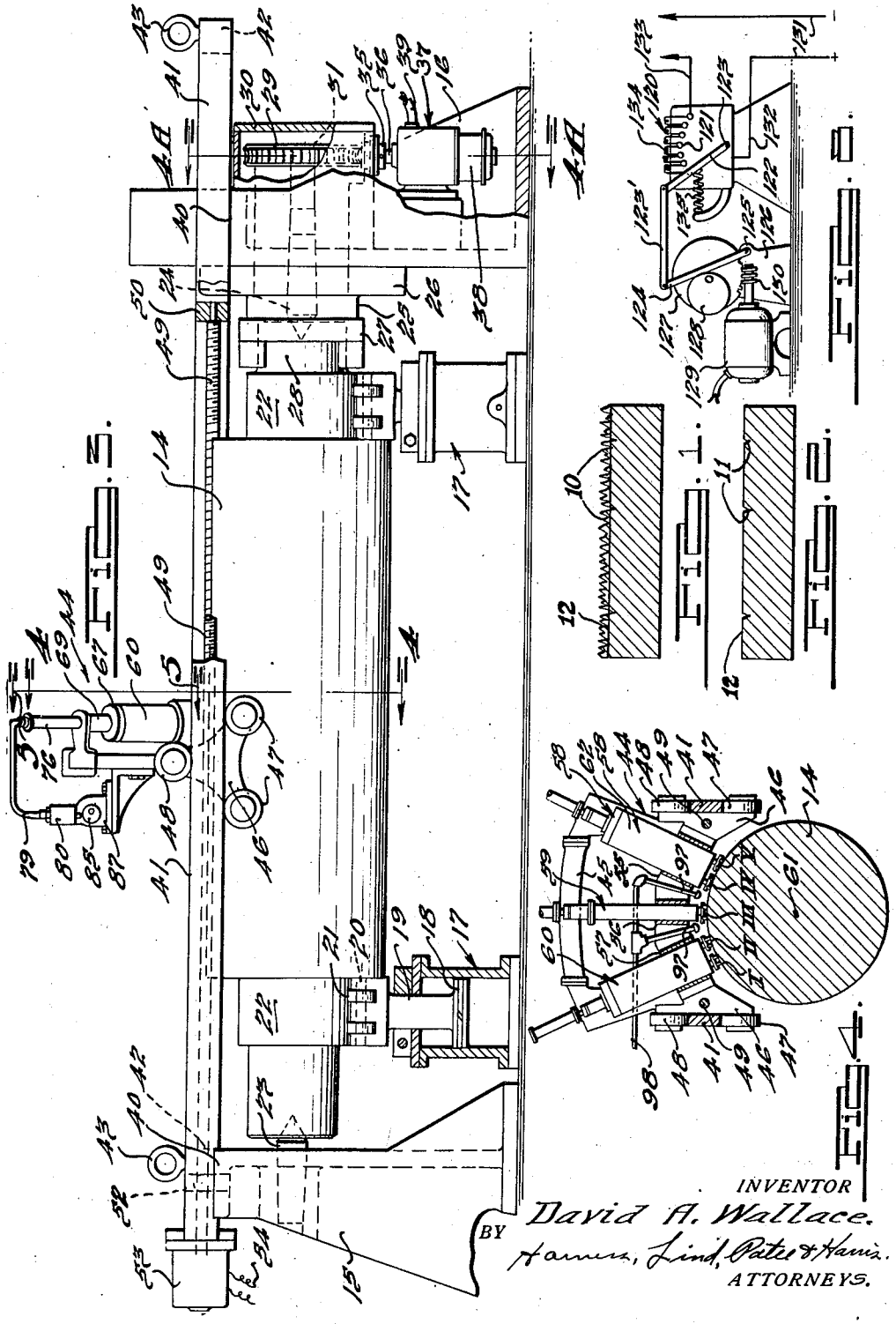
March 26, 1940. D. A. WALLACE 2,195,064

LAPPING APPARATUS AND METHOD

Filed Sept. 23, 1938 2 Sheets-Sheet 1



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LAPPING APPARATUS AND METHOD

Filed Sept. 23, 1938 2 Sheets-Sheet 2

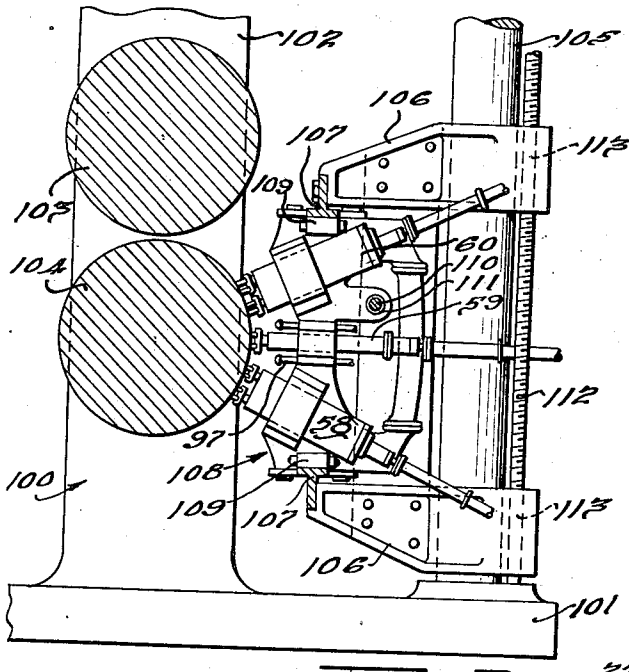


FIG. 7.

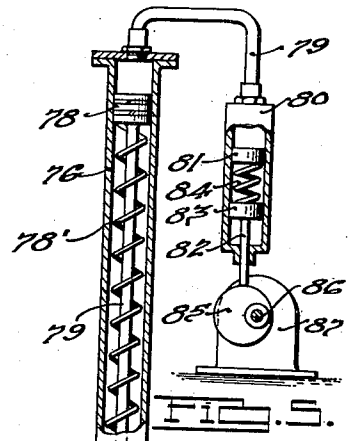


FIG. 5.

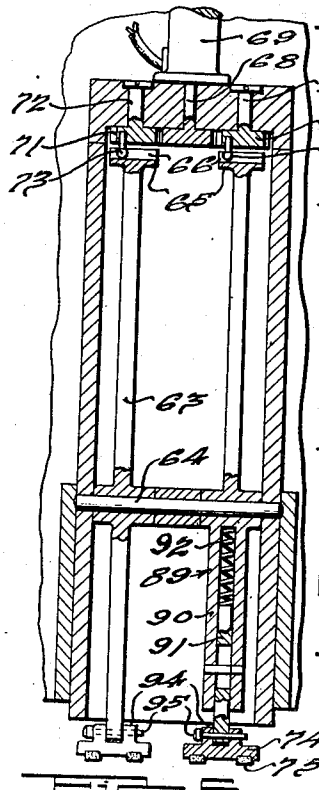


FIG. 6.

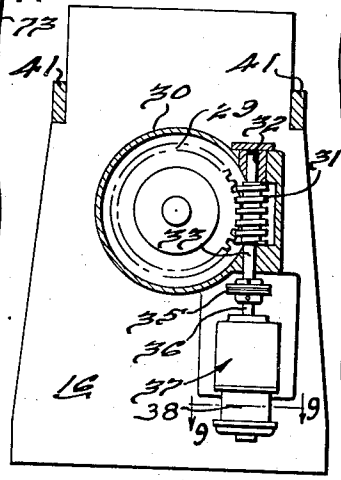
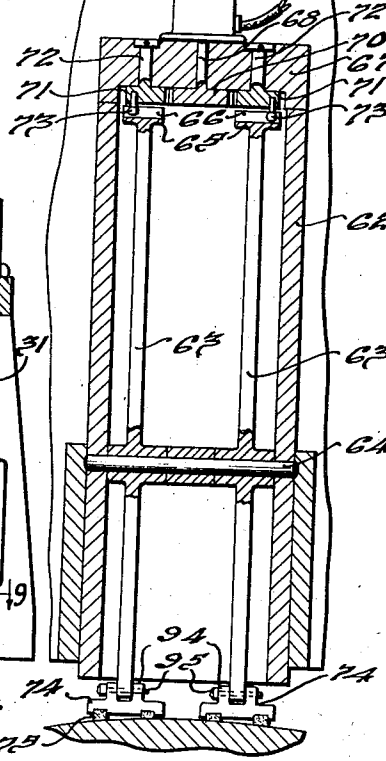


FIG. 4A.



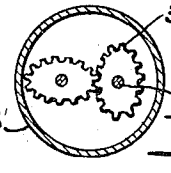


FIG. 9.

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Patented Mar. 26, 1940 2,195,064

UNITED STATES PATENT OFFICE

2,195,064

LAPPING APPARATUS AND METHOD

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Application September 23, 1938, Serial No. 231,404

24 Claims. (Cl. 51—278)

This invention relates to an improved apparatus for and method of finishing surfaces.

The purpose of finishing operation is to eliminate the irregularities of comparatively minute dimensions which result from various causes such as wear, corrosion and particularly from operating upon surfaces of diverse contours with grinding, machining or other material removing tools of the type which are used to shape and to bring articles to predetermined dimensions. Under microscopic examination, tool marks are found to comprise ridges or serrations of somewhat regular spacing and depth and are generally triangular in cross section with their vertices extending outwardly from the body of the article. At the bottoms of the ridges of greatest depth is the so-called "continuous base material section" to which the ridges must be substantially removed without introducing scratches in order to produce a perfect surface substantially free from grinding and machining marks and other irregularities.

Briefly, this is accomplished in the practice of my improved finishing method by applying to the work a suitable abrading element and producing components of relative movements of a comparatively low rate of feet per minute between the abrading element and the work which results in a scrubbing action on the work surface without heating the latter to a ductile state, this scrubbing action being performed while the work and abrading element are urged together with a relatively low pressure and in the presence of a lubricating coolant which will, under such pressure, hold the protruding, active particles of the abrading material against scratch forming and further cutting contact with the work at the continuous base material section thereof.

One of the main objects of the invention is the provision of a finishing method and apparatus of this kind by which ridges resulting from grinding, machining and other previous operations on the surface of a piece of work may be removed substantially to the continuous base material section of such surface in a high speed, production manner and without introducing finishing formed scratches or other irregularities.

A further object of the invention is the provision of an improved finishing method and apparatus during the operation of which abrading of the material operated upon discontinues as soon as the ridges are removed and no appreciable dimensional change takes place upon continuation of the operation beyond this stage.

Another object of the invention is the provision in a finishing apparatus and method for guarding against heating of the coolant and accompanying lowering of its viscosity, and heating of the outer skin of a work surface to a state such that it is rendered susceptible of being scratched during finishing, by suitably controlling the rates of the component relative movements of the work and abrading element, the abrading character of the element, the pressure with which it is urged against the work surface and the viscosity of the lubricating coolant applied thereon.

A further object of the invention is the provision of a finishing method and apparatus of this kind by which mainly all machining, grinding and otherwise formed ridges and projecting disfigurations of a surface are abraded substantially to a common line at substantially all cross sections of the surface so that any irregularities which remain comprise only widely spaced indentures from the surface formed by the common extremities of the abraded ridges which are adapted to serve as lubricant reservoirs.

An additional object of the invention is the provision, in a finishing method and apparatus of this character, for cyclic variation of the speed of one or more of the components of relative abrading movements of the work and abrading element as well as a variation of the relative feed movement of the work and the abrading element in order to further guard against scratch forming operation of the abrading element on the work surface and to cause successive resultant relative movements of the work and abrading element to occur in different directions.

A still further object of the invention is the provision, in a finishing method and apparatus of this kind, for cyclic variation of the pressure of application of the abrading element to the work.

Additional objects of the invention are to provide an improved finishing apparatus for cylindrical surfaces which is particularly adapted for finishing rolls of large and diverse diameters; to provide in finishing apparatus of this kind a tool having a plurality of independently reciprocably operable abrading elements which successively operate upon substantially the same increments of the work surface during each relative rotation of the work and abrading element; to provide means for reciprocating such abrading elements throughout different lengths of stroke and at different speed; to provide a plurality of abrading element carrying tools in apparatus of this kind which are shiftable in a converging course to accommodate adaptation of

the tools to cylindrical pieces of work of diverse dimensions; to provide means for selectively urging such tools independently toward the work with a constant or varying pressure respectively, of the same or different values; and to provide fluid pressure actuated mechanism for urging the abrading elements against the work which is adapted to cause such elements to follow the slightly longitudinally rolled contour of rolls of the type used in metal rolling processes.

Other objects of the invention are the provision of means for so mounting a tool of this character and a roll machine bed as to facilitate convenient performing of finishing operations on one or more rolls, for example of the large variety used in metal rolling processes, while such rolls are mounted on their normal bearing supports and without requiring dismantling of the rolling machine; and to provide a finishing tool of this kind which may be supported by a structure independent of a roll machine bed and conditioned to finish both the bearing surfaces and operating surfaces of a roll.

Illustrative embodiments of the invention are shown in the accompanying drawings, in which:

Fig. 1 is an enlarged diagrammatic sectional view of a piece of work having a surface to be finished.

Fig. 2 is a view, similar to Fig. 1, of the work shown therein after it has received a finishing operation embodying the invention.

Fig. 3 is a side elevational view, partly in section, of apparatus embodying the invention and by which the improved finishing process may be practiced.

Fig. 4 is a transverse sectional view taken on the line 4—4 of Fig. 3.

Fig. 4A is a transverse section taken on line 4A—4A of Fig. 3.

Fig. 5 is an enlarged longitudinal sectional view of one of the tools of the apparatus illustrated in Figs. 3 and 4, taken mainly on the line 5—5 of Fig. 3 and shown in section the pressure exerting mechanism associated therewith.

Fig. 6 is a fragmentary view similar to Fig. 5 but illustrating a tool embodying a modified form of the invention.

Fig. 7 is a vertical sectional view of a rolling machine equipped with roll finishing apparatus embodying the invention and by which the improved finishing method may be practiced.

Fig. 8 is a side elevational view of apparatus by which the speed of operation of the driving motors of the apparatus may be cyclically varied.

Fig. 9 is a transverse sectional view taken on the line 9—9 of Fig. 4A.

In practicing the improved finishing method, a piece of work having a surface to be finished and an abrading element comprising natural stone or compressed particles of suitable grit are mounted for contacting relative abrading movements with respect to each other. When operating upon cylindrical surfaces of a piece of work, the latter is preferably drivingly rotated while the abrading element is reciprocated relative to the work in the direction of its rotative axis. In finishing flat or end surfaces, the work may be rotated about an axis intersecting such surface while the abrading element is reciprocated radially of such an axis. Internal cylindrical surfaces may be finished by simultaneously rotating and reciprocating an abrading element while the latter is yieldably held in abrading contact therewith. Various types and directions of component movements may be employed to derive a desired resultant relative movement between the work and an abrading element.

The pressure with which the abrading elements are urged against the work surface being finished and the rate of the resultant movement between the work and the abrading element are maintained at low values as compared with the pressures and rates of relative movement employed in grinding, machining, honing, turning and other conventional operations during which substantial material is removed from the work. In finishing surfaces of work comprising cast iron, steel or aluminum, for example, finishing pressures of from 15 to 16 pounds per square inch are preferably employed, pressures of 30 pounds per square inch, or less, being satisfactory. The relative rotative movement of such work and the abrading element is preferably held at a rate of 35 to 50 feet per minute, 50 feet per minute or less being satisfactory, and the rate of relative reciprocatory movement of the work and abrading element is preferably 15 to 25 feet per minute, satisfactory results being attainable at 50 feet per minute or less. Such finishing operations may be performed with abrading elements or stones of 500 mesh grit in the presence of an oil having a viscosity of 460 seconds Saybolt at 100° F.

The rate of the resultant relative movement between the work and the abrading element and the pressure with which the latter is urged against the work is sufficiently low to prevent heating of the skin of material at the surface operated upon to a state of scratchable ductility. When excessively high pressure and speeds are employed, there is found to be an instantaneous rise in the temperature of the increment of surface under operation, in some cases to temperature of 600° to 700° F., which results in scratching thereof by the particles of grit of the abrading element.

Essentially, the finishing operation comprises removing all irregularities which project above a predetermined base line 12, as illustrated in Fig. 1, without, while so doing, causing any additional irregularities by removing any portion of the material below the base line 12. As the abrading element is moved into engagement with the surface to be finished it first engages the tops of the ridges 10. As the abrading element is held in engagement with the surface to be finished with a predetermined pressure, the unit pressure between the tops of the ridges and the abrading element will be very high and the rate at which the tops of the ridges are removed by transverse movement of the abrading element is consequently high. As the tops of the ridges are removed the abrading element engages portions of the ridges of gradually increasing area, which causes a reduction in the unit pressure therebetween and consequently a reduced rate of cutting or removal of material, which is, of course, desired, as the line 12 is approached. The area of the material in engagement with the abrading element, and consequently being removed, continues to increase as the base line 12 is approached, and the unit pressure between the relatively movable surfaces correspondingly decreases.

As is well known, when oil is applied to any surface, it forms a film of oil thereon which causes any other surface in engagement therewith to slide freely thereon provided that the unit pressure therebetween is not sufficiently great to rupture that oil film, in which event the two surfaces are in direct engagement, with resulting friction. The strength of the oil film varies with the vis-

cosity of the oil and with the temperature thereof.

In order to take advantage of this fact, oil is applied to the surface being finished, the oil employed being of such viscosity that the unit pressure between the abrading element and the surface is sufficiently great to rupture the oil film when the abrading element engages the tops, and later the intermediate portions, of the ridges 10, but which is insufficient to break the oil film as the base line 12 is reached, thus causing the abrading element to engage and reduce the height of the projections until such time as the gradually falling unit pressure is insufficient to break the oil film, after which it slides freely thereover.

Obviously the pressure applied to the abrading element must bear such relation to the contacting area thereof and to the viscosity of the oil employed that the oil film will be broken thereby until the desired degree of smoothness of surface has been attained and after which the oil film will present an unbroken surface over which the abrading element will slide freely without removing any further material. In addition, the irregularity of the contacting surface of the abrading element must be taken into account in determining the pressure applied thereto so as to maintain the unit pressure in the correct relationship with the strength of the oil film. If the unit pressure is too high with respect to the viscosity of the oil, so that the oil film is ruptured at the minimum unit pressure, the abrading element will continue to remove material after the base line 12 has been reached, which is, of course, undesirable, and if the unit pressure is too low with respect to the viscosity of the oil, only the tops of the ridges will be removed, and a poorly finished surface results.

In highly accurate finishing operations it is desirable to maintain the oil, which also serves as a coolant to prevent local hot spots, at a uniform predetermined temperature, the strength of the oil film decreases as the temperature of the oil increases.

With proper control of the unit pressure and the strength of the oil film, the degree of fineness of finish may be varied within considerable limits.

Although I have referred, in both the specification and claims, to employing oil to prevent abrading the surface to be finished beyond the desired degree, it is apparent that any other material may be employed for this purpose which will form, and readily reform, a protective film or coating which will, within practical limits, resist rupture and beyond these limits permit rupture and direct contact between the abrading element and the surface being finished.

While numerous types of relative abrading movements of the work and abrading element may be employed, the foregoing combination of rotative and one or more reciprocative movements is preferable. The rates of any or all of these component movements may be cyclically varied, and if a feeding movement of the abrading element carrying tool is practiced, the rate of this movement may also be varied cyclically during the finishing operation. Since the direction of the resultant relative movements of the abrading element and work are dependent upon the rates of the respective component movements, cyclic variation of the rates of the component movements produces changes in the directions of resultant movements, causing all parts upon the surface of the work to be traversed by relative movements in a plurality of directions. The cyclic variation of one or more of the component movements may be relied upon to vary the direction of the successive resultant movements occurring during alternate half cycles of the relative reciprocatory movement.

In the drawings is illustrated one type of lapping apparatus embodying the invention and by which the improved lapping method may be performed. The lapping apparatus shown in the drawings is particularly adapted for the lapping of cylindrical surfaces of large rolls 14 of the type used in the metal rolling, paint manufacturing and paper manufacturing industries, for example. Obviously apparatus of substantially the same construction and of different dimensions may be employed in the lapping of external surfaces of bearings, journals and various articles of diverse sizes. The lapping apparatus illustrated includes a frame structure comprising a pair of vertically upstanding supports 15 and 16 between which is located a pair of hydraulic jacks 17. Each jack 17 includes a piston portion 18 and an externally extending piston rod portion 19 on which is rotatably mounted at 20 two spaced pair of rollers 21. The rollers 21 are arranged, as illustrated in Fig. 3, to receive bearing portions 22 provided at the opposite extremities of the roll 14. The hydraulic jacks 17 may be manipulated in a conventional manner to bring the axis of the roll 14 to a desired elevation and condition of level. The roll 14 may be independently supported during the lapping operation by the jacks 17 or it may be rotatably mounted, if desired, upon centers 23 and 24 provided on the vertically upstanding supports 15 and 16 respectively.

The roll 14 is adapted to be drivingly rotated by a driving member 25 rotatably mounted in a bearing plate 26 which is secured to the left side of the support 16, as viewed in Fig. 3. The driving member 25 is provided at its left end, as viewed in Fig. 3, with a chuck 27 in which is received either the normal bearing 22 of the roll 14 or an outwardly extending portion 28 thereof. The chuck 27 is adapted to firmly grip the projection 28 of the roll for the purpose of drivingly rotating it. The right end portion of the driving member 25 is provided with a worm gear 29 located within the gear housing 30 mounted on the support 16. This worm gear meshes with a worm 31 located within the gear housing 30 and between spaced abutments 32 therein. A drive shaft 33 is splined within the worm and it is connected at its lower end by a coupling 35 to a shaft 36 of a combined motor and transmission gear unit generally designated by the numeral 37, as shown in Fig. 4A. The transmission mechanism 38 of the unit 37 preferably comprises eccentric gearing by which the rotative speed of the shaft 36 and driving member 25 are cyclically varied within predetermined limits. This eccentric gearing comprises an elliptical pinion 36' on the shaft 36 which is meshed with an elliptical pinion 37' driven by the motor 37. Cyclic variation of the rotative speed of the roller 14 may be accomplished in the foregoing manner or without the use of eccentric gearing by interposing suitable circuit control mechanism (not shown) in the circuit 39 of the electrical motor.

The upper end portions of the supports 15 and 16 are provided with horizontal seats 40 for receiving a pair of longitudinal guide rails 41

which are connected together at their opposite end portions by transverse cross members 42. The cross members 42 have upstanding eyes 43 secured thereto by which the guide rails may be conveniently lifted from the seats 40 with the aid of conventional cranes customarily employed in shops equipped to handle rolls of the type illustrated at 14.

Shiftably mounted on the guide rails 41 is a tool carriage generally designated by the numeral 44 in Fig. 3. This tool carriage comprises a frame structure 45 having opposite side flanges 46 on which are rotatably mounted a pair of rolls 47 adapted to engage the lower edge portion of a rail 41 and a roll 48 located between the rolls 47 which is adapted to engage the upper edge portion of a rail 41. The carriage 44 is adapted to be reciprocably fed longitudinally on a roll 14 by a pair of screws 49 threaded in apertures formed in the opposite flanges 46 in the carriage. The rear ends of the screws 49 are journalled in an aperture formed in a cross member 50 extending between the guide rails 41 which is secured to the latter. The right end portions of these screws are journalled in apertures formed in cross member 52 which also extends between rails 41. One of the screws 49 is connected to be driven by a shaft of a reversing motor 53 carried by the rails 41 and the other screw 49 is drivingly connected by a chain of gearing (not shown) so as to be driven in unison therewith. The reversing motor 53 may be operated at a constant speed or its speed of operation, and accordingly the speed of operation of the screws 49, may be cyclically varied by interposing in the electrical circuit 54 thereof suitable circuit control apparatus for cyclically changing current or voltage of the circuit 54. The reversing motor 53 may be relied upon to drivingly feed the tool carriage 46 back and forth over the surface of the roll 14 operated upon.

Provided in the frame structure 45 are a plurality of arcuately arranged bearings 55, 56 and 57 in which lapping tools, generally designated by the numerals 58, 59 and 60, are shiftably supported. The bearings 55, 56 and 57 are preferably so constructed and arranged as to confine shifting movement of the tools 58, 59 and 60 in courses which converge substantially at the axis 61 of the roll 14.

The tool 58 includes a casing 62 of rectangular cross section in which is mounted a pair of oscillatable levers 63 which are pivotally supported on a common pin 64 carried by the opposite side walls of the casing 62. The upper end portion of each lever 63 is provided with an enlarged head 65 having a slot 66 extending substantially parallel to the axis of the pivot pin 64. A block 67 is mounted on the upper end of the casing 62 and provided with a central aperture through which extends a driving shaft 68 of a combined motor and transmission gear unit generally designated by the numeral 69. The transmission gearing of this unit may comprise eccentric gearing by which the rotative speed of the shaft 69 may be cyclically varied. If desired, the shaft 69 may comprise the shaft of an electric motor having a circuit in which is included voltage or current varying apparatus by which the speed of operation of the motor may be directly cyclically varied. The drive shaft 68 has an end portion located within the casing 62 on which is fixed a gear 70. The gear 70 meshes at diametrically opposite extremities with pinions 71 having upwardly extending hub portions 72 journalled in apertures formed in the block 67. Each pinion 71 has an eccentric roll 73 depending downwardly therefrom and received in the slot 66 of one of the oscillatable levers 63.

The lower end of each oscillatable lever 63 is provided with an abrading element holder 74 in which are mounted abrading elements 75 comprising natural stone or compressed particles of grit. These abrading elements may be comprised of materials of the type conventionally used in honing operations. The abrading element holders 74 are provided with a pair of upstanding flanges 94 between which the lower extremities of the levers 63 are received and to which the latter is pivotally attached by a pin 95 extending transversely of the rotative axis of the roll 14.

The abrading elements 75 are adapted to engage the surface of the roll 14 or other piece of work to be finished and these abrading elements are preferably yieldably urged against the work surface by fluid pressure mechanism comprising a cylinder 76 mounted on the frame structure 45 of the tool carriage and in which is slidably mounted a piston 78 having a piston rod 79 attached to the housing of the motor unit 69. The piston 78 and tool with which it is connected is normally urged away from the work by a spring 78' in the cylinder 76. A flexible conduit or hose 79 communicates at one end with the upper end portion of the cylinder 76 and at its other end with a cylinder 80 which is provided with a plunger 83 having an externally projecting plunger rod 82. Slidably mounted in the cylinder 80 is a piston 81 which is normally urged upwardly as viewed in Fig. 5 by a spring 84 bearing between the piston 83 and the plunger 81. The interior of the fluid pressure mechanism, from the piston 78 of the cylinder 76 to the piston 83 of the cylinder 80, is filled with a column of fluid medium on which is applied the expansion force of the spring 84. The action of the spring 84 may be maintained at a selected constant value if desired or it may be varied by adjustably shifting the plunger 81. Cyclic variation of compression of the spring 84 and accordingly corresponding variation of the pressure with which the lapping elements are urged against the work by the column of fluid medium in the hose 79 may be produced by causing a cam 85 to operate upon the plunger rod 83 as viewed in Fig. 5. The cam 85 may be non-rotatably secured to a shaft 86 of a motor 87 or other suitable driving mechanism.

The pinions 71 by which the oscillative levers 63 are actuated may be of the same size or one of these pinions may be of larger diameter than the other as illustrated in the drawings. A difference in size of the pinion 71 will produce a corresponding difference in the speed of oscillation of the levers 63. The amount of eccentricity of the eccentrics 73 carried by the pinions 71 may differ so as to produce oscillative strokes of the same or different predetermined lengths while the number of oscillations per unit of time of both levers may be selectively predetermined by the sizes of the pinions 71. By this construction a finishing tool is provided having a pair of independently reciprocable lapping elements which may be reciprocated throughout the same or different numbers of strokes per unit of time and throughout strokes of the same or different lengths.

The tool 60 is substantially identical in construction to the tool 58 and is provided with fluid

pressure mechanism of the same character as that with which the tool **58** is provided for urging its abrading elements against the work. The tool **59** is similar in construction to the tools **58** and **60** but in the tool **59** is provided only a single oscillative lever **88**.

Either or both of the oscillative levers **63** in the tools **58** and **60** may be formed in accordance with the construction of the oscillative lever generally designated by the numeral **89** and shown in Fig. 6. One of these oscillative levers comprises telescoping parts **90** and **91** between which is interposed a spring **92** for predetermining the pressure of application of the lapping elements **75** thereof upon the work.

If only one of the pair of oscillative levers of a tool such as the tool **58** comprise telescoping sections between which a spring is disposed as illustrated in Fig. 6, then the pressures by which the lapping elements of tre respective oscillative levers are urged against the work may be brought to different predetermined values and these pressures will be maintained at different values throughout cyclic variation thereof of the foregoing type.

Lubricant may be discharged upon the surface of the work from nozzles **97** mounted on the carriage **44** and supplied with lubricant, from a source not shown, by suitable conduits **98**.

For the purpose of setting forth one specific example of the lengths of stroke and rate of reciprocation which may be used to advantage in finishing a roll surface by my improved finishing apparatus and method, the lapping elements appearing in Fig. 4 have been designated by Roman numerals I to V, inclusive. The lengths of stroke of the elements I, II, III, IV and V may be respectively ⅛, $\frac{3}{16}$, ¼, ⅜ and ½ inch and these abrading elements may be reciprocated at 500, 400, 300, 250 and 200 reciprocations per minute. The reciprocative rates of the abrading elements of each of the tools **58**, **59** and **60**, as well as the rotative speed of the work, may be maintained at constant values, or cyclically varied as heretofore set forth. Cyclic variation of the rotative speed of the work may take place while the rate of reciprocative action of the abrading elements is also cyclically varied or only either one of these cyclic variations may be practiced.

In the form of the invention illustrated in Fig. 7, the improved finishing apparatus is illustrated as a permanent part of a rolling machine generally designated by the numeral **100** comprising a base portion **101** and vertically upstanding side frame members **102** between which are journalled a pair of rolls **103** and **104**. Mounted on the base structure **101** of the roll machine adjacent opposite longitudinal extremities is a pair of vertically upright posts **105**, only one of which is shown in Fig. 7. Vertically slidably mounted on each of the posts **105** are brackets **106** which extend toward the rolls **103** and **104**. Each bracket **106** is provided with a track **107** between which a finishing tool carriage, generally designated by the numeral **108**, is mounted for reciprocatory movement longitudinally of the rolls **103** and **104**.

The finishing tool carriage **108** is similar in construction to the finishing tool carriage **44** shown in Figs. 3 and 4 and is provided with finishing tools **58**, **59** and **60** substantially identical in construction to the corresponding finishing tools shown in Figs. 3 and 4. The finishing tools of the apparatus shown in Fig. 7 are provided with fluid pressure apparatus, not shown in Fig. 7, substantially identical to that shown in Figs. 3, 4 and 5 and these tools are capable of operating in precisely the same manner as the operation described in connection with the form of the invention shown in Figs. 1 to 6, inclusive.

The carriage **108** is provided with rollers **109** which set upon the tracks **107** so as to facilitate smooth reciprocatory movement of the carriage and finishing tools over the lengths of the rolls **103** and **104**. This reciprocatory movement may be provided by a threaded shaft **110** threaded in an aperture **111** formed in the frame structure of the carriage **108**. The threaded shaft **110** may be drivingly operated in the same manner as the threaded shafts **49** in the form of the invention shown in Figs. 3 and 4.

The tool carriage **108** and the tools carried thereby may be vertically adjustably positioned so as to bring the abrading elements of the tools selectively into engagement with either the roll **103** or the roll **104**, or to move the tools to a position above the upper roll **103** in order to avoid obstructing the access to the rolls during normal operation thereof. This adjustment of the tool carriage **108** and tools carried thereby may be effected by rotation of threaded shafts **112** each extending along one of the posts **105** respectively and threaded in apertures **113** formed in the brackets **106**.

Cyclic variation of the speed of operation of any of the motors employed to drive either the work or the tools may be produced by the apparatus shown in Fig. 8 which includes a rheostat generally designated by the numeral **120** having a plurality of fixed contact elements **121** and a movable contact element **122** pivotally mounted at **123**. The upper end of the lever **122** is operatively connected by a link **123'** with an actuating arm **124** which is pivoted at **125** on a bracket **126**. Rotatably mounted on the bracket **126** is a worm gear **127** having a cam **128** non-rotatably fixed thereto and operatively engaging the lever **124** which is normally urged by a spring **135** in a counterclockwise direction, as viewed in Fig. 8, about its pivotal axis **125**. The worm gear **127** may be driven at a constant speed by a motor **129** having a worm **130** on its shaft, meshed with the teeth of the worm gear **127**.

This apparatus is particularly adapted for varying the supply to direct current motors of the type conventionally used in apparatus of this character. The rheostat **120** is connected in a circuit comprising an input line **131** having a conductor **132** connected with the movable contact **122** and a conductor **133** connected with the fixed contacts **121** of the rheostat, between which are connected in series a plurality of resistance elements **134**. The conductor **133** and one of the line conductors **131** may be employed for supplying current to the motor in order to cyclically vary the speed thereof and the part of the apparatus driven thereby.

In finishing surfaces by my improved apparatus and method, the abrading action on the material of the work protruding beyond the base line **12** thereof is so controlled by proportioning of the pressure with which the abrading elements are urged against the work, the viscosity of the lubrication film on the work surface, the speed of relative movement of the work and abrading element, and the character of the grit of the latter as to discontinue cutting action upon the work as the protruding portions are removed to the base line **12**, as illustrated in Fig. 2. The viscosity of the lubricant film on the work surface holds the grit of the abrading element

against penetrating the film under the unit pressure existing at the base line 12 and therefore the formation of finishing formed scratches is prevented.

During removal of the ridges 10, the lubricant serves to carry away the abraded particles of the material of the work which are effectively unloaded from the abrading elements by the reversal in its movement during reciprocation, thus maintaining the abrading elements in efficient cutting condition when abrading action is desired.

The relatively low rate of relative movement between the work and the abrading element assures maintaining of the temperature of the surface operated upon at substantially room temperature and far below the instantaneous temperatures existing in conventional metal removing processes during which the metal is heated to a state of scratchable ductility. Such control of the temperature of the work surface also prevents reducing of the viscosity of the oil film thereon. The shortness of the stroke of the reciprocatory movement eliminates all possibility of the formation of scratches of substantial length even during initial stages of the finishing process when the unit pressure of application of the abrading element is of a maximum value.

The abrading factors may be so predetermined as to discontinue the cutting action before the ridges have been removed to the base line indicated at 12 in Fig. 2, in instances where the surface requirements are satisfied by the condition of surface existing before the base line has been reached. The resulting surface is, however, free from finishing formed scratches, although it may still contain residual portions of the lands 11. Due to excessive depths of spaced isolated lands, some residual land portions may remain after the ridges have been removed to the base line 12 but in any event the residual lands constitute only an insignificant portion of the smooth finished area and they serve as lubricant reservoirs when the surface is lubricated in use. The substantially continuous surface presented at the base line 12 differs from surfaces finished by processes and apparatus heretofore employed by which the tool formed ridges are either converted to similar ridges of smaller height and closer spacing, substituted by such smaller ridges, or polished on their sides to present only a light reflecting appearance of smoothness. Any irregularities such as the residual land portions, illustrated in Fig. 2, remaining after the finishing operation extend inwardly from the base line 12 into the body of the work rather than outwardly from the base line. Such finished surfaces therefore are free from the protruding particles which heretofore, particularly in bearing and journal structures, have had a tendency to penetrate an oil film and wear the parts with which they are operatively associated. This property of surfaces finished in accordance with the invention results in longer life of both the finished parts of a structure and the parts which operatively contact therewith. No appreciable dimensional changes are produced during removal of the ridges since their heights are so minute and cutting discontinues when they have been removed to the base line.

Cyclic variation of one or more of the component movements which contribute to the resultant relative abrading movement of the work and abrading elements causes successive resultant movements to occur in different directions and assures a variety of directional applications of the abrading element to all portions of the surface being finished. The cyclic variation of the pressure with which the abrading element is applied to the work, which is kept within limits such that abrading ceases as heretofore set forth, similarly subjects all portions of the surface under treatment to a variety of unit pressures. These variations in the abrading functions produce a scrubbing action of the abrading elements upon the work during which retracing of the same path on the work by localized large or hard particles of grit of the abrading element is effectively guarded against.

By embodying in a tool a plurality of abrading elements which are so arranged as to successively operate upon substantially the same increments of area of the work in an alternate manner as the work rotates, and by maintaining the abrading operations of the respective elements at different values, no portion of the work is so subjected continuously to the action of any one abrading element as to result in imparting to the work surface under treatment only the characteristics of any one abrading element or its mode of operation.

Although but several specific embodiments of the invention are herein shown and described, it will be apparent that various changes in the size, shape and arrangements of parts may be made without departing from the spirit of the invention.

I claim:

1. The method of finishing a surface having a multiplicity of minute ridge-like projections or scratches thereon to substantially remove said projections and produce a surface substantially free from scratches which comprises moving an abrading element over said surface in engagement therewith at a predetermined speed and pressure and maintaining a film of oil on said surface of such viscosity that the unit pressure between the abrading element and the surface is sufficient to rupture said oil film to engage and wear away the tops of any irregularities of said surface and is insufficient to rupture said oil film during further relative moving application of said element to said surface under said pressure when said surface is substantially free from irregularities.

2. The method of finishing a surface of a piece of work which comprises the steps of supporting said work and an abrading element for contacting relative movement which is a resultant of at least two different directional component movements, drivingly cyclically producing said component movements while said abrading element is held in operative engagement with said surface of said work, and changing the ratio of the number of cycles of one of said component movements to the number of cycles of the other by varying the rate of occurrence of one of said component movements.

3. The method of finishing a surface of a piece of work which comprises the steps of supporting a piece of work and an abrading element for relative movement which is the resultant of components of relative rotative and relative reciprocatory movement of said work and abrading element, simultaneously drivingly cyclically producing said relative component movements, urging said abrading element against said work during said relative movements, and repeatedly varying the rate of occurrence of cycles of at least one of said components between maximum and

minimum limits during said finishing operation.

4. The method of finishing a surface of a piece of work which comprises the steps of supporting a piece of work and an abrading element for relative movement which is the resultant of components of relative rotative and relative reciprocatory movement of said work and abrading element, simultaneously drivingly producing said relative component movements, urging said abrading element against said work during said relative movements, and changing the ratio of the number of reciprocative to rotative component movements by varying the speed of said reciprocatory component movements from one value to another.

5. The method of finishing a surface of a piece of work which comprises the steps of supporting a piece of work and an abrading element for relative movement which is the resultant of components of relative rotative and relative reciprocatory movement of said work and abrading element, simultaneously drivingly producing said relative component movements, urging said abrading element against said work during said relative movements, and varying the directions of successive resultant movements of said work and abrading element by cyclically varying the rate of said rotative component.

6. The method of finishing a surface of a piece of work which comprises the steps of supporting a piece of work and an abrading element for relative movement which is the resultant of components of relative rotative and relative reciprocatory movement of said work and abrading element, simultaneously drivingly producing said relative component movements, urging said abrading element against said work during said relative movements, and varying the direction of successive resultant movements of said work and abrading element by cyclically varying the rates of both of said component movements.

7. The method of finishing a surface of a piece of work which comprises the steps of supporting said work and an abrading element for relative movement which is the resultant of relative rotative, relative short stroke reciprocative and relative long stroke feeding component movements, drivingly producing said relative component movements, urging said abrading element against said work during said relative movements, and varying the directions of successive resultant movements by cyclically varying said feeding movement component.

8. The method of finishing a surface of a piece of work which comprises simultaneously applying to adjacent increments of said surface a pair of reciprocative abrading elements, drivingly reciprocating said elements at respectively different speeds, and drivingly producing such additional relative movement between said work and said elements as to cause substantially the same increment of area of said surface to be operated upon alternately by each of said abrading elements respectively.

9. The method of finishing a cylindrical surface of a piece of work which comprises the steps of rotatively supporting said work, simultaneously applying to circumferentially spaced increments of said surface a pair of reciprocative abrading elements, drivingly reciprocating said elements at respectively different speeds, and alternately bringing substantially the same increments of area of said surface into operative engagement with each of said abrading elements respectively by drivingly rotating said work.

10. The method of finishing a cylindrical surface of a piece of work which comprises the steps of rotatively supporting said work, simultaneously applying to circumferentially spaced increments of said surface a pair of reciprocative abrading elements, drivingly reciprocating said elements through strokes of different length and at different speeds respectively, and alternately bringing substantially the same increments of area of said surface into operative engagement with each of said abrading elements respectively by drivingly rotating said work.

11. The method of finishing a cylindrical surface of a piece of work which comprises the steps of rotatively supporting said work, simultaneously applying to circumferentially spaced increments of said surface a pair of reciprocative abrading elements, drivingly reciprocating said elements at respectively different speeds, alternately bringing substantially the same increments of area of said surface into operative engagement with each of said abrading elements respectively by drivingly rotating said work, and urging said elements against said work with respectively different pressures.

12. The method of finishing a cylindrical surface of a piece of work which comprises the steps of rotatively supporting said work, simultaneously applying to circumferentially spaced increments of said surface a pair of reciprocating abrading elements, drivingly reciprocating said elements at respectively different speeds, alternately bringing substantially the same increments of area of said surface into operative engagement with each of said abrading elements respectively by drivingly rotating said work, and cyclically varying the pressure with which said elements are applied to said work during the finishing operation.

13. The method of finishing a cylindrical surface of a piece of work which comprises the steps of rotatively supporting said work, simultaneously applying to circumferentially spaced increments of said surface a pair of reciprocative abrading elements, drivingly reciprocating said elements at respectively different speeds, alternately bringing substantially the same increments of area of said surface into operative engagement with each of said abrading elements respectively by drivingly rotating said work, and cyclically varying the rotative speed of said work during the finishing operation.

14. Apparatus for finishing a surface of a piece of work including an abrading element, means for supporting said abrading element and work for contacting rotative and reciprocatory movement relative to each other, mechanism for drivingly producing relative rotative and reciprocatory movements of said work and abrading element, and mechanism for urging said abrading element against said work under pressure including a resilient pressure applying element and means operable independently of said first-mentioned mechanism for automatically repeatedly changing on all portions of the work surface operated on the magnitude of said pressure applied by said element between maximum and minimum limits.

15. Finishing apparatus including a frame structure, means thereon for rotatively supporting a piece of work having a surface to be finished, a tool support, a tool on said support including a pair of independently reciprocable finishing abrading elements each engageable with increments of said surface spaced arcuately

about the rotative axis of said work, means for drivingly reciprocating each of said elements at respectively different rates, and mechanism for rotating said work during operation of said abrading elements.

16. Finishing apparatus including a frame structure, means thereon for rotatively supporting a piece of work having a surface to be finished, a tool support, a tool on said support including a pair of independently reciprocable finishing abrading elements each engageable with increments of said surface spaced arcuately about the rotative axis of said work, means for drivingly reciprocating each of said elements throughout respectively different lengths of stroke, and mechanism for rotating said work during operation of said abrading elements.

17. Finishing apparatus including a frame structure, means thereon for rotatively supporting a piece of work having a surface to be finished, a tool support, a tool on said support including a pair of independently reciprocable finishing abrading elements each engageable with increments of said surface spaced arcuately about the rotative axis of said work, means for drivingly reciprocating each of said elements at respectively different rates and throughout respectively different lengths of stroke, and mechanism for rotating said work during operation of said abrading elements.

18. Finishing apparatus including a frame structure, means thereon for rotatively supporting a piece of work having a surface to be finished, a tool support, a tool shiftably mounted on said support for movement toward and away from said surface including a pair of independently reciprocable abrading elements each engageable with segments of said surface spaced arcuately about the rotative axis of said work, means for yieldably urging said tool toward said work and predetermining the pressure of application of said abrading elements on said surface, mechanism for drivingly reciprocating said abrading elements including a common driving member and drive transmission means operatively connecting the latter with said abrading elements, said drive transmission means being so constructed and arranged as to establish the reciprocating characteristics of said abrading elements at different predetermined values, and means for drivingly rotating said work about said axis.

19. Finishing apparatus including a frame structure, means thereon for rotatively supporting a piece of work having a surface to be finished, a tool support, a tool shiftably mounted on said support for movement toward and away from said surface including a pair of independently reciprocable abrading elements each engageable with segments of said surface spaced arcuately about the rotative axis of said work, means for yieldably urging said tool toward said work and predetermining the pressure of application of said abrading elements on said surface including mechanism for repeatedly varying the magnitude of said pressure between predetermined limits during a finishing operation, mechanism for drivingly reciprocating said abrading elements including a common driving member and drive transmission means operatively connecting the latter with said abrading elements, said drive transmission means being so constructed and arranged as to establish the reciprocating characteristics of said abrading elements at different predetermined values, and means for drivingly rotating said work about said axis.

20. Finishing apparatus including a frame structure, means thereon for rotatively supporting a piece of work having a surface to be finished, a tool support, a pair of tools shiftably mounted on said support for movement toward and away from said surface and arcuately spaced about the rotative axis of said work, each of said tools including a reciprocable abrading element engageable with said surface, means for drivingly reciprocating the abrading elements of said tools and establishing their reciprocating characteristics at different predetermined values respectively, mechanism for yieldably urging said elements against said surface with respectively different predetermined pressures, and means for drivingly rotating said work during reciprocation of said abrading elements, whereby substantially the same increments of area are brought into operative engagement with each of said abrading elements during a single rotation of said work.

21. Finishing apparatus including a frame structure, means thereon for rotatably supporting a piece of work having a surface to be finished, a tool support shiftably mounted on said frame structure for feeding movement in the direction of the rotative axis of said work, a pair of tools shiftably mounted on said support for movement toward and away from said surface and arcuately spaced about the rotative axis of said work, each of said tools including a reciprocable abrading element engageable with said surface, means for drivingly reciprocating the abrading elements of said tools and establishing their reciprocating characteristics at different predetermined values respectively, mechanism for yieldably urging said elements against said surface with respectively different predetermined pressures, means for drivingly rotating said work during reciprocation of said abrading elements, whereby substantially the same increments of area are brought into operative engagement with each of said abrading elements during a single rotation of said work, and means for shifting said tool support in the direction of the axis of said work to feed said abrading elements over the length of said surface.

22. Apparatus for finishing the surface of a pair of rolls having adjacent cooperating peripheral portions while the latter are supported on their normal bearings of a roll including machine comprising a tool support, a tool mounted on said support including a main body portion and a reciprocative abrading element and means for drivingly reciprocating the latter relative to said main body portion, means for shiftably supporting and adjustably mounting said support in proximity to said rolls, said means and said tool support being spaced laterally from registering portions of said rolls and so constructed and arranged as to accommodate selective movement of said tool into unobstructing relationship with respect to the adjacent peripheral portions of said rolls and into operative engagement with each of said rolls respectively, said tool support and tool being shiftable as a unit in the direction of the axes of said rolls for feeding movements, and means for feeding said tool over the length of said rolls.

23. Apparatus for finishing the surface of a roll including a frame structure, means thereon for rotatably supporting said roll on its normal axis, a carriage shiftably mounted on said frame structure for reciprocatory movement in the di-

rection of said axis, a plurality of lapping tools shiftably mounted on said carriage in courses substantially converging at said axis, said tools having reciprocatory abrading elements engageable with circumferentially spaced increments of the surface of said roll, means for drivingly reciprocating said elements, rotating said roll and reciprocating said carriage, and fluid pressure mechanism operating upon each of said tools for yieldably urging the abrading elements thereof against said surface.

24. The method of finishing a surface having a multiplicity of minute ridge-like projections thereon to substantially remove said projections and produce a surface substantially free of projections which comprises the steps of: applying an abrading element of predetermined grit size to said surface under a predetermined unit pressure, in the presence of a lubricant coolant of predetermined viscosity, and producing relative movement of predetermined speed between said surface and said abrading element, said predetermined speed, grit size, unit pressure, and viscosity of said coolant being so related that after said projections have been removed and said surface is rendered smooth, a film of said coolant is automatically formed between said surface and said abrading element and prevents the grit particles of said abrading element from further cutting into said surface and the grit particles in effect are caused to float upon said surface without scratching or otherwise disfiguring the same, even though said relative movement and application of said pressure continue.

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