact 1TR1 closes to energize relay 41CR and slow feed reset timer relay 6TR.

Relay contact 40CR3 closes to energize feed stop solenoid 20.

Feed stop valve 84 is shifted to the right to cut off the supply of fluid to cylinder 73.

Relay contact 41CR1 closes in the circuit which includes normally closed relay contact 6TR1 to energize slow feed reset relay 42CR. Relay contact 42CR2 closes to energize fast feed reset solenoid 19.

Fast feed reset valve 83 is shifted to the right to direct fluid under pressure to the rod end of cylinder 73, returning piston 72 to starting position and retracting grinding wheel 30 to the position from which fast feed starts.

During this portion of the feed cycle, workpiece W has not been supported by work rest 100 and the work has been permitted to deflect under the force of the grinding wheel feed. Because of the variable stiffness and consequent variable deflections, workpiece W at this point is elliptical in shape as shown in FIG. 5 and is still several thousandths oversize on the minor diameter.

When timer relay 6TR times out, normally closed relay contact 6TR1 opens to deenergize slow feed reset relay 42CR. Relay contact 6TR2 closes in a circuit with previously closed relay contact 41CR2 to energize relay 43CR. Relay contact 43CR3 closes in a holding circuit which includes relay contact 45CR3. Relay contact 43CR4 closes to energize relay 46CR. Relay contact 46CR1 is a holding contact. Normally closed relay contact 45CR2 opens to deenergize work rest reset relay 11CR. Relay contact 11CR2 opens to deenergize work rest reset solenoid 5. The work rest is similar in construction to that shown in co-pending application, Serial No. 192,205, filed May 3, 1962.

Work rest reset valve 110 returns to central position, shutting off the passage of fluid through the right hand end of said valve to work rest cylinder 111 which holds work rest 100 in reset position against wedge 112 actuating springs 115. Instead, the fluid under pressure bypasses valve 110 and is directed to cylinder 111 at a lower pressure determined by relief valve 113 in the bypass. The pressure of the fluid exerted on work rest piston 114 is less than that exerted by springs 115 in the opposite direction. Work rest 100 is fully advanced and the work deflected to a position where work rest 100 is spaced from the center of rotation, a distance equal to the radius of a finished workpiece as shown in FIG. 6.

When slow feed reset relay 42CR was energized, relay contact 42CR1 completed a circuit to energize relay 44CR. Relay contact 44CR2 is a holding contact.

As soon as relay 43CR is energized at the end of the slow feed reset period, relay contacts 43CR1 and 44CR1 close to complete a circuit to fast feed relay 1CR, energizing solenoid 1 and shifting fast feed valve 90 to the right, directing fluid under pressure through throttle valve 91 to the head end of cylinder 73.

Grinding wheel 30 advances at fast feed until it reaches a point spaced from work rest 100 slightly more than

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the major diameter of the elliptical workpiece W as shown in FIG. 6. At this point, the #2 feed slow down limit switch 8LS is opened to deenergize relay 44CR. Relay contact 44CR1 opens to deenergize fast feed relay 1CR, deenergizing solenoid 1.

Fast feed valve 90 returns to the left end position to reduce the feed rate for the remainder of the grinding operation. During this period, the major diameter is gradually reduced until it is the same dimension as the minor diameter as shown in FIG. 9 at which point the work is round and still oversize.

Also during this period, limit switches 17LS and 18LS are actuated by their respective cams, but perform no function.

Limit switch 17LS is rendered inactive as follows:

Relay 39CR is energized from the beginning through normally closed relay contact 45CR1 and held through limit switch 17LS and relay contact 39CR3.

Rapid feed energizes relay 45CR, opening normally closed relay contact 45CR1 so that when limit switch 17LS opens to deenergize relay 39CR, said relay 39CR cannot be energized again until feed completion deenergizes relay 45CR, closing normally closed relay contact 45CR1 in relay 39CR circuit.

Limit switch 17LS is thus inactive during the second advance of fast feed.

Limit switch 18LS is rendered inactive as follows:

The circuit to feed stop relay 40CR includes normally closed relay contact 43CR2 of relay 43CR.

Relay 43CR is energized by timer relay contact 6TR2 and held by relay contacts 45CR3 and 43CR3.

When timer relay 6TR times out, it energizes relay 43CR, opening normally closed relay contact 43CR2 in the circuit to feed stop relay 40CR.

Relay 43CR is held by relay contact 45CR3 and relay contact 43CR3, but cannot be deenergized until feed is completed when relay 45CR is deenergized along with infeed relay 2CR by opening limit switch contact 6LS1.

Thus, on the second advance of piston 72, limit switch 18LS is actuated by one of the cams on shaft 41, but with normally closed relay contact 43CR2 open, closing limit switch 18LS does not complete the circuit to stop fast feed. Therefore, fast feed continues until feed completion limit switch 6LS is opened by cam B on shaft 41 and both rapid feed and fast feed are retracted.

After the major diameter has been reduced to the same dimension as the minor diameter, the feed movement continues until cam B on shaft 41 actuates feed completion limit switch 6LS. Limit switch 6LS may be used to start a precision feed, or in this case, stop the grinding operation at the required work diameter. Limit switch contact 6LS1 opens to deenergize infeed relay 2CR. Limit switch contact 6LS2 closes to energize relay 9CR.

Relay contact 9CR1 closes to complete a circuit through previously closed relay contact 11CR1 to energize work rest low pressure release relay 10CR, closing relay contact 10CR3 to energize work rest low pressure solenoid 4. Relay contact 10CR1 is a holding contact.

Work rest reset valve 110 is shifted to the right connecting cylinder 111 with exhaust and the full pressure of springs 115 is applied to work rest 100.

When relay 10CR is energized to energize solenoid 4, normally closed relay contact 10CR2 opens to deenergize relay 11CR and solenoid 5.

At the same time, relay contact 2CR2 opens to deenergize infeed solenoid 2.

Infeed pilot valve 120 is shifted to the left to direct fluid to the left hand end of reversing valve 121 which directs fluid to the rod end of cylinder 51 to retract piston 50 and wheel support 31.

After the center main bearing has been ground to size and grinding wheel 30 retracted, work rest 100 remains in engagement with said bearing until the end bearings are ground. This is accomplished by preventing energization of work rest reset relay 11CR and solenoid 5.

The circuit to relay 11CR includes normally closed relay contact 46CR2. Relay 46CR was originally energized by relay contact 43CR4 and held through a circuit having relay contacts 6CR2 and 46CR1.

So long as relay 46CR remains energized, normally closed relay contact 46CR2 in the work rest reset circuit will remain open and work rest 100 will remain in engagement with the center main bearing for the grinding of the end bearings.

Work rest 100 will not reset until footstock 16 has been retracted to release workpiece W when footstock limit switch 7LS will open to deenergize relay 6CR.

Relay contact 6CR2 in the holding circuit to relay 46CR will open to deenergize relay 46CR.

Relay contact 46CR2 will then close, energizing work rest reset relay 11CR and solenoid 5 to retract work rest 100 to inoperative position.

Carriage 11 is then traversed to place the end bearings in line with grinding wheel 30. In either of these positions of carriage 11, thrust grind limit switch 19LS is not actuated. Limit switch contact 19LS1 is open and limit switch contact 19LS2 is closed.

Rapid feed is initiated in the same manner as described above. However, dash pot rate control valve 130 operates in a different manner than for the #4 bearing. Limit switch contact 19LS2 completes a circuit through previously closed relay contact 5CR1 to energize dash pot relay 7CR. Relay contact 7CR2 completes a circuit to energize dash pot solenoid 3.

Dash pot rate control valve 130 is shifted to the right and fluid discharged from cylinder 55 may pass through valve 130 to the throttle valve 132 which by-passes side wall throttle valve 133 and permits a more rapid advance of wheel support 31 until the lower side walls of the end bearing is reached when solenoid 3 is deenergized.

As wheel support 31 advances, limit switch 16LS is opened by cam 140 on wheel support 31 to deenergize relay 7CR and solenoid 3.

Valve 130 then moves to the left, blocking the passage of dash pot fluid to the valve 132 and leaving the side wall throttle valve 133 to control the discharge from dash pot 54 to reduce the rapid feed movement to a feed rate suitable for grinding the lower side walls.

The side wall grinding continues until stop member 47 is reached and infeed pilot valve 80 is shifted to direct fluid under pressure to the head end of fast feed cylinder 73.

During the operation of the fast feed on either of the end bearings, limit switch 8LS is opened by cam D on shaft 41. The function normally performed by the opening of limit switch 8LS is deenergization of relay 44CR and the slowing down of fast feed. However, relay 44CR has already been deenergized because of carriage 11 being in position to grind one or the other of the end bearings in one position.

Limit switch contact 19LS1 is opened in the circuit to relay 8CR which is, therefore, deenergized. Normally open contacts of relay 8CR which are necessary to energize relay 44CR thus prevent relay 44CR from being energized.

When limit switch 8LS is rendered inactive, the fast feed movement continues at the same rate until feed completion limit switch 6LS is opened, either to deenergize infeed relay 2CR and retract grinding wheel 30, or to actuate through a circuit (not shown) to initiate a precision finishing feed.

Rotation of the manual feed mechanism by piston 72 in cylinder 73 continues until cam B on shaft 41 actuates limit switch contact 6LS1 to open the circuit to infeed relay 2CR and deenergizing infeed solenoid 2 to retract wheel support 31 through piston 72 and cylinder 73, and at the same time, to retract piston 72 and associated feed mechanism in preparation for the grinding of another workpiece W.

Resetting piston 72 must be accomplished at different

times under different conditions. At the end of the preliminary grinding operation on the center main bearing, fast feed reset solenoid 19 is energized to shift fast feed reset valve 83 to direct machine pressure to the rod end of cylinder 73. Exhaust from the head end of cylinder 73 may return through check valve 78 to reset valve 83 which is in a position to direct said exhaust fluid through reversing valve 121 which is in the right hand position and will direct said fluid to the main exhaust passage.

At other times, when solenoid 19 is deenergized, valve 121 which directs fluid under pressure to the rod end of cylinder 51 also directs fluid through valve 83 in the left hand position, and connects the conduit leading from reversing valve 121 with line 94 to the rod end of cylinder 73. When reset in this manner, the exhaust from the head end of cylinder 73 may not return through check valve 78 to valve 73 because said valve is in position to direct machine pressure against check valve 78. The exhaust fluid must, therefore, be directed through check valve 79 to reversing valve 121 which is in the right hand or reset position and directs exhaust fluid from check valve 79 to the main exhaust line.

When reversing valve 121 is in left hand position, check valve 79 prevents fluid under pressure from reaching the right hand end of fast feed cylinder 73 uncontrolled instead of through fast feed valve 90.

When footstock 16 is retracted after grinding the two end bearings, to remove workpiece W from the machine, limit switch 7LS is opened to deenergize relay 6CR. Relay contact 6CR2 opens in the holding circuit to deenergize relay 46CR.

Normally closed relay contact 46CR2 closes to energize work rest reset relay 11CR and solenoid 5.

Normally closed relay contact 11CR1 opens in the circuit to work rest low pressure release relay 10CR, deenergizing solenoid 4.

Work rest reset valve 110 moves to the left, connecting cylinder 111 with full pump pressure, resetting wedge 112 against springs 115 to permit retraction of work rest 100.

When it is desired to traverse carriage 11 from the position for grinding the center main bearing to a position for grinding either of the end bearings, traverse control lever 135 is shifted to actuate limit switch 9LS in a circuit which includes limit switch 15LS which is closed only when wheel support 31 is in retracted position where grinding wheel 30 will not interfere with the traverse movement.

Traverse start relay 22CR is energized and relay contact 22CR1 closes to energize traverse start solenoid 11. Traverse start valve 141 is shifted to the right to direct fluid under pressure to shift pressure operated traverse start valve 142 to direct fluid under pressure to traverse reversing valve 143 from which said fluid is directed alternately to opposite ends of traverse cylinder 144 to shift carriage 11.

I claim:

1. In a grinding machine for grinding axially spaced portions of a workpiece in which the stiffness of the workpiece varies from portion to portion, a bed, a grinding wheel support slidably mounted on said bed, a grinding wheel rotatably mounted on said wheel support, a work carriage slidably mounted on said bed, means on said work carriage for rotatably supporting a workpiece, means for effecting relative transverse and longitudinal movements of said wheel support and said work carriage, a plurality of limit switches adapted to be actuated by said transverse moving means, a limit switch on said bed, and means on said work carriage for actuating said bed mounted limit switch, said bed mounted limit switch being operable to render certain of said first mentioned limit switches active to control said transverse moving means, said bed mounted limit switch being operable in another position of said work carriage to render others of said

first mentioned limit switches active to control said transverse moving means.

2. In a grinding machine for grinding axially spaced portions of a workpiece in which the stiffness of the workpiece varies from portion to portion, and in a given portion, from one angular position to another, a bed, a grinding wheel support on said bed, a grinding wheel on said wheel support, a work carriage on said bed, means for effecting relative transverse and longitudinal movements of said wheel support and said work carriage, a limit switch on said bed corresponding to one of said axially spaced portions of the workpiece and adapted to be actuated when said work carriage places that particular portion of the workpiece opposite said grinding wheel to initiate a feed cycle different from that used on other portions of said workpiece.

3. In a grinding machine for grinding axially spaced portions of a workpiece in which the stiffness of the workpiece varies from portion to portion, a bed, a grinding wheel support on said bed, a grinding wheel rotatably mounted on said wheel support, a work carriage on said bed, means for effecting relative transverse and longitudinal movements of said work carriage, a plurality of limit switches adapted to be actuated by said transverse moving means, a limit switch on said bed corresponding to one of said axially spaced portions of a workpiece, said bed mounted limit switch being operable when the corresponding portion of the workpiece is in grinding position to co-act with one or more of the limit switches actuated by said transverse moving means to control a grinding feed cycle adapted to the requirements of the portion of the workpiece to be ground.

4. In a grinding machine for grinding axially spaced portions of a workpiece in which the stiffness of the workpiece varies from portion to portion, and in a given portion, from one angular position to another, a bed, a grinding wheel support on said bed, a grinding wheel rotatably mounted on said wheel support, a work carriage on said bed, means for effecting relative transverse and longitudinal movements of said wheel support and said work carriage, a limit switch on said bed corresponding to one of said axially spaced portions of the workpiece, means on said work carriage for actuating said limit switch when said work carriage places that particular portion of the workpiece opposite said grinding wheel to initiate a feed cycle peculiar to that portion of said workpiece, comprising feed means for advancing and retracting said wheel support, a plurality of limit switches arranged adjacent said feed means, and a plurality of cams movable with said feed means for successively actuating certain of said limit switches to control the operation of said feed means.

5. In a grinding machine for grinding axially spaced portions of a workpiece in which the stiffness of a workpiece in a given portion varies from one angular position to another, a bed, a grinding wheel support movable on said bed, a grinding wheel on said wheel support, means on said bed for rotatably supporting a workpiece, means for moving said work support longitudinally on said bed, means for effecting a feeding movement of said wheel support toward and from said work support, a limit switch, means on said work support corresponding to one of said axially spaced portions of the workpiece for actuating said limit switch, means responsive to said limit switch when said work carriage places a particular portion of the workpiece opposite said grinding wheel to advance said grinding wheel for a preliminary grinding operation during which said workpiece is deflected by a different amount in different angular positions with a resultant elliptical or other non-cylindrical contour, control means to retract said grinding wheel after a predetermined advance, a work rest movable into and out of operative relation with said workpiece, means to repeat said feed movement with said work rest holding said workpiece in a predetermined position, control means operable before said wheel advances far enough to engage the major

radius of the workpiece, to reduce the rate of said feed and then to gradually reduce the major radius of the workpiece by grinding to the same dimension as the minor radius of the workpiece to provide a work surface concentric with the true axis of the workpiece, and control means operable when said round workpiece has been ground to the desired size for retracting said grinding wheel.

6. In a grinding machine for grinding axially spaced portions of a workpiece in which the stiffness of a workpiece in a given portion varies from one angular position to another, a bed, a grinding wheel support movable on said bed, a grinding wheel rotatably mounted on said wheel support, means on said bed for rotatably supporting a workpiece, means for moving said work support longitudinally on said bed, means for effecting a feeding movement of said wheel support toward and from said work support, a limit switch, means on said work support corresponding to one of said axially spaced portions of the workpiece for actuating said limit switch, means responsive to said limit switch when said work carriage places a particular portion of the workpiece opposite said grinding wheel to advance said grinding wheel for a preliminary grinding operation during which said workpiece is deflected by a different amount in different angular positions with a resultant elliptical or other non-cylindrical contour, control means to retract said grinding wheel after a predetermined advance, a work rest movable into and out of operative relation with said workpiece, means to repeat said feed movement with said work rest spaced from the axis of rotation of said workpiece a distance equal to the radius of the finished workpiece and holding said workpiece in a predetermined position, control means operable before said grinding wheel advances far enough to engage the major radius of the workpiece, to reduce the rate of said feed and then to gradually reduce the major radius of the workpiece by grinding to the same dimension as the minor radius of the workpiece to provide a work surface concentric with the true axis of the workpiece, and control means operable when said round workpiece has been ground to the desired size for retracting said grinding wheel.

7. In a grinding machine for grinding axially spaced portions of a workpiece, a bed, a grinding wheel support on said bed, a grinding wheel rotatably mounted on said wheel support, a work carriage on said bed, means for effecting relative transverse and longitudinal movements of said wheel support and said work carriage, feed means for advancing said wheel support for a preliminary grinding operation, a pair of limit switches operated sequentially by said feed means for controlling said preliminary grinding operation, one of said limit switches being operable to retract said feed means, means to again advance said feed means, a second pair of limit switches sequentially operable to control said second feed movement, and means for making one of said second pair of limit switches inactive when said work carriage is in another longitudinal position.

8. In a grinding machine for grinding axially spaced portions of a workpiece in which the stiffness of the workpiece varies in a given portion from one angular position to another, a bed, a grinding wheel support movable on said bed, a grinding wheel rotatably mounted on said wheel support, a work support on said bed, means for feeding said wheel support to effect a preliminary grinding operation on one of said portions, means to retract said grinding wheel when it has advanced to a predetermined position, means to again actuate said feeding means to feed said grinding wheel to a less advanced position than for said preliminary grinding operation, means to advance a work rest to engage and support a workpiece in position to rotate about its true axis, and means to retract said grinding wheel after it has advanced to another predetermined position.

9. In a grinding machine for grinding axially spaced

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portions of a workpiece in which the stiffness of the workpiece varies from portion to portion and in a given portion, from one angular position to another, a bed, a work support on said bed, means for rotatably supporting a workpiece on said work support, a grinding wheel support 5 slidably mounted on said bed for movement toward and from said work support, one or more grinding wheels rotatably mounted on said wheel support, means for feeding said wheel support toward and from said work support to effect a preliminary grinding operation on one or more 10 of said portions, the resulting contours of said portions being such that each has a minor and a major diameter, means to retract said wheel support when it has advanced to a predetermined position, work rests for one or more 15 selected portions of a workpiece, and means operable while said wheel support is retracted to advance each of said work rests to engage and support each portion of a workpiece in a position to rotate about its true axis, means to again feed said wheel support to a position to conform 20 to the major diameter of the workpiece, means to continue the feeding movement of said wheel support to gradually reduce the major diameter of each portion of a workpiece until it has the same dimension as the minor diameter, and means to retract said wheel support after all portions 25 of said workpiece have been ground to the desired diameter.

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10. In a grinding machine for grinding a workpiece in which the stiffness of the workpiece varies in a given portion from one angular position to another, a bed, a grinding wheel support movable on said bed, a grinding wheel rotatably mounted on said wheel support, a work support on said bed, means for feeding said wheel support to effect a preliminary grinding operation on said workpiece, means to retract said grinding wheel when it has advanced to a predetermined position, means to again actuate said feeding means to feed said grinding wheel to a less advanced position than for said preliminary grinding operation, means to advance a work rest to engage and support a workpiece in position to rotate about its true axis, and means to retract said grinding wheel after it has advanced to another predetermined position.

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