

[54] **SURFACE GRINDING DEVICE**

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[58] Field of Search **51/144, 145 R, 145 T, 135 BT, 51/216, 216 T, 237, 328**

[56] **References Cited**

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[57] **ABSTRACT**

A method of and an apparatus for grinding a planar surface on a workpiece when the workpiece is pressed against an abrasive belt moving in an arcuate path. The workpiece is held by the apparatus with the plane at which the planar surface is to be formed oriented generally parallel to the axis of the arcuate path of the abrasive belt, and is moved about an axis normal to and intersecting the axis of the arcuate path while it is pressed into high pressure grinding contact with the abrasive belt to move the workpiece toward the abrasive belt in a direction normal to the axis of the path of the abrasive belt. When the plane at which the planar surface to be formed is tangent to the abrasive belt, the movement of the workpiece toward the belt is halted so that the desired planar surface is formed on the workpiece.

13 Claims, 2 Drawing Figures

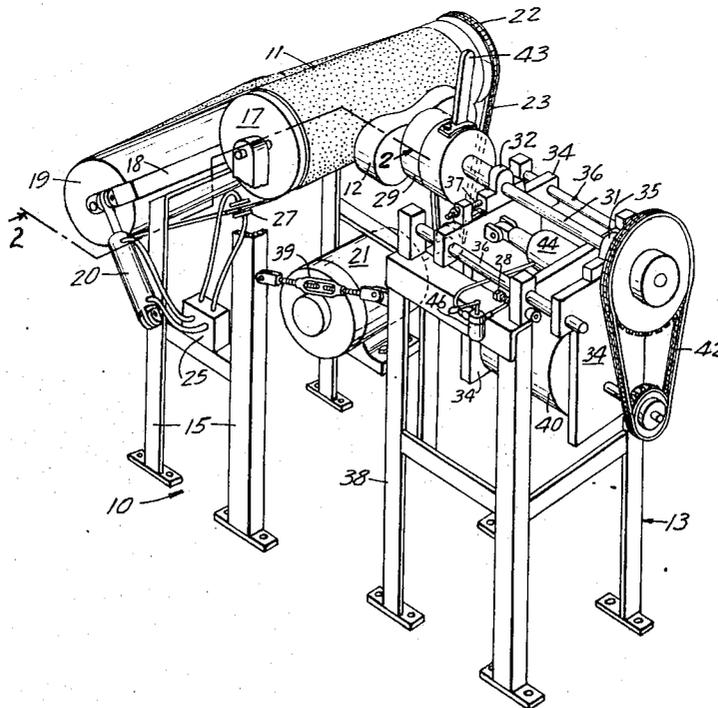


FIG. 1

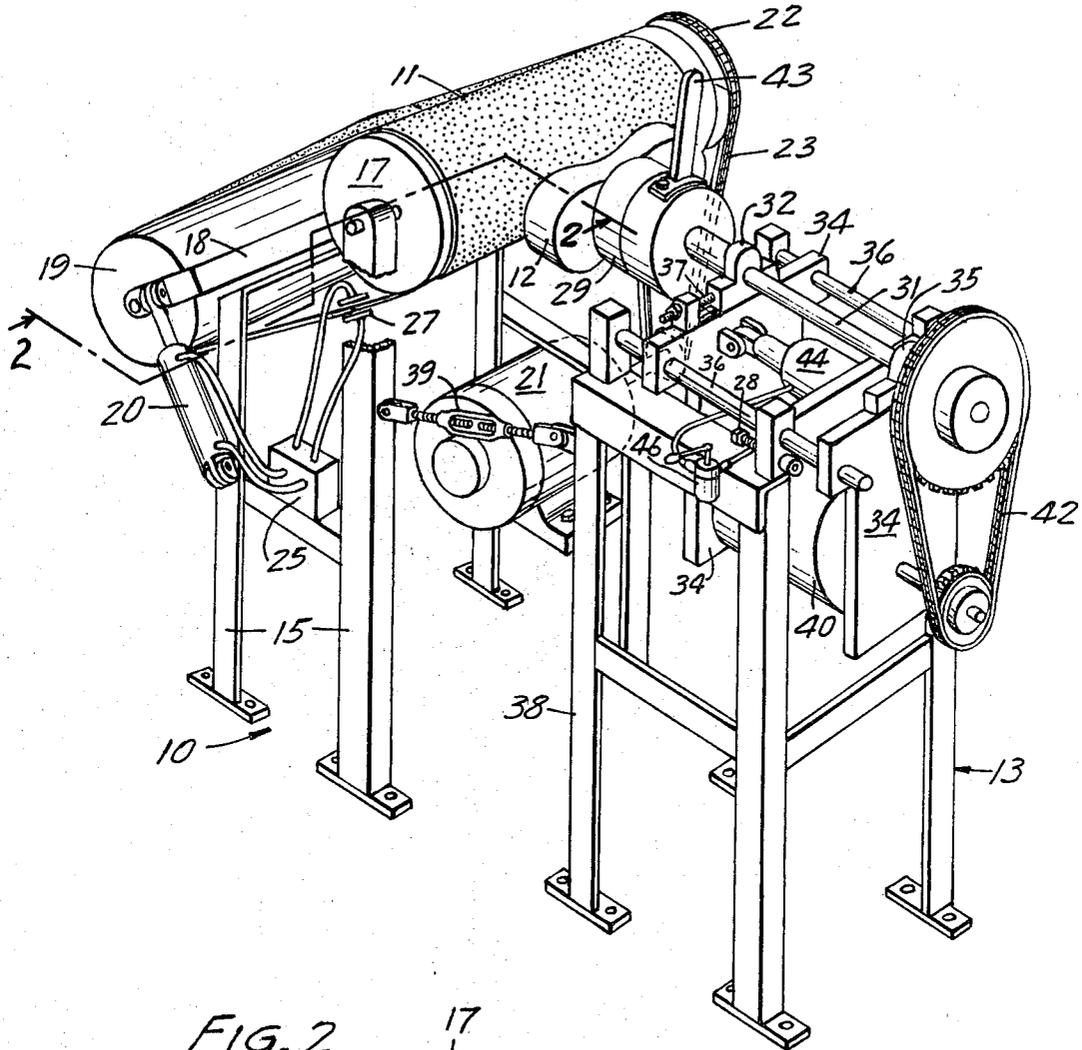
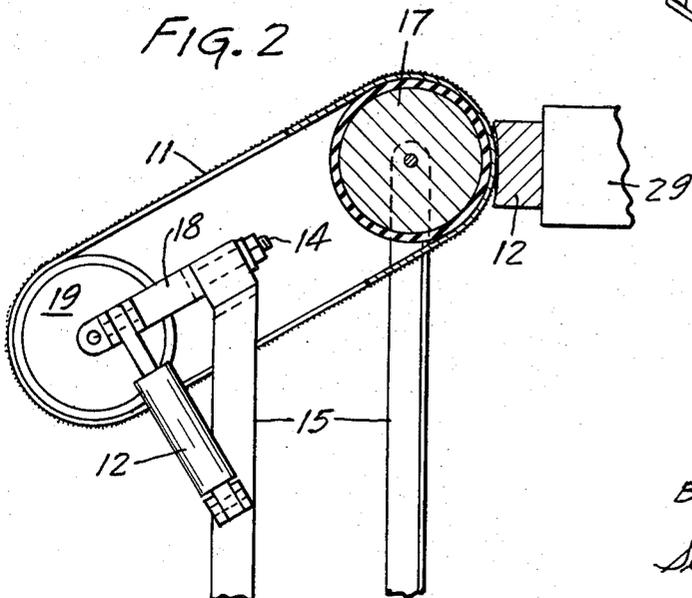


FIG. 2



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SURFACE GRINDING DEVICE

This invention relates to a method and an apparatus for grinding and in one aspect to belt grinding a planar surface on a workpiece such as a casting.

The operation of forming or cleaning a surface, as on a casting, is commonly done by abrading, either through the use of a bonded grinding wheel or the use of an abrasive belt machine. U.S. Pat. No. 3,369,328 discloses a machine for delivering a large and infinitely adjustable force to press a workpiece against an abrading means. Other patents, such as U.S. Pat. No. 2,425,234, and U.S. Pat. No. 2,621,449, demonstrate mechanical manipulation of either an abrading means or of a workpiece relative to the other to form a desired shape on a workpiece. There is no known prior art disclosing an apparatus which rotates a workpiece about an axis normal to a plane at which a planar surface is desired while pressing the workpiece into high pressure grinding contact with an abrasive belt driven in an arcuate path to remove material down to said plane to form a highly accurate planar surface on the workpiece. Such a device is disclosed in the present application.

Heretofore, the grinding of accurate planar surfaces, on hard metal workpieces, and the removal of considerable amounts of metal from hard metal workpieces, has been accomplished by a milling operation or by abrading on a surface grinding machine utilizing a bonded abrasive wheel. The use of abrasive belts and normal grinding pressure has not had wide commercial acceptance for such tasks. The amount of metal removed by abrasive belts used at normal grinding pressure is relatively low due to a rapid decline in cutting rate caused by damage from frictional heat developed during the grinding process. Thus, the use of abrasive belt grinding has been generally uneconomical for the forming of highly accurate planar surfaces on metal parts.

Disclosed in the aforementioned U.S. Pat. No. 3,369,328 is a method of high pressure grinding against an abrasive belt which greatly increases the rate of metal removal by pressing the abrasive granules into efficient grinding contact with the surface being ground. With high pressure grinding above a predetermined minimum pressure metal is removed so swiftly that a large percentage of the heat generated is removed with the chips. This results in a temperature rise of a workpiece which is greatly reduced as compared with the temperature rise of the workpiece when it is ground at pressures below the predetermined minimum pressure, so that damage to the part and to the abrasive belt is minimized.

While the power and workpiece feeding force required to grind small areas with high pressure grinding methods are readily available, the forming of a large surface by high pressure grinding requires belt driving horsepower and a force to feed the workpiece which are beyond the capabilities normally available in grinding machinery.

Accurate planar grinding even at normal grinding pressures requires that an abrasive belt be supported. Such support is typically supplied in existing abrasive belt grinding machines by a flat stationary platen. When the entire surface of a workpiece to be ground is pressed against a stationary platen, problems with clearance of chips through the long grinding path and heat buildup on and wear of the platen resulting in dimensional inaccuracies are experienced. These problems are amplified with the addition of high grinding pressure.

The apparatus of the present invention makes high pressure grinding feasible for forming an accurate planar surface of relatively large area on a workpiece. Since in the present invention the abrasive belt is supported by a rotating roller in the area in which it contacts the workpiece, the problems involved in moving an abrasive belt over a stationary platen are eliminated. The area of grinding contact at any one time between the rotating material being processed, (i.e., workpiece or pieces on a rotating chuck) and the abrasive belt on the arcuate periphery of its supporting roller is a narrow band. Since this band is only a small percentage of the total area of the planar face to be formed, the power required to grind this band is relatively low and the pressure on the band of grinding

can be maintained at the required high pressure for efficient abrasive belt grinding with a relatively small force against the workpiece. Because the band of grinding or surface area of the workpiece contacting the abrasive belt is narrow and the belt is directed away from this band, the problem of swarf clearance from the band is minimized. Additionally, this belt path and narrow band of grinding facilitates introducing a coolant to the entire band of grinding and since the position of the band of grinding on the workpiece is continuously changing as the workpiece rotates, the potential for heat buildup on the surface from which metal is being removed is restricted.

The accuracies of surfaces ground by the apparatus disclosed have been surprisingly good. For generally circular castings with radii exceeding 4 inches, a variation of less than 0.001 inch between the high and low areas on the plane formed has been consistently achieved.

The grind or scratch pattern left on the surface formed by the apparatus of the present invention is circular. This circular pattern can be an advantage when the surface to be formed comprises a mating surface such as a flange. Closed circular grinding marks will be left on a continuous portion of the surface to be formed which is located generally at an equal distance from the axis about which the workpiece is rotated. These marks tend to seal mating metal surfaces and provide an ideal gripping surface for gaskets which may be used between mating surfaces.

The apparatus of the present invention provides a method of grinding a planar surface on a workpiece through use of an abrasive belt having a given width between its spaced edges which comprises the steps of: driving the abrasive belt along an arcuate path having an axis; holding a workpiece with the plane at which the planar surface is to be formed oriented essentially parallel to the axis of the arcuate path about which the abrasive belt is driven; rotating the workpiece about an axis positioned between the edges of the abrasive belt, which axis is normal to and intersects the axis of the arcuate path; pressing the workpiece into grinding contact with the abrasive belt to move the workpiece toward the abrasive belt with a contact area pressure of not less than about 300 pounds per square inch in a direction normal to the axis of the arcuate path; and stopping the movement of a workpiece toward the abrasive belt when the desired plane is tangent to the abrasive belt on the arcuate path so that a planar surface will be formed upon further rotation of the workpiece.

The invention will be further described with reference to the accompanying drawing, wherein like numbers refer to like parts in the several views, and wherein:

FIG. 1 is a view in perspective, partly in section, of an apparatus according to the present invention; and

FIG. 2 is a fragmentary verticle sectional view taken approximately along the line 2—2 of FIG. 1.

Referring now to FIGS. 1 and 2, the apparatus for grinding a planar surface on a workpiece is comprised of two assemblies. A first assembly 10 is an apparatus or means for driving an abrasive belt 11 in an arcuate path and a second assembly 13 is connected to and positioned relative to said first assembly for holding, rotating, and pressing a workpiece 12 into grinding contact with the abrasive belt 11 on the arcuate path to form the aforementioned planar surface.

The first assembly 10 comprises a frame 15 on which is journaled a front roller 17. A yoke 18 journals a rear roller 19. The yoke 18 has at its center a shaft 14 which is journaled on the frame 15. The axis of the shaft 14 is positioned at right angles to and intersects the axes of the rollers 17 and 19. Thus by pivoting the yoke 18 the roller 19 is moved in a plane which forms a right angle with a plane through the axis of the rollers 17 and 19 when the axes of rollers 17 and 19 are parallel. The position of the yoke 18 with respect to the frame 15 and thus the axis of the roller 19 with respect to the axis of roller 17 is determined by a hydraulic cylinder 20 operably attached between the yoke 18 and the frame 15 to afford a steering mechanism for the belt as will hereinafter be explained. Between the rollers 17 and 19, the endless abrasive belt 11 is

tensioned. A force to drive the abrasive belt 11 around the rollers 17 and 19 is provided by a motor 21 which drives a pulley or sprocket 22 attached to roller 17 through a belt or chain 23. The roller 17 drives the belt 11 by frictional contact. The peripheral segment of the front roller 17 in contact with the belt 11 forms an arcuate path for the belt 11 and supports the belt 11 in the arcuate path while the grinding is performed. The surface of the front roller 17 is made of a hard rubber material of about 65 Shore "D" durometer to provide a firm, slightly compressible support for the abrasive belt 11 which will provide resilience to minimize fracturing of individual abrasive grains between the workpiece 12 and the roller 17.

The belt steering mechanism on the first assembly 10 provides means for reciprocating the abrasive belt 11 back and forth along the axis of the roller 17. These belt-reciprocating means are provided to widen and vary the contact path of the abrasive belt 11 with the workpiece 12 during the grinding process, thereby maximizing the dimensional accuracy of surfaces formed by the abrasive belt 11 over the usable life of the abrasive belt 11 by compensating for any slight variance in thickness of the abrasive belt 11 caused by belt wear or inherent in the belt 11. The reciprocation also evens belt wear for a given amount of grinding, by distributing the grinding load across the full width of the belt 11 rather than in a path more narrow than the belt width.

To provide reciprocation of the moving abrasive belt 11, the hydraulic cylinder 20 is operably connected to alternatively extend and retract its piston, thereby moving the roller 19 in the previously mentioned plane. When the roller 19 is pivoted about the shaft 14 so that the axes of the rollers 17 and 19 are no longer parallel, the belt 11 will be moved axially with respect to roller 17 in a direction dependent upon the direction in which the yoke 18 is pivoted. Thus, operating the cylinder 20 to alternate the position of the yoke 18 and roller 19 with the proper timing will cause the belt 11 to reciprocate axially on the rollers 17 and 19.

A pneumatically operated switching system 25 is provided for properly operating the cylinder 20 to cause reciprocation of the moving abrasive belt 11 between limits determined by signals from a pair of air operated limit switches 27 (only one of which is shown). The switches 27 sense a pressure differential across a gap when an object passes into it, and are located along opposite edges of the belt 11. As previously explained, with the piston of cylinder 20 either retracted or extended, the belt 11 will move axially along the rollers 17 and 19. When the leading edge of the belt 11 passes into the gap of the switch toward which it is moving, that switch 27 through the switching circuit 25 will cause the position of the piston in the cylinder 20 to change so that the belt 11 will change its axial direction of movement. Thus the abrasive belt 11 is caused to reciprocate within established limits in a direction essentially parallel with the axis of the front roller 17.

The second assembly 13 provides means for holding the workpiece 12 with the plane on the workpiece 12 at which the planar surface is to be formed oriented parallel to the axis of the front roller 17. Means is provided for rotating the holding means about an axis generally normal to and intersection the axis of the front roller 17 at a predetermined speed and for moving or advancing the holding means and a workpiece in a direction normal to the axis of the front roller 17 and normal to the plane at which the surface is to be formed from a first position at which the workpiece 12 is spaced from the abrasive belt 11 to a second position where the desired planar surface is tangent to the abrasive belt 11 supported on the roller 17. Means is also provided for exerting at least a predetermined minimum grinding pressure between the abrasive belt 11 and a workpiece 12 until the desired planar surface is substantially formed at the second position.

The second assembly 13 comprises a holding means or chuck 29 which holds the workpiece 12 and which is attached to a shaft 31 which is journaled by a pair of bearings 32 and 35 supported on a slidable frame 34. While the self-aligning bearing 35 is fixed to the frame 34, the bearing 32 is slidably

mounted thereon for slight horizontal movement normal to the axis of the shaft 31 so that the axis of the shaft 31 may be positioned slightly out of normal relationship with the axis of the roller 17 for reasons which will later be explained. The position of the bearing 32 relative to the frame 34 is finely adjustable by means of a screw and nut assembly 37 operably connected therebetween.

The frame 34 is slidably supported by two rods 36 on a main support frame 38 for horizontal movement normal to the axis of the roller 17 from the first position where the frame 34 is most distant from the assembly 10 to the second position defined by a pair of stops 28 (only one of which is shown). The frame 38 of assembly 13 is tied to the frame 15 of the first assembly 10 by a pair of turnbuckle assemblies 39 (only one of which is shown) to prevent relative movement between the assemblies 13 and 10 during the grinding process. Rotating means for the chuck 29 is provided by a variable speed motor 40 supported on the slidable frame 34 (the reason for the variable speed of which will be later explained) and a suitable drive system, (e.g., a v-belt or chain and sprocket assembly 42) for driving the shaft 31.

The chuck 29 used in this illustration is a three-jaw machinist's chuck with a quick release operated by a lever 43 to allow quick change of similar workpieces being ground, however other chucks such as magnetic, electromagnetic, electrically or pneumatically operated, or manual four-jaw chucks, in addition to specialized holding fixtures for one or more workpieces can be used as needed to carry material being processed into grinding contact with the belt.

Means is provided for moving the slidable frame 34 with respect to the main frame 38 and for urging or pressing the workpiece 12 held by the chuck 29 into high pressure grinding contact with the abrasive belt 11. As illustrated, this means is provided by a double acting air cylinder 44 which is operably connected between the slidable frame 34 and the main support frame 38. The cylinder 44 is actuated by positioning a directing valve 46 to direct a pressure regulated supply of air into the appropriate parts of the cylinder 44 to cause extension or retraction of the piston. When properly activated, the cylinder 44 will urge the frame 34 toward the assembly 10 to press the workpiece 12 into contact with the abrasive belt 11 until the stops 28 are contacted by the frame 34. The cylinder 44 will also move the frame 34 to the first position to retract the workpiece 12 from contact with the abrasive belt 11 when the cylinder 44 is properly activated by the directing valve 46. An air flow regulating valve (not shown) is installed in the air supply line to the cylinder 44 and may be adjusted to control the maximum rate of movement of the piston in the cylinder 44 so that the maximum rate of workpiece movement toward or away from the abrasive belt may be controlled.

As stated, the movement of the slidable frame 34 toward the first assembly 10 in response to urging of the cylinder 44 is limited by the adjustable stops 28 which are attached to the frame 38. The adjustable stops 28 determine the second position, or the position at which a planar surface will be formed on the workpiece 12 held by the chuck 29. As illustrated, rotation of the holding means or chuck 29 through more than 180° after the frame engages the stops 28, for any one position of the stops 28 with respect to the front roller 17, will generate a generally flat or planar surface on a single workpiece 12 tangent to the periphery of the abrasive belt 11.

Proper air pressure to and/or sizing of the piston in the air cylinder 44 is important in the present invention to provide adequate force to supply high grinding pressure for the various metals and metal surface areas that may be encountered in the grinding of planar surfaces on various workpieces. From experimentation, it has been found that to remove metal from an area being ground at an efficient rate, feed pressures are required above a minimum pressure peculiar to the metal being ground. Pressures below these minimum pressures do not efficiently force the abrasive granules on the abrasive belt 11 into the surface of the workpiece 12 and as a result a large proportion of the driving energy supplied to the abrasive belt

11 is expended as heat of friction generated when the abrasive granules are rubbed across the surface of the workpiece 12. Such frictional heat can cause overheating or "burning" of the workpiece 12, and corresponding heat damage and/or "welding" of removed metal to the abrasive granules of the abrasive belt 11.

Grinding pressures above the previously mentioned minimum pressure force the granules on the belt 11 into the workpiece 12 so that a larger percentage of the energy delivered to the belt 11 is used to remove metal. Also, it has been found with high pressure grinding that the metal is removed from the workpiece 12 at a rate such that a smaller percentage of the heat generated is conducted into the workpiece 12, and the increase in temperature of the workpiece 12 is minimized. Thus, when abrasive belt grinding can be performed with pressures above the indicated minimum pressures, it becomes a fast method of metal removal which causes a minimum of heat damage to the workpiece or the abrasive belt used.

As far as is known, once above the minimum grinding pressure mentioned, grinding pressures which may be utilized are limited only by the strength of the backing or by the strength of the bond between the abrasive granules and the abrasive belt to the limits of the belt's capacity to carry away the material removed. Pressure increases above the minimum grinding pressure will not produce a proportional increase in metal removal rates because chips accumulate on the belt 11 during its traversal across the area being ground and these chips will limit the amount of metal which can be cut away by that segment of the belt 11 in that one pass.

Example values of the minimum grinding pressures for a few metals, using a new abrasive belt of the grade indicated, such as a new resin bond aluminum oxide belt, are given in the following table along with minimum stock removal rates to be expected when operating near or above the indicated pressures:

Metal	Grade	Minimum grinding pressure (psi)	Metal removal rate (per square inch of grinding area)
Ductile, malleable, or Grey Iron	24X	400	
Carbon steel (C.R.) (to 35Rc)	36X	350	0.5 cu.in./sec.
Carbon steel (Tool) (60 + Rc)	24X	375	0.25 cu.in./sec.
Stainless (304)	36X	300	0.125 cu.in./sec.
High Nickel Alloy metals	36X	600	0.167 cu.in./sec.
	50X	500	0.167 cu.in./sec.

As is illustrated in FIG. 2, with the apparatus of the present invention the grinding contact made between the surface of a workpiece 12 and the abrasive belt 11 on the front roller 17 is a horizontal band cut into the surface of the workpiece by the abrasive belt 11, the band being in contact with the arc of the abrasive belt 11 extending from the new surface being formed on the workpiece to the surface from which metal is being ground. Due to the small area of the band of contact between the abrasive belt 11 and the workpiece 12, a grinding pressure above the minimum indicated may be exerted with a much smaller force against the workpiece 12 than would be required to simultaneously grind the entire face of the workpiece 12 at that same grinding pressure. Grinding chip interference in the band of grinding on the belt 11 is lessened as the length of abrasive belt 11 in contact with the workpiece 12 is quite short. Additionally, the continual changing of position of the band of grinding relative to the surface being ground restricts heat buildup on the surface of the workpiece 12 being ground.

Maintaining the minimum grinding pressure while limiting depth of cut into any one workpiece per half revolution of the chuck 29 can be accomplished by regulation of the air pressure applied to the cylinder 44 and the speed of rotation of the

chuck 29. One approach is to first set the force exerted by the cylinder 44 to exceed the minimum pressure value for the maximum band contact area between the workpiece 12 and the abrasive belt 11. Through a control circuit for the variable speed motor 40, the rate of rotation for the workpiece 12 is then experimentally adjusted to present a volume of metal under the band of grind at a rate (corresponding to the grinding pressure established) at which the abrasive belt 11 will not advance more than a desired depth (typically about 0.1 inch) into the workpiece 12 on each half-revolution of the workpiece 12.

It is important to the proper operation of the apparatus as illustrated that while the cylinder 44 provides a constant predetermined force to press the workpiece 12 into grinding contact with the abrasive belt 11, movement of the workpiece 12 being ground is possible in the direction away from the grinding belt 11, as is possible with an air operated cylinder. The requirement exists because of the varying lengths of the band of grinding contact which will occur between the belt 11 and a workpiece 12 of irregular shape as such a workpiece 12 turns through 180° with its distal surface in contact with the abrasive belt 11. For a fixed force by the cylinder 44 and fixed speed of rotation of the chuck 29, the pressure and corresponding rate of stock removal will increase as the length of the band of grinding contact on a workpiece decreases. Thus, for an irregular workpiece 12, at the angular positions of shortest band contact with the belt 11, deeper horizontal cuts per revolution will occur in the workpiece 12. Thus, resilience as is supplied by the air operated cylinder 44 is needed to allow the chuck 29 to follow the slightly wavy surface which will be generated on an irregular workpiece 12 while it is being ground.

At the instant the forward travel of the slideable frame 34 is halted by the stops 28, there will remain two generally tapered protrusions above the desired planar surface, the majority of which will be ground away during the subsequent 180° rotation of the chuck 29. Additionally, a small amount of material will be removed from the surface of the workpiece as a result of relaxing of compression of the roller 17 and the backing of the belt 11 and the slight motion of the workpiece 12 toward the abrasive belt 11 which will result from the relief of stresses in the grinding machine.

As the minimum grinding pressure will not be maintained during this final surface grinding, it is desirable to greatly decrease contact time of the band of grinding in any one area to help prevent surface burning. This is done by increasing the rate of rotation of the chuck 29. Additionally, the increased rate of rotation of the workpiece 12 finishes the surface in the least possible time and reduces the amount of metal removed with each revolution of the chuck 29 so that the workpiece 12 can be retracted from grinding contact with the belt 11 before grinding pressure is entirely eliminated without leaving an irregularity on the surface of the workpiece 12 from the last band of grinding contact which will affect the accuracy of that surface. The increase in rotation of the workpiece 12 is in response to the actuation of a switching system which will vary the rotational speed of the motor 40. The switching system is energized by a sensor (not shown) which senses the decrease in power or amperage flow to the motor 40 after the frame 34 has contacted the stop 28 and the grinding pressure and rate of metal removal has begun to decrease. The sensor will signal the switching system to increase the rotational speed of the motor 40 to a predetermined maximum in an attempt to maintain a constant power output from the motor 40.

Means are provided for moving the plane on the workpiece 12 at which the planar surface is to be formed to a position slightly out of parallel with the axes of the roller 17 to equalize the rate of metal removal across the surface of the workpiece 12 after the stops 28 are contacted by the frame 34. This is done so that an accurate planar surface will be quickly formed on the workpiece 12 after the second position of the frame 34 is reached and before the compressible backing on the abrasive belt 11 and surface on the roller 17 have completely ex-

panded. Because the center of rotation of the surface formed on the workpiece 12 is constantly in contact with the abrasive belt 11 on the roller 17, this center area receives more grinding time per revolution of the workpiece 12 than areas on the surface spaced radially from this center. The areas about and radially spaced from the center are ground for proportionally shorter periods of time during each rotation of the workpiece 12. This additional grinding time against the central area of the surface being formed affords a slightly faster rate of material removal from the central area of the surface being formed during the final fast spinning of the workpiece 12 after the frame 34 has reached the stops 28, as the compressed surface of the roller 17 and backing on the abrasive belt can expand more quickly against this central area. This variation in the depth of grind on the surface being formed, which for a 10 inch diameter workpiece might be in the range of 0.001 inch, would be eliminated in time after the backing of the belt 11 and the surface of the roller 17 were completely expanded, however, the time involved would be too great for rapid finishing of workpieces. To quickly produce an accurate planar surface on the workpiece 12 without allowing the compression in the backing of the belt 11 and the surface of the roller 17 to be completely relieved, the nuts of the assembly 37 are adjusted for a given workpiece to move shaft 31 or the axes of rotation of the desired planar surface to form an angle slightly less than 90° with the axis of the roller 17. This misalignment produces an increasingly greater grinding pressure along the band of grinding in a direction from the axis of rotation toward one edge of the workpiece 12. This added pressure will cause a greater rate of material removal in areas on the surface spaced radially from the center of rotation of the workpiece 12 to match the aforementioned greater rate of removal at the center of the workpiece 12 due to a greater amount of grinding time per revolution of the workpiece 12. Thus, an accurate planar surface is quickly formed on the workpiece 12 after the second position is reached without waiting for complete expansion and cessation of the grinding pressure between the workpiece 12 and the abrasive belt 11.

OPERATION

To prepare the apparatus for forming a planar surface on a given workpiece 12, the chuck 29 is adjusted to grip and hold the workpiece 12 with the plane on the workpiece at which the surface is to be formed oriented normal to the axis about which the chuck 29 rotates, which plane is also normal to the axis of the roller 17 in the apparatus as illustrated. The stops 28 are adjusted to halt movement of the slidable frame 34 toward the first assembly 10 when the frame 34 and the workpiece 12 have advanced toward the belt 11 so that the plane on the workpiece 12 at which the surface is to be formed is tangent to the abrasive belt 11. The air supply pressure to the valve 46 controlling cylinder 44 and the initial rate of chuck 29 rotation are cooperatively adjusted as previously explained to provide grinding pressures above the minimum desired value and to produce approximately the desired depth of workpiece material removal per half revolution of the chuck 29.

To grind a planar surface on the workpiece 12, the motor 21 is started to drive the abrasive belt 11. The directing valve 46 is positioned to cause cylinder 44 to move the slidable frame 34 and chuck 29 to their first position which is most distant from the belt 11. By manipulation of lever 43, a workpiece 12 is clamped in the chuck 29. The motor 40 is started to rotate chuck 29 at the predetermined rate. The directing valve is positioned so that cylinder 44 will force the sliding frame 38 and chuck 29 toward the abrasive belt 11 urging the workpiece 12 into grinding contact with the abrasive belt 11. The workpiece 12 moves against the abrasive belt 11 until the frame reaches the stops 28 defining the second position where the surface to be formed is tangent to the abrasive belt 11. After the frame 34 reaches the stops 28, the rotational speed of the motor 40 is greatly increased, thus increasing the rate of

rotation of the chuck 29 and workpiece 12 and the desired planar surface is formed as evidenced by a marked reduction of grinding sparks.

The directing valve 46 is then positioned to cause cylinder 44 to return the slidable frame 34 to the retracted or first position where, after stopping motor 40, the finished workpiece 12 may be removed from the chuck 29.

Having thus described the invention in relationship to a preferred embodiment, I claim:

1. A method of forming a planar surface on a metal workpiece through use of an abrasive belt having a given width between its spaced edges which comprises the steps of:

driving the abrasive belt along an arcuate path having an axis;

holding the workpiece with the plane at which the planar surface is to be formed oriented essentially parallel to the axis of the arcuate path about which the abrasive belt is driven;

moving the workpiece about an axis positioned between the edges of the abrasive belt, which axis of movement is normal to the axis of the arcuate path;

urging the workpiece toward the arcuate path of said abrasive belt in a direction parallel to the axis of movement, said moving and urging of the workpiece affording grinding contact between the workpiece and the abrasive belt at a pressure in the contact area of not less than 300 pounds per square inch to advance the workpiece toward the abrasive belt; and

stopping the advancing movement of the workpiece toward the abrasive belt when the desired plane is tangent to the abrasive belt on the arcuate path so that the planar surface will be formed upon further rotation of the workpiece, thereby relieving the grinding pressure.

2. A method according to claim 1, further comprising the step of:

varying the path of contact between the abrasive belt and the surface of a workpiece along the axis of the arcuate path about which the abrasive belt is driven.

3. A method according to claim 1, further comprising the step of:

reciprocating the abrasive belt back and forth along the axis of the arcuate path about which the abrasive belt is driven.

4. A method according to claim 1, wherein said moving step comprises moving the workpiece about said axis at a first rate during the initial grinding of a workpiece on the abrasive belt, and moving the workpiece about the axis at a second rate of angular velocity which is substantially higher than the first rate before separation of the workpiece from the belt.

5. A method according to claim 1, wherein said moving step comprises rotating said workpiece about an axis passing through the center of said workpiece to form concentric grinding marks on said planar surface.

6. An apparatus for forming a planar surface on a workpiece which comprises:

an abrasive belt;

means for driving said abrasive belt in an arcuate path;

means for holding a said workpiece with the plane on the workpiece at which said planar surface is to be formed oriented generally parallel to the axis of said arcuate path about which said abrasive belt is driven;

means for rotating said holding means at a predetermined speed about an axis normal to the axis of said arcuate path, for advancing said holding means and a said workpiece from a first position at which a said workpiece is spaced from said abrasive belt toward a second position where said planar surface is tangent with said abrasive belt on said arcuate path, and for exerting a grinding pressure of at least 300 pounds per square inch between a said workpiece and said abrasive belt in the area of grinding contact so that material will be efficiently removed from a said workpiece until said planar surface is substantially formed on said workpiece at said second position.

7. An apparatus according to claim 6, which further comprises:

means for providing relative movement between said abrasive belt and said workpiece along the axis of the arcuate path, thereby varying the path of contact of a said workpiece on said abrasive belt throughout the grinding process.

8. An apparatus according to claim 6, which further comprises:

means for reciprocating said abrasive belt back and forth along the axis of said arcuate path, thereby varying the path of contact of a said workpiece on said abrasive belt throughout the grinding process.

9. An apparatus according to claim 7, wherein said last mentioned means comprises air cylinder means for urging said holding means toward said second position, and means are provided for increasing the rate of rotation of said rotating means for said holding means after said holding means reaches said second position to increase the rate of completion of said planar surface.

10. An apparatus according to claim 9, further comprising: adjustable stop means for determining said second position of said holding means with respect to said abrasive belt on said arcuate path.

11. An apparatus according to claim 7, wherein said means for driving said abrasive belt in an arcuate path comprises a roller and means for moving said axis of said rotating means to move said plane on a said workpiece at which a said planar

surface is to be formed to a predetermined position slightly out of parallel with the axis of said arcuate path to equalize the rate of material removal across the surface of a said workpiece after said second position is reached.

12. An apparatus according to claim 6 wherein the axis about which the holding means is rotated intersects the axis of said arcuate path.

13. A method according to claim 1, wherein said moving and urging of the workpiece affords grinding contact between the workpiece and the abrasive belt at a minimum pressure in the contact zone of between 300 and 600 pounds per square inch which pressure is further selected for the specific material in accordance with the following table:

Metal	Abrasive Belt Grade	Minimum grinding pressure (in pounds per sq. inch)
Ductile, malleable, and grey iron	24X	400
Carbon steel, 35 Rc hardness	36X	350
Carbon steel 60+ Rc hardness	24X	375
304 Stainless steel	36X	300
High Nickel	36X	600
Alloy metals	50X	500

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