Nov. 24, 1964 C. B. KURTZ 3,157,968

METHOD AND MEANS FOR BELT LAPPING AND FINISHING

Filed Sept. 9, 1960 8 Sheets-Sheet 1

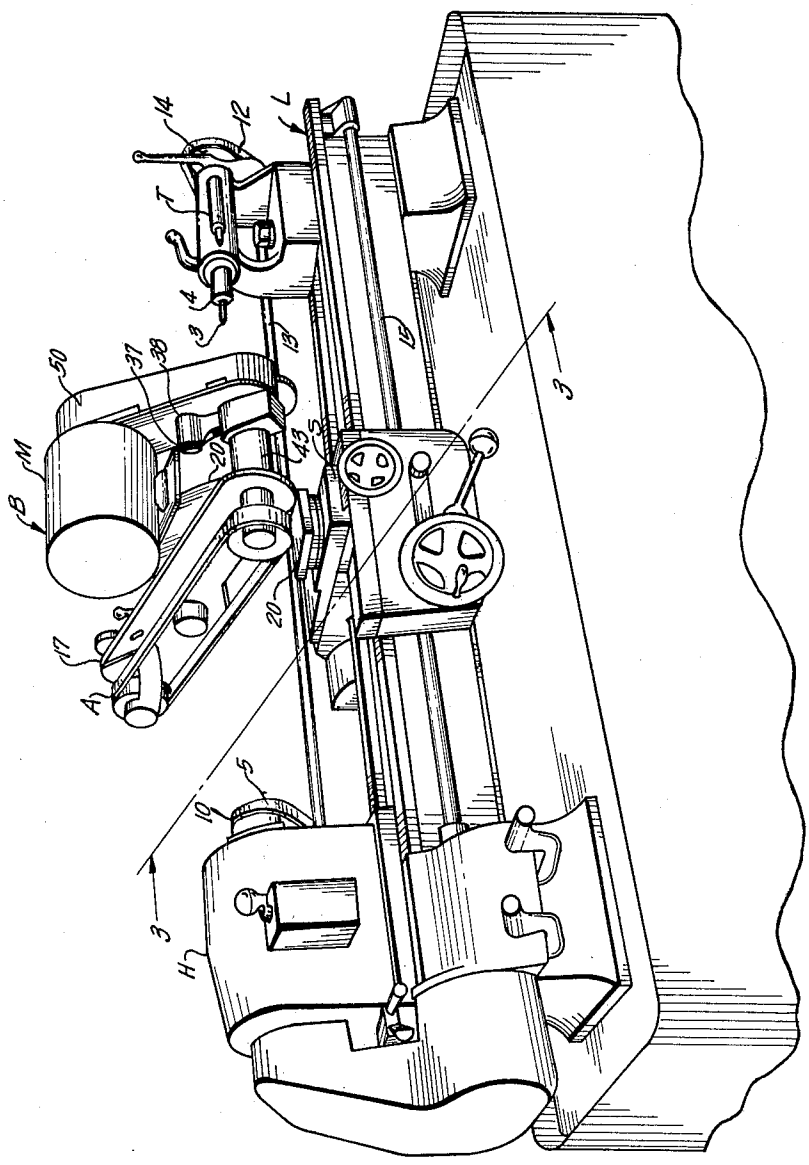


Fig. 1

INVENTOR.
CYRUS B. KURTZ
BY Bacon & Thomas, Spencer, Fisher, Britton & Knobbe
ATTORNEYS

Nov. 24, 1964 C. B. KURTZ 3,157,968

METHOD AND MEANS FOR BELT LAPPING AND FINISHING

Filed Sept. 9, 1960 8 Sheets-Sheet 2

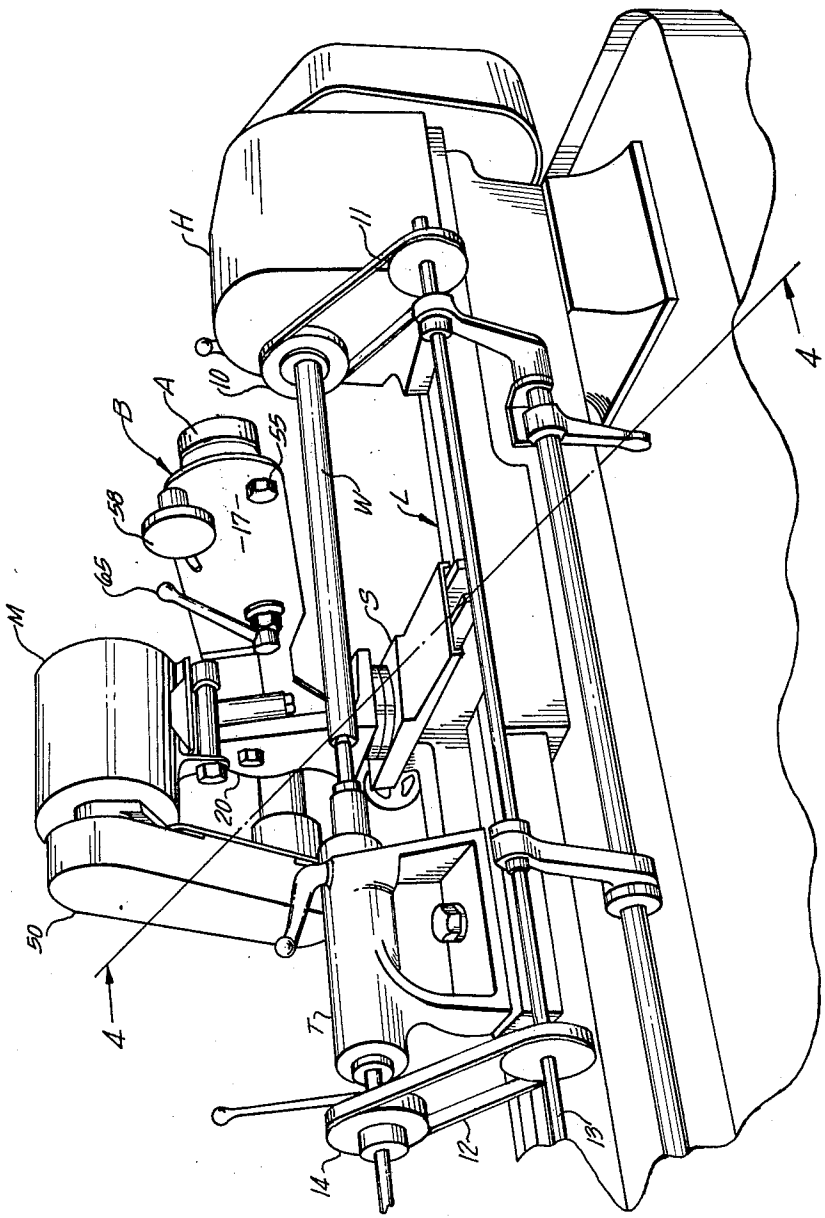


Fig. 2

INVENTOR.
CYRUS B. KURTZ
BY Burnett, Jenkins, Hemstead & Kramer
ATTORNEYS

Nov. 24, 1964 C. B. KURTZ 3,157,968

METHOD AND MEANS FOR BELT LAPPING AND FINISHING

Filed Sept. 9, 1960 8 Sheets-Sheet 3

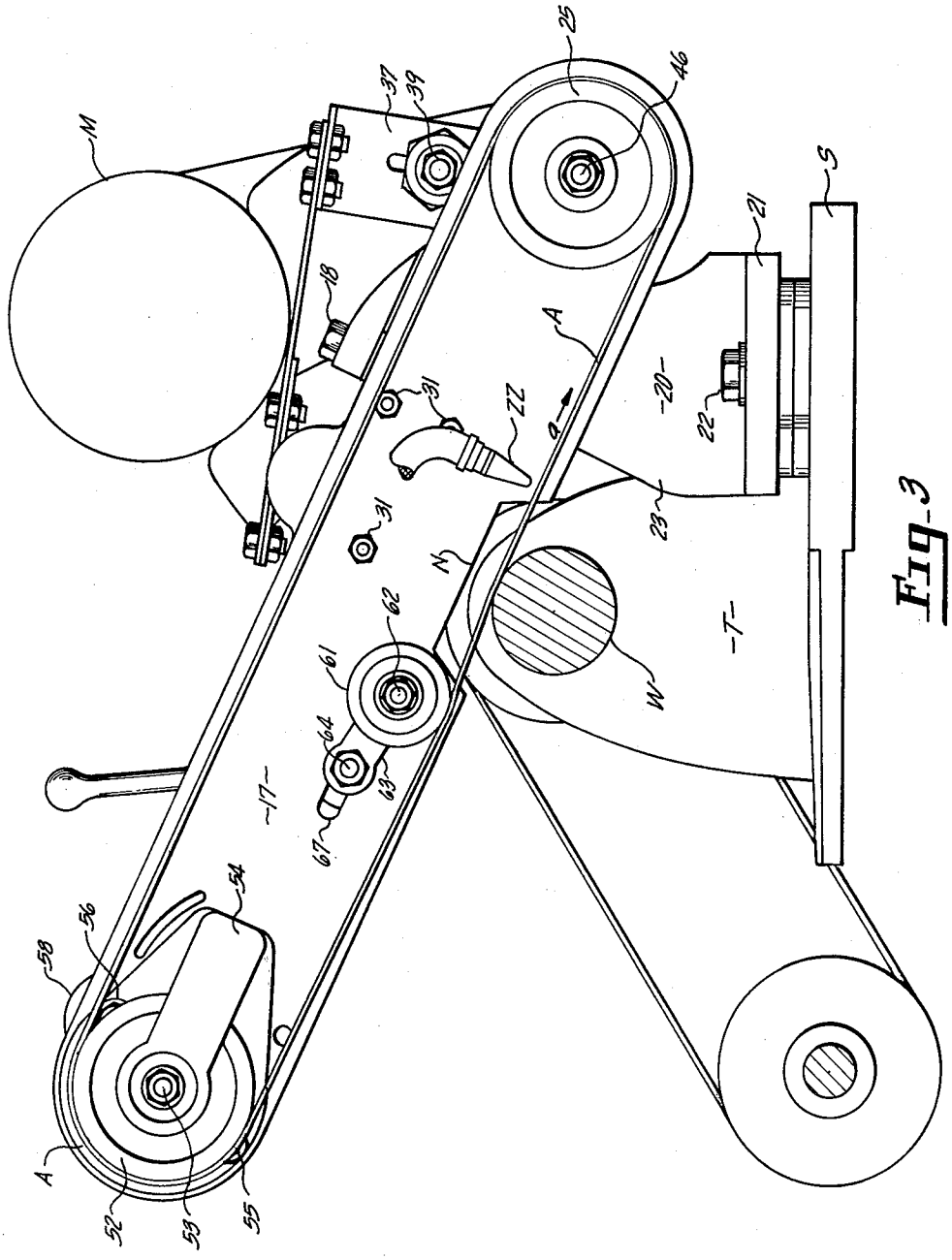


Fig. 3

INVENTOR.
CYRUS B. KURTZ
BY Banner, Jenning, Harrison & Knowles
ATTORNEYS

Nov. 24, 1964 C. B. KURTZ 3,157,968

METHOD AND MEANS FOR BELT LAPPING AND FINISHING

Filed Sept. 9, 1960

8 Sheets-Sheet 4

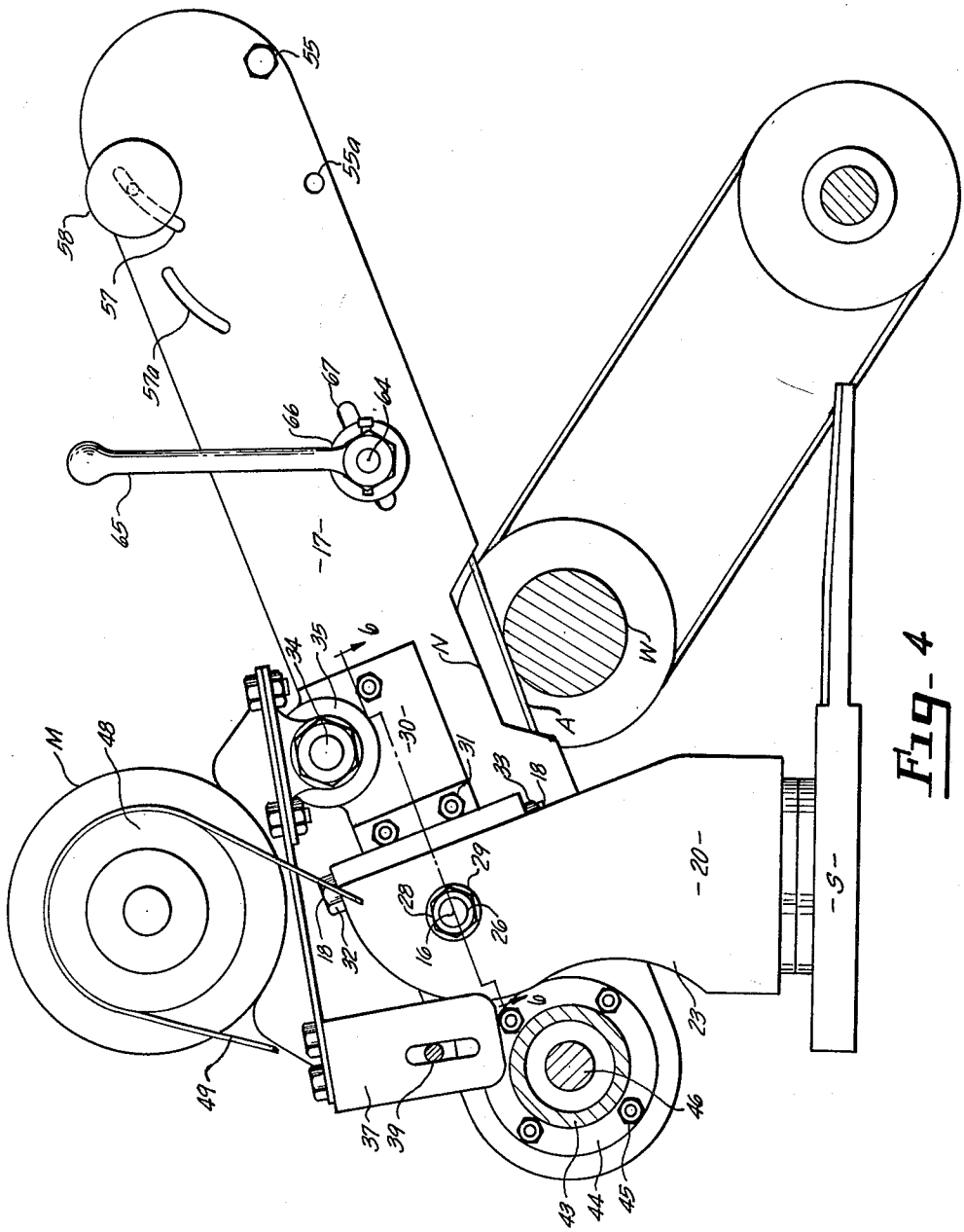


Fig. 4

INVENTOR.
CYRUS B. KURTZ

BY Burton, Simins, Hartman & Knowles
ATTORNEYS

Nov. 24, 1964 C. B. KURTZ 3,157,968

METHOD AND MEANS FOR BELT LAPPING AND FINISHING

Filed Sept. 9, 1960 8 Sheets-Sheet 5

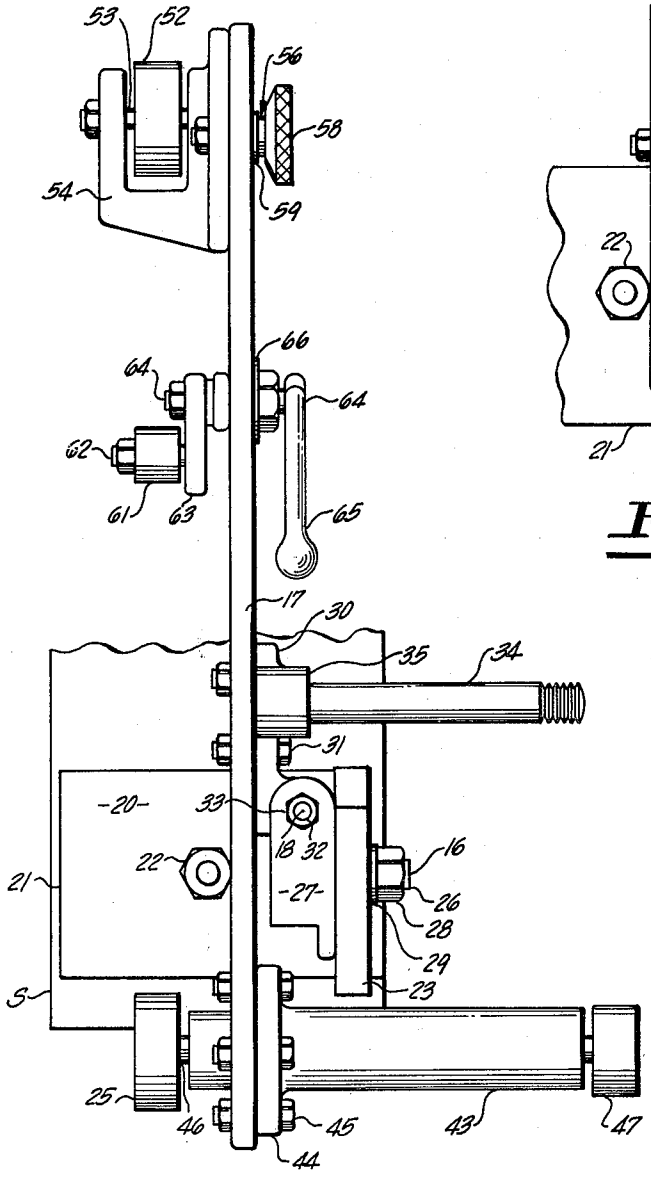


Fig. 5

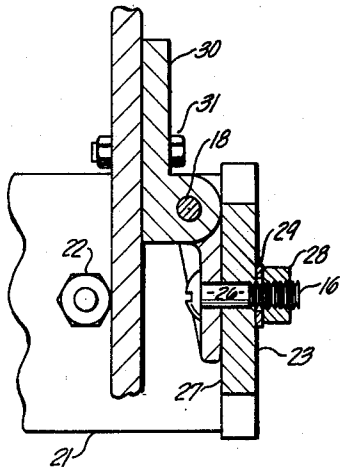


Fig. 6

INVENTOR.
CYRUS B. KURTZ
BY Burns, Jenkins, Hamilton & Knowles
ATTORNEYS

Nov. 24, 1964 C. B. KURTZ 3,157,968

METHOD AND MEANS FOR BELT LAPPING AND FINISHING

Filed Sept. 9, 1960 8 Sheets-Sheet 6

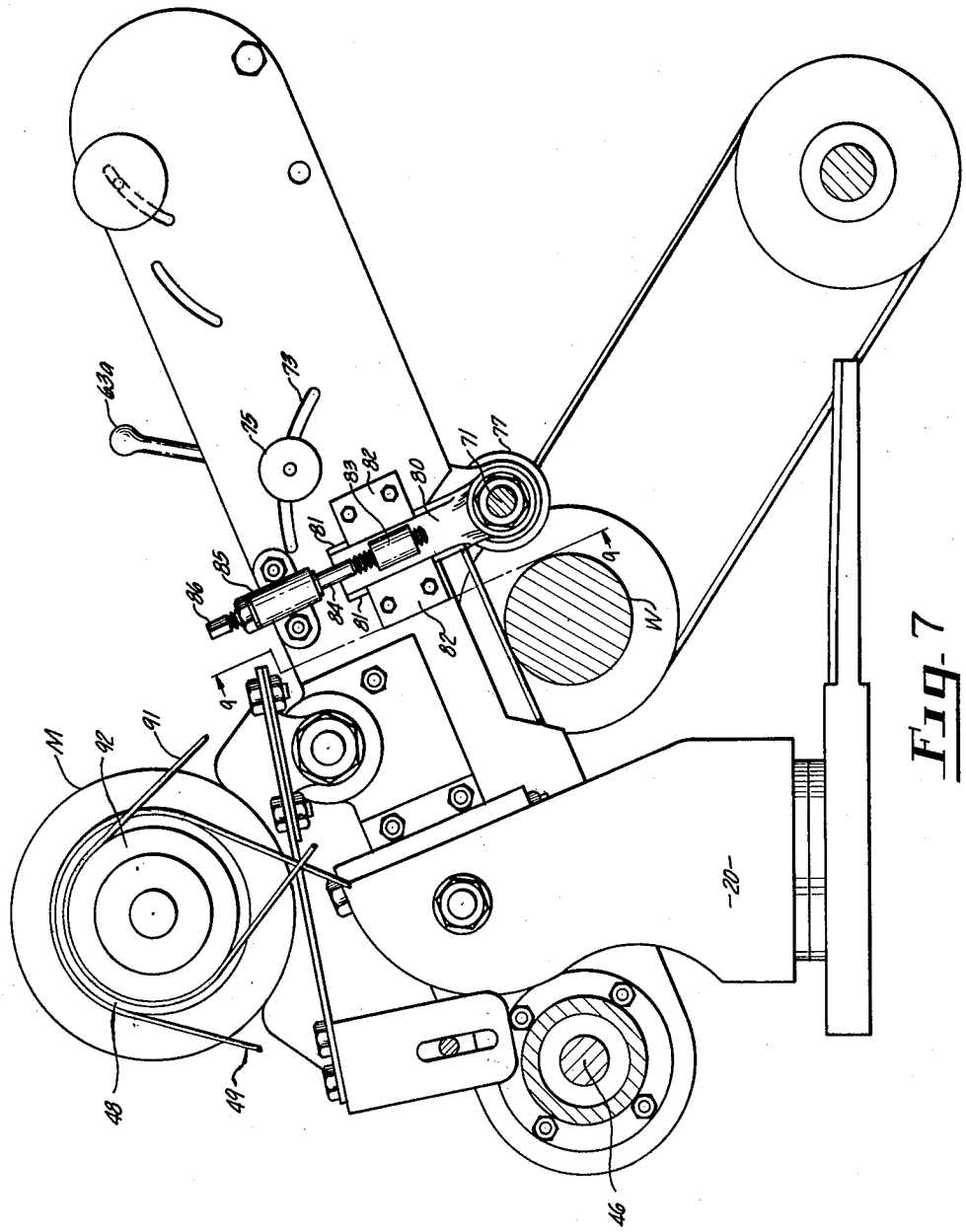


Fig. 7

INVENTOR.
CYRUS B. KURTZ
BY Burnett, Simons, Hewitson & Kreuder
ATTORNEYS

Nov. 24, 1964 C. B. KURTZ 3,157,968

METHOD AND MEANS FOR BELT LAPPING AND FINISHING

Filed Sept. 9, 1960 8 Sheets-Sheet 7

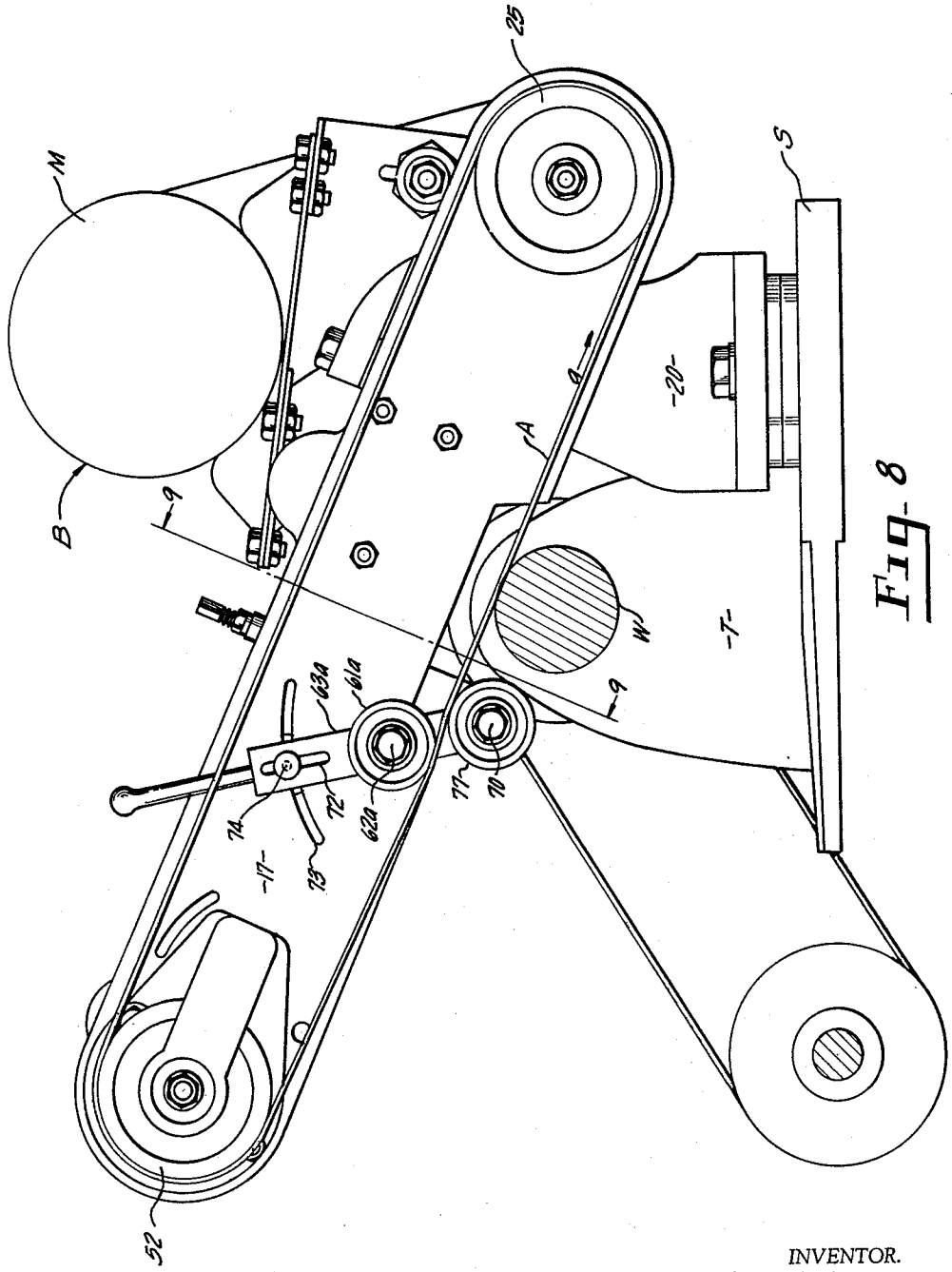


Fig. 8

INVENTOR.
CRUS B. KURTZ
BY Bennett, Semmes, Harrison & Knowles
ATTORNEYS

Nov. 24, 1964 C. B. KURTZ 3,157,968

METHOD AND MEANS FOR BELT LAPPING AND FINISHING

Filed Sept. 9, 1960 8 Sheets-Sheet 8

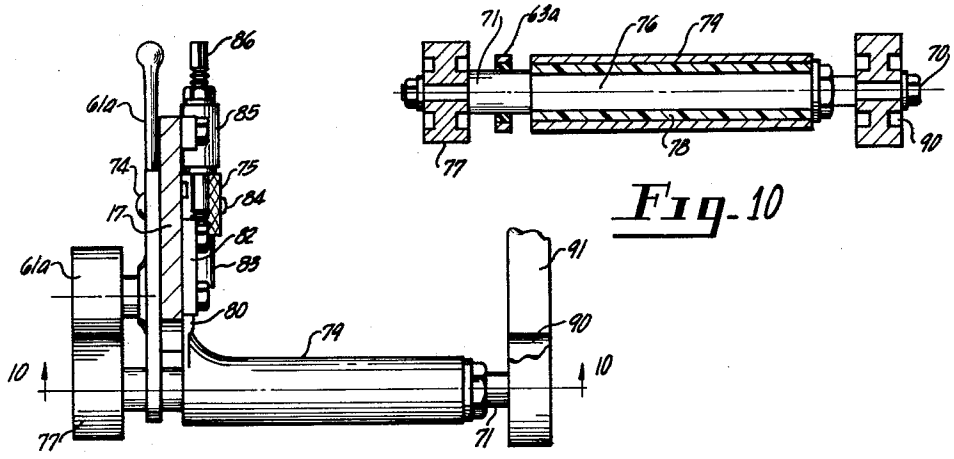


Fig. 10

Fig. 9

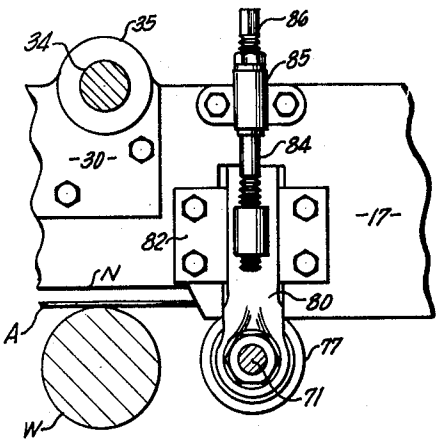


Fig. 11

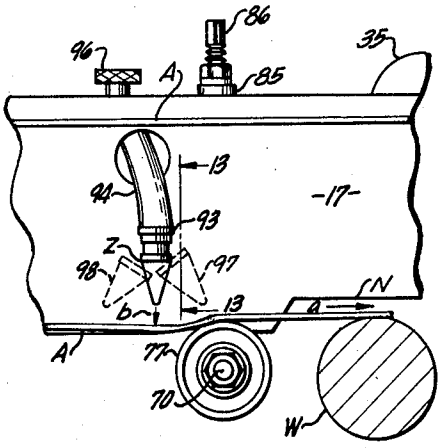


Fig. 12

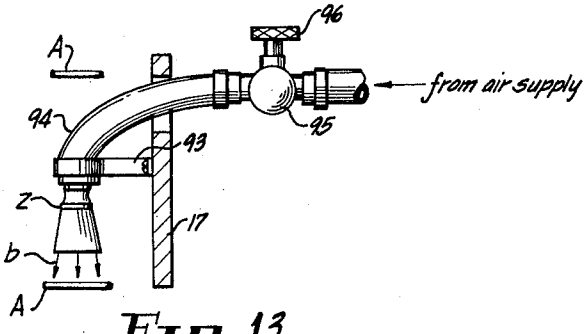


Fig. 13

INVENTOR.
CYRUS B. KURTZ
BY Burnett, Jenkins, Hemstreet & Kennedy
ATTORNEYS

United States Patent Office 3,157,968 Patented Nov. 24, 1964

3,157,968

METHOD AND MEANS FOR BELT LAPPING AND FINISHING

Cyrus B. Kurtz, 3372 Mayfield Road, Cleveland, Ohio

Filed Sept. 9, 1960, Ser. No. 55,008
10 Claims. (Cl. 51—145)

This invention relates to fine finishing the surfaces of solid bodies, and will be largely illustrated and described herein with reference to apparatus for and the art of finishing hard metallic surfaces wherein the acceptable or desirable departures from true geometrical smoothness may range from somewhat less than one to only a few micro inches.

It is among the objects of my invention to provide method and means for removing imperfections from the surfaces of hard, or relatively hard, material objects, things, bodies and pieces, such as steel or other metallic shafts, journals, arbors, pistons, valves, pump gears and the like, and/or imparting beneficent fine smoothness to such surfaces, with novel convenience and economy, and to do the same to such things having a considerable range of sizes, materials, hardness and/or initial roughness.

Another object of my invention is to perfect the surface finishes of such things as those mentioned above with a minimum alteration or change in the essential and intended tolerable dimensions thereof. For example, if a sliding valve part has its finished sliding external cylindrical surface of one inch diameter with a tolerance of only .001" plus or minus, but has a hard ground surface roughness of the order of 10 or 12 microinches which is sought to be improved to a finish of 1 or 2 microinches then, unless the part in its rough ground state is quite close to its minimum tolerable diameter, it is an example of this object of my invention to improve the finish of the surface, as mentioned above, without deleteriously reducing external diameter of the piece below the specified limit of tolerance.

Another object of my invention is to provide smooth finished surfaces in such aforesaid bodies, things, material objects and the like which are not only free from substantially all measurable or discernable roughness, but are also clean in the sense of being not only quite free from abrasive charge, but also free from partially removed or insecurely attached, or less than entirely integrated, constituent parts or microscopic pieces or particles of the stock of the surface of the body, thing or object which, with time, use or wear, could or will tend to separate or detach from the surface and injure or destroy the same or affect the quality thereof, or the parts with which it is intended to coact, deleteriously.

Another object is to provide method and means which tend to be of aid and comfort to the users thereof in the practice of my invention in the sense of facilitating inspection and understanding of the progress of finishing operations at desirable stages between the beginning and completion thereof, and similarly to facilitate the selection of the most expeditious and efficient steps and operations to do the intended work.

Other objects and advantages of my invention will appear from the following description of preferred and modified forms thereof; reference being had to the accompanying drawings, in which:

FIGURE 1 is a front elevation in perspective of a machine embodying and useful in the practice of my invention.

FIGURE 2 is a rear elevation in perspective of the machine of FIGURE 1 with, however, a work piece shown in position to be worked upon.

FIGURE 3 is a partial transverse elevation, partly in section showing the abrasive belt driving parts of the

machine as seen in a plane normal to the axis about which the work is supported taken along the line 3—3 of FIGURE 1, looking from the headstock rightwardly as viewed in FIGURE 1, and with the work piece of FIGURE 2 supplied.

FIGURE 4 is a partial transverse elevation taken oppositely of FIGURE 3 of much the same parts of the machine as shown in FIGURE 3 as seen in a plane normal to the axis of the work along the line 4—4 of FIGURE 2, looking, however, from the tail stock rightwardly as viewed to FIGURE 2.

FIGURE 5 is a top plan view of part of the abrasive belt carrying mechanism shown in FIGURES 1–4 with, however, the belt and driving motor removed.

FIGURE 6 is a section taken in the plane of the line 6—6 of FIGURE 4.

FIGURE 7 is a view corresponding in posture to FIGURE 4 and showing a modified form of belt positioning means.

FIGURE 8 is a view corresponding to the posture of FIGURE 3 and showing the opposite side of the modified form of the belt positioning means of FIGURE 7.

FIGURE 9 is a sectional view taken in the plane of the lines 9—9 of both FIGURES 7 and 8.

FIGURE 10 is a sectional view taken in the plane of the lines 10—10 of FIGURE 9.

FIGURE 11 is a fragmentary view corresponding in part to FIGURES 4 and 7 and showing a second modified form of belt positioning means of my invention.

FIGURE 12 is a fragmentary view corresponding in part to FIGURE 8 showing the opposite side of the backing plate with the second modified belt positioning means, and

FIGURE 13 is an elevation of the air nozzle of FIGURE 12 as viewed in the plane of the line 13—13 of FIGURE 12.

Referring to FIGURES 1 and 2, a preferred embodiment of the machine embodying my invention presents the abrasive belt A to the cylindrical work W with facility of position, contact and control including, among other things, the speed and direction of movement of the belt relative to the work, the pressure of contact therebetween and the feed of the belt over the surface of the work. I have found it practical to practice and embody my invention in apparatus which includes some familiar parts of the conventional lathe L for supporting and driving the work W on the one hand, and for supporting and positioning the abrasive belt driving and tensioning mechanism B on the other hand, which is carried for substantially universal positioning movement relative to the axis of the work on the cross slide S of the lathe L. Preferably the work W is rotated about its own axis so that its surface contacting the abrasive belt A may have movement relative to the locus of the belt, preferably in the same direction as the motion of the belt.

In this form of my invention the work W is supported and driven by live centers 3 at both ends, one rotatably carried by the spindle of the headstock H and the other carried by a rotatable spindle 4 of the tailstock T; the headstock having appropriate conventional driving mechanism, not shown, and carrying on its driving spindle adjacent its live center, a pulley 10 which, through V belts 11 and 12, jack shaft 13 and tailstock live center pulley 14, drives the live center carried by the tailstock at the same speed as the spindle and live center of the headstock. I prefer to support the work drivably and rotatably at both ends, or throughout, to avoid angular pulsations that might be caused as by friction with a dead center, for instance. The carriage C of the lathe L, which carries the cross slide S with the belt driving and positioning mechanism B is driven longitudinally of the

lathe bed at conventional selected or selectable rates of feed as by the feed screw **15**, FIG. 1, and/or manually in the conventional way; either or both means moving the abrasive belt A as a whole longitudinally, i.e. in the direction of the axis of the work. Correlation of the feed to the speed of rotation of the work determines the helix of the progress of the place of contact between the belt and the work. The coincidence with, or departure of coincidence from, the path of motion of the belt at the work and a tangent to the said helix facilitates one element of the operator's choice among specific visual and microscopic cutting and finishing patterns on the surface of the work.

Preliminarily, it may be observed with reference to FIGURES 1–4 that the abrasive belt A may be disposed with its work contacting strand adjustably inclined to the horizontal, i.e. inclined about the axis **16**, FIGS. 4, 5 and 6, with respect to the direction of motion of the cross slide S, whereby movement of the cross slide S with and carrying the belt supporting mechanism B will provide a quick gross movement of the working strand of the belt toward and away from the work. As will be more fully described below, the belt may also have wide angular positioning movement relative to the axis of the work W, and relative to planes normal to the axis of the work, by adjustably swinging the belt backing plate **17** about the axis **18**, FIGS. 3, 4, 5 and 6 without moving the work engaging strand of the belt relative to desirable tangency with the work; the axis **16** and **18** being mutually normal to planes containing the other axis which intersect each other at right angles. The axis **18** is also normal to the plane of the lower, i.e. work engaging strand of the belt A in all its positions of movement about the horizontal axis **16**. The belt may be swung through a wide range of angular relations relative to the axis of the work without changing the radial distance from the axis of the work to the nearest part of the belt. The backing plate **17** may be swung about the axis **18** when the belt has a desired pressure or working engagement with the surface of the work through a wide range of angles at and departing from coincidence with the helix of the place of contact between the belt and the work and without impairing the pressure of contact between the belt and the work, so long as the axis **16** remains parallel with and at a fixed distance from the axis of the work and the backing plate **17** is restrained from pivotal motion about the axis **16**.

As the description of the mechanism proceeds it will be convenient to have in mind steps and principles of my method of finishing which may be practiced with the aid of my machine. A principle of my method is to bring about smoothness in the surface to be finished of a hardened and ground circular, cylindrical, steel work piece, for example, by the removal of constituent upstanding parts of the irregularities of the material stock in the surface, as distinguished from changing the shape of the surface stock irregularities as by pushing, bending, hot or cold-flowing or displacing the microscopic hilltops and ridges of the work stock over and/or into the microscopic valleys or craters thereof, therebetween. Collateral to this principle and procedure is the maintenance of entire cleanliness of the finished surface by the persistent and exclusive removal of work stock or material with the avoidance of retaining, trapping or embedding abrasive particles, or surface stock particles, in the surface or under or adjacent a displaced, bent-over or flattened out part of the surface stock.

A step of my method consistent with this principle is the high speed impingement of abrasive particles carried by the belt against the microscopic ridges and hilltops of the surface with such speed and direction that the abrasives will cut off and sever cleanly significant microscopic chunks, bits or pieces of the upstanding stock of the surface and remove them bodily and entirely from the surface and from the work of which the surface is being finished.

Another step or consideration is to progressively employ finer abrasive particles as the roughness of the surface is reduced. My teaching is also to employ greater pressure between the abrasive carrying surface of the belt and the work for the coarser cutting with coarser abrasives and to progressively reduce the pressure between the belt and the work as finer abrasives are employed and diminished quantities of surface particles are sought to be removed, and/or actually removed, with the increase in the smoothness of the surface.

Pervading these teachings, my method also comprehends that the high speed motion of the belt and the abrasives carried thereby across the surface of the work be accompanied by selection of successive and/or sequential directions of the cutting motion of the abrasives transversely or (at visually discernible and appreciable angles to) the microscopic ridges and valleys in the rough, relatively rough and/or next preceding state of relative roughness of the surface of the work whereby to cut transversely across the first existing, i.e. larger, ridges and then sequentially, preferably with the change from relatively coarse to relatively fine abrasives, to cut down the ridges made by preceding coarser cuts by subsequent finer transverse cuts into the ridges left by the preceding and/or coarser cuts.

A dividend of added utility and convenience following my method is that visual inspection of the work between different abrasive "cuts" in which preceding cuts are identifiable on the surface by depth and direction, reveals to the operator his progress toward the desired finished surface by the separately identifiable patterns of the original roughness and of the progression of different cutting operations which have reduced the original and following roughnesses progressively.

Within these steps and principles, I seek to remove a minimum total substance of the stock of the work as by reducing or tending to remove the peaks and ridges of the unfinished rough surface without digging new valleys in the floors of old ones. In the realm of roughness and smoothness in which my invention has its present best utility it is practicable to enhance the surface finish down to about one microinch without deleterious change in the dimensional tolerance of carefully ground work pieces.

While the description of the mechanism embodying my invention proceeds, it may profitably be kept in mind that I have presently found it advantageous to rotate the work at a rate to give a steady surface speed of from about 50 to 200 feet per minute, preferably in the same general direction as the movement of the belt, and to move the abrasive particles, carried by the belt, across the surface to be finished at speeds of from about 8000 to about 12,000 feet per minute. It is desirable that the work be moved in a manner to be free of bodily and angular vibration and to have noticeable surface motion of substantially constant velocity preferably in the same general direction as the direction of motion of the belt. The advantage of similar directions of motion is to avoid the tendency of the belt, by its forcible, abrasive, working engagement with the surface of the work, to retard the motion of the work deleteriously or bring it to a stop, as a result of which the belt would engage a single place in an accelerating or stationary surface more than or rather than a succession of places all moving to and from engagement with the belt at a substantially constant rate. When the work piece is cylindrical and is rotated in a special lathe as herein specifically illustrated, its direction and speed of rotation and, therefore, its surface direction and speed, depending upon its diameter, can be readily selected, established and/or changed by the familiar speed selection and gearing in and associated with the headstock. The speed of the belt is preferably and most economically selected and established by the speed of the driving motor, its driving pulley and the pulley

driven by it as will more fully appear below. I do not exclude from my teaching the employment of variable speed motors nor variable speed drives between a constant speed motor and the belt driving shaft in cases where the same may be advantageous or desirable.

With such speed and direction relationships between the belt and the work, I prefer to employ an abrasive charge of about 325 to 600 mesh, or from about 20 to 60 microns, charged into a thin, flexible, charge-carrying, stretch-resistant belt, for the coarse work of beginning to finish a surface having roughness of about 12 to 18 microinches as measured, for example, with a Brush surface analyzer from the deeper of the microscopic valleys to the higher of the microscopic ridges. With such a belt of one inch width, such speed and abrasives, and for such coarse cutting, I have found it practicable to exert a pressure of from about 50 ounces to about 100 ounces upon the belt near, but from about 1" to 2" "ahead of" the work when the work comprises a hardened steel circular, cylindrical piece of about 1" diameter. I have noticed that pressures of about 100 ounces so exerted, or pressures not greatly in excess thereof, tend to cause noticeable sparking at the surface of the work. This is a thing which I prefer to avoid because I presently believe it tends to mark the approximate desirable limit of maximum desirable beneficent pressure to be exerted between the belt and the work for this order of coarser cutting and finishing.

My present observation and belief is that (1) up to about the point of visible sparking due to pressure exerted by the rapidly moving belt, and/or abrasives, upon the work that the peaks and ridges in the relatively rough surface are cut cleanly and coolly, and that the stock thereof is cleanly severed as cool, solid particles and removed entirely from the work as I prefer, but (2) higher pressures and appreciable and/or greater sparking suggests a condition of heat and minute fusing and melting with less than complete, clean, cold removal of the whole particle sought to be severed away; fused parts of such intended particles tending to flow or be pushed into a valley in the surface to give an illusive and transitory appearance of smoothness with, however, a consequent tendency and potential to leave its temporary residence and become a wandering element of injurious wear or destruction. Moreover, bent-over or flattened-out particles may well entrap and hold, temporarily, abrasive particles for deleterious release when the surface is used.

Maintaining about the same range of belt speeds and progressively changing directions and increasing the fineness of the abrasives as described above, I have found it advantageous to employ on my belts for the finishing cuts and passes, abrasive charges of from about 600 mesh to about 3000 mesh or less, i.e. from about 20 to about 3 or 4 microns, and to use the finer abrasives with softer and more flexible belts rather sparsely charged and with the application of belt pressures as light as from about 5 to 15 ounces between the belt and the work. This to bring the surface finish down to the order of about 1 to 2 microinches. For still finer finishes my teaching is to employ belts with softer surfaces more lightly charged with still finer abrasives and with still lighter pressure between the belt and the work but still employing high velocity of motion of the belt with the abrasives charge across the surface of the work and with frequent changes of direction of the cutting path. Such a step may be adequate for the concluding operation of bringing the smoothness of the surface down to less than 1 microinch "roughness."

The foregoing has assumed, inter alia, appropriate means for relating the belt to the work, and, in my machine, the whole of the belt driving and supporting mechanism B is capable of functioning as a going concern, wherefore a preferred form of the latter will now be more fully and particularly described.

The mechanism B for supporting, driving, tensioning and positioning the belt A relative to the work and controlling the pressure of contact between the abrasive face of the belt and the work includes in addiion to the carriage C and the cross slide S, the means and structures carried thereby comprising the angles base **20**, see FIGS. 3–5, which is a stout load-bearing casting having a lower horizontal leg **21** fixedly attached to the cross slide S as by a cap screw or means **22**, and having a vertical leg **23** with respect to which the backing plate **17** is supported for adjustable angular disposition about both of the axes **16** and **18** discussed above; the backing plate carrying the belt driving pulley **25** and other belt supporting and controlling pulleys to be described below, on the one hand, and the belt driving motor M with its driving connections, on the other hand.

The axis **16** lies in and comprises the bolt or screw **26** carrying the hinge element **27**, FIGS. 5 and 6, and with the nut **28** and friction washer **29**, adjustably secures the hinge element **27** in any selected angular relation to the leg **23** about the axis **16**. Preferably, the angled base **20** is secured to the cross slide S with the axis **16** parallel to the axis of the work W. Hinge element **30** is fixedly secured to belt backing plate **17** as by bolts and nuts **31**, and is hinged to element **27** by hinge pin **32** which contains and comprises axis **18**; a nut **33** securing hinge pin **32**. FIGS. 1, 5 and 6 show that hinge element **27** is undercut near the upper edge of the backing plate to allow wide counterclockwise, as viewed in FIG. 5, swinging movement thereof about axis **18**.

The hinge element **30** carries the motor supporting shaft or arbor **34** pressed into the boss **35**, FIGS. 4 and 5; the arbor pivotally supporting the motor base **36** at its forward end, that is leftwardly as viewed in FIG. 3; the base having a downwardly turned and slotted portion **37** at the opposite, i.e. rearward end, rightwardly as viewed in FIG. 3 for adjustable clamping engagement with an element **38**, see also FIG. 1 which is fixedly related to the arbor **34** through the backing plate **17** whereby to adjustably modify the relative distance between the axis of the motor M and the axis of the abrasive belt driving pulley **25**. Clamping means **39** protruding through the slot in the part **37** and secured to the part **38** secure the motor in its desired adjustable positions.

As best shown in FIGS. 1, 4 and 5, a housing **43** is rigidly attached to the end of the backing plate **17** through the flanged end **44** of the housing as by clamping means **45** on the side of the plate opposite the driving pulley **25**. The housing carries interiorly anti-friction bearings, not shown, for the driving shaft **46** which carries the abrasive belt driving pulley **25** at the left end as viewed in FIGS. 1 and 5 and carries the shaft driving pulley **47** at the right end thereof; the pulley **47** having a belted connection with the motor pulley **48** through the driving belt **49**, FIG. 4. As best shown in FIG. 1 the motor supporting element **38** is removably but rigidly attached externally of the housing **43** and preferably carries also the belt cover **50**, FIGS. 1 and 2, which covers the driving belt **49**. The adjustably related parts **37** and **38** with the clamping means **39** described above facilitate tensioning of the motor driven belt **49** wherewith to deliver power and rotation to the driving pulley **25** and the abrasive belt A mounted thereon.

It may be pointed out here that the backing plate **17** with its motor supporting arbor **34** and drive shaft housing **43** all fixedly related, comprise a unitary structure which with the motor, pulleys, belts, bearings, adjustment means and the like carried thereby comprises a unitary assembly for driving the abrasive belt A in all the many useful and various positions and directions which may be desired to be given to the belt by any of the motions in any of the directions herein mentioned or suggested.

We turn now to the several means which are also carried by the backing plate **17** and are more directly and intimately associated with the abrasive belt A, its placement upon and removal from the machine, the driving, tensioning and positioning thereof and its controlled

and/or forcible engagement with the work; the plate being notched at N adjacent the work to expose the belt thereto.

At the end of the backing plate 17 remote from the driving pulley 25 I provide a belt tensioning pulley 52, FIGS. 1, 3 and 5, having an anti-friction mounting on a journal 53 which is parallel with and adjustably positionable toward and away from the driving shaft 46 by virtue of being mounted in an outboard and inboard bearing bracket 54 pivotally mounted on a support and axis 55, FIGS. 2 and 4, and held selectively by manually releasable and engageable clamping means 56 extending through an arcuate slot 57 in the plate 17 opposite the pivotal support 55. The clamping means includes the hand knob 58 with the friction washer 59 coacting with the plate 17 to adjustably position the bracket 54 with its shaft and pulley whereby to release the abrasive belt for easy removal from the pulleys 25 and 52, to secure the belt thereupon, and to effect and modify the tension sought to be maintained in the belt. As suggested in FIGS. 1 and 5 the pulleys 25 and 52 rotate on parallel axes and are transversely aligned and equally spaced from the plate 17 for proper drive and support of the belt in operative position spaced from and parallel with the backing plate as shown. I prefer that the driving pulley 25 rotate counterclockwise as viewed in FIG. 3 whereby to tension the lower strand of the belt between the work W and the pulley 25 and give it the direction of motion across the work shown by the arrow *a*, FIG. 3. I also prefer to duplicate the slot 57 as at 57*a* and duplicate the aperture in the plate 17 for the pivotal axis 55 as at 55*a*, FIGS. 3 and 4, so that abrasive belts of markedly different lengths may be employed by shifting the bracket 54 with its shaft, pulley and clamping means to coact therewith in the same way at a position nearer the pulley 25. Presently certain abrasive belts suitable to my purposes are available commercially in one inch width and two different "standard" lengths of about 36" and 42"; wherefore the 55–57 and 55*a* and 57*a* positions of the bracket 54 are chosen and provided to accommodate such belts.

As suggested in FIG. 2 the pulley 25 is desirably positioned a few to several inches away from the work W. This spacing and the flexibility of the belt give the belt its "head" in reference to the driving pulley 25 and let the belt moving at high speed follow the surface of the work with substantially uniform pressure of contact, regardless of not unusual deviations thereof from true geometrical perfection within useful commercial dimentional tolerances. For example, a nominal 1" diameter hardened steel journal might well have literal radial and/or circumferential deviations from .001" to .0001" and still need and profit from a surface smoothness of about one microinch. By letting the belt follow the work I tend to confine the abrasive cutting action of the belt-carried abrasives to finishing the surface without being impaired by, or becoming deleteriously involved in trying to change, the dimensional imperfections in the work piece. Preferably the pulleys 25 and 52 are slightly crowned, at about 2° for example, for the usual purpose; a minimum crowning with substantial spacing of the work from either crowned pulley, see also the disposition of the notch N, preserves the freedom of the belt A to "follow" the work.

In addition to controlling general desirable tension in the abrasive belt by adjustment of the pulley 52, I also provide an adjustably positionable pressure pulley 61, FIGS. 1, 3 and 5, with a right circular cylindrical belt-engaging surface and carried by the backing plate 17 in a position where it may engage the inward face of the lower work engaging strand of the belt A on the face opposite the work and well ahead of, or "upstream" of, the work in respect to the motion of the belt toward the pulley 25. Pulley 61 may be depressed upon the belt more or less, as shown best in FIG. 3, ahead of the work to increase, or change, the arcuate small area of contact between the abrasive side of the belt and the work, preferably from about 5° to 15° on cylindrical work, and to increase, or change, the pressure of contact therebetween. The pressure pulley 61, FIGS. 3 and 5, is aligned with pulleys 25 and 52 in the direction of belt movement and is preferably mounted on anti-friction bearings on an axis 62 parallel with the drive shaft 46, which axis is carried in the swingable end of a lever 63 mounted for swinging movement about the axis of the shaft 64 as the same may be induced by manual effort exerted on the operating lever 65 on the "other" side of the plate 17; desired selected pressure positions of the roller 61 being maintained against belt tension and motion through forcible friction contact between the washer 66 and the plate 17. The plate 17 is preferably slotted as at 67 to admit selective positioning of the shaft 64 and pulley 61 longitudinally of the plate 17 and of the direction of abrasive belt movement for greater or less proximity to the work W. By such multiple positioning of the pulley 61 the extent of arcuate contact between the belt and the work may be modified with or without correspondingly changing the pressure therebetween. As suggested in FIG. 3 the area of contact of the pulley 62 is from about 1½" to 3" ahead of the work. Generally speaking I prefer that the area of contact between the belt and the work be small for sever cutting and relatively large for fine polishing.

In the preferred mode of operation of this form of my invention an abrasive belt having the desired abrasive surface character and quality as suggested above, is mounted on the pulleys 25 and 52 whilst the pressure pulley is withdrawn from the free taut path of the lower strand of the belt, and the belt is given the desired initial tension for efficient driving engagement with the driving pulley 25 in view of the drag to be exerted by abrasive removal of stock from the face-being-finished of the work. Thereupon the backing plate 17 is swung to the desired angle of attack in respect to the axis of the work, and then the whole plate and mechanism B is advanced by the cross slide S to mere noticeable initial contact between the belt and the work, and at about the same time, or shortly theretofore, the work is begun to be rotated about its own axis by rotation of the headstock spindle. Then, desirably, the cross slide S is backed off a "hair" to just remove the abrasive surface of the belt from significant contact with the work. At about this time the carriage C may be moved to a position where the belt will contact the extreme end of the work remote from the direction of carriage feed, and then the pressure roller 61 is moved to press the abrasive belt into forcible working contact with the work at about the same time the carriage is engaged by the feed screw 15 to initiate a first "cut" of the belt across and along the circumference and length and face of the work. Longitudinal feed of the belt along the work will be halted at the desired end of the "cut," and these or like steps may be repeated with the belt positioned at like or different angles to the axis of the work, and with greater or less pressure exerted between the belt and the work until a desirable or desired finish is obtained, or until all the cutting that is sought with the particular belt first applied is fully had. Ordinarily a succession of abrasive belts is desirably employed, often going from coarse to fine "cutting" and then "finishing" with polishing belts that have successively less abrasive charge or quality as such. The facile removal and replacement of belts of different character and/or length or both is facilitated by my invention.

In a practicable embodiment of my machine the pulleys 25 and 52 are 3" in diameter which tends to limit my choice of belts for the speeds I prefer to drive them. Light flexible woven fabric belts of fine mesh weave made of fine strong nylon or silk thread or the equivalent and devoid of overlapping joints or other departures from uniform thickness have been satisfactory for my purposes. Soft faced belts with little or no charge are convenient for the finest finishing or polishing and cleaning. Soft

metal belts of steel or beryllium copper accept abrasive charges satisfactorily and in thickness of .005" can be used on 3" pulleys, but the best advantages of such belt are to be had in somewhat greater thicknesses and with larger pulleys 25–52 and/or with work of greater diameter.

It is frequently of advantage in the practice of my invention to alter the angle between the direction of belt movement and the axis of the work between successive cuts across the length of the work so that the operator may observe the effects of one cut with respect to another and/or with respect to the initial roughness that is sought to be removed. That is to say: Often the finest ground surface, roughness of 30–40 microinches for example, that is desired to be given smoothness of 2 or 3 microinches by my invention will have a microscopically evident roughness with the appearance of a plowed field in which the furrows trend in much the same direction; on cylindrical work, often in low pitch helical patterns. When such a pattern has been noted by the operator using my invention, he will prudently select a speed of rotation of the work, a rate of feed of the belt longitudinally of the work, a belt speed and a belt direction that will make his "cut" or "cuts" take different patterns, whereby to be able to observe the efficacy and depth thereof in relation to the rough peaks and ridges that are sought to be removed. Moreover the angle between the movement of the belt and the axis of the work permits the operator of my invention to take his abrasive "cuts" in angled relation to the direction of preceding rough "cuts" of his own making, both for greater efficiency of finishing and for greater facility of observing the progress of the succeeding finishing "cuts" or passes of the belt over the work.

As surface smoothness is brought to a greater state of fineness, it becomes increasingly useful and/or necessary to restrain and control the rate of abrasive removal of the remaining small microscopic ridges and peaks or parts thereof. In FIGS. 7 to 10 inclusive, I have provided one example of novel means for restraining the deflections of the path of the belt toward the work and, similarly, of restraining the area and pressure of contact between the abrasive face of the belt and the work. Everything disclosed in FIGS. 7 and 8 except the novel means for pressing the abrasive face of the belt upon and in contact with the work W may be taken to be the same as shown in FIGS. 3 and 4 and will not be described again beyond necessary reference to the said novel means.

Referring first to FIG. 8 a pressure pulley 61*a* corresponding in office and function to the pulley 61 described above is engageable with the inner face of the belt A and is freely rotatable on an axis 62*a* which is parallel to the drive shaft 46 like the shaft 62, and is carried by a swingable lever 63*a* which performs the same offices as those of the lever 63 in respect to moving and holding the pressure pulley 61*a* toward, into and from the path of the lower strand of the belt; the lever 63*a*, however, being mounted to swing oppositely of lever 63 and about the adjustably movable axis 70 of the rotatable shaft 71, see also FIGS. 9 and 10. As will be presently described the shaft 71 is movable transversely of the free taut path of the lower strand of the belt A, i.e. in a plane at right angles to the plane of the axes of rotation of the pulleys 25 and 52. Therefore, to provide that the lever 63*a* may be adjustably positioned angularly about the axis 70 and accommodate different up and down positions of that axis, the lever 63*a* is slotted longitudinally at 72 and the plate 17 is slotted arcuately at 73 so that a clamp bolt 74 passing through both slots and coacting with a clamping nut or knob 75 on the other side of the plate 17, see FIGS. 7 and 9, may secure the lever 63*a* in any desired angular relation about the axis 70 relative to the lower strand of the belt A.

Referring now also to FIGS. 7, 9 and 10 there is secured on the near end of the shaft 71 as viewed in FIG. 8 a pulley 77 which has a cylindrical exterior surface and is aligned transversely of its axis with the pulleys 25, 52 and 61*a*, and with belt A. Pulley 77 is disposed to engage the belt on the bottom or on the abrasive side "ahead" of and/or "upstream" of the work W in respect to the movement of the belt. When the belt A, plate 17, etc. is positioned in relation to the work W as shown in FIG. 8, the pulley 77 may be adjusted to raise the belt ahead of the work out of contact with the work, or, alternatively to lower the belt ahead of the work by only such determinable increments as will limit the depth of the "cut" or maximum working engagement between the belt and the work. Since the pulley 77 has its working engagement with the abrasive side of the belt A, I prefer to drive the pulley 77 so that its peripheral speed and direction will coincide with belt speed and direction whereby to have substantially no drag or slip with respect to the belt and be not worn or abraded thereby, and for that matter, to offer no, or minimum, wear to the abrasive side of the belt. Therefore, shaft 71 has a portion 76, FIG. 10, journalled in an anti-friction bearing such as a Teflon sleeve 78 carried by a bearing housing 79, see also FIG. 9, the end of which housing near the plate 17 is integrally formed or related to an upstanding arm or bracket portion 80, see also FIG. 7, which is slideably secured and related to the plate 17 on the side opposite the belt engaging pulleys and is adjustably movable in relation to the plate. Bracket portion 80 has beveled sides 81 in constraining sliding engagement with the complementarily beveled sides of retaining plates 82, FIGS. 7 and 9, and has an internally threaded boss 83 into which adjusting screw 84 is threaded; the latter being rotatably journalled and restrained from axial motion in a bearing bracket 85 and having a non-circular, exposed upper end 86 receptive of a wrench or lever, not shown, for turning the screw and raising or lowering the shaft 71 and pulleys 77 and 61*a*; clamping knob 75 having been judiciously released to permit the same.

The far end of the shaft 71 has a driving pulley 90, FIGS. 9 and 10, fixedly secured thereto for driven engagement with a power transmitting belt 91 driven by an aligned auxiliary driving pulley 92, FIG. 7, carried on the end of the shaft of motor M outwardly of the main driving pulley 48. For convenience, belt 91 being light and having a light load, may be stretchable to obviate other means of maintaining proper driving tension in the belt between pulleys 90 and 92; the load being only that required to rotate pulley 77 in non-slipping relation to belt A which also tends to rotate the pulley. The diameters of pulleys 48, 47 and 52 on the one hand, and pulleys 92, 91 and 77 on the other, shall be chosen with an eye to providing the non-slipping contact between pulley 77 and belt A. All of these pulleys, and shafts 46 and 71 will have clockwise rotation as viewed in FIG. 7.

In this form of my invention the general operation corresponds to that of my preferred form first described with, however, more precisely restrained control of the path of the abrasive belt relative to the work. Here the pressure pulley combination 61*a*–77 may be preliminarily positioned to let the lower strand of the belt A run substantially free and straight between the pulleys 25–52 and out of contact with the work W, but with appreciable contact with the pulley 77. Then the motor may be energized to drive pulleys 25 and 77 and belt A. Then the whole B mechanism with the belt inclined about as shown is moved "forwardly," leftwardly as viewed in FIG. 8, by the cross slide S until mere contact between the belt and the work is obtained, and then backed away "a hair" to bare clearance between the belt and the work. Thereupon the pulley 77 may be lowered (whilst the pulley 61*a* exerts little or no pressure on the belt) to that limited extent desired to control the maximum depth of the "cut" or polish about to be made. This lowering may or may not be accompanied by contact between the belt and the work. Next, pressure may begin to be applied on the inside of

the belt by the pulley 61*a* to initiate working contact between the belt and the work sufficient for a useful first "pass" at the work and not necessarily as deep a cut as the position of the pulley 77 will permit. The next or a subsequent pass or passes will, as I prefer, bring the parts to about the position shown (with a little exaggeration) in FIG. 8 where the pressure pulley 61*a* has brought the belt down to the maximum contact with the work that the pulley 77 will permit, and has added tension to the belt to reinforce the straightness of its path from the pulley 77, across the work, to the driving pulley 25. In this form of my invention the area of contact between the belt and the work will also be controlled more effectually since, inter alia, the belt tension, and the pressure of the belt on the work incident thereto, may be increased by counterclockwise movement of the pulley 61*a*, as viewed in FIG. 8, without lowering the belt just ahead of the work as in the form of my invention first above described.

The employment of an air stream jet, or blast exerted upon the belt A to press the belt forcibly against the work W and/or as limited by the pulley 77 is illustrated in FIGS. 11, 12 and 13, like parts being given the same reference characters and performing the same offices and functions above described. Here, at about the place of, and acting in lieu, more or less, of either of the pressure pulleys 61 or 61*a*, a forcibly flowing air stream or jet is directed through the nozzle Z, FIGS. 12 and 13, against the inner face of the belt on the side opposite the work W, and ahead of the work in the sense of belt movement. Preferably the nozzle Z has a wide thin orifice at its lower end wherewith to distribute the air emitted therefrom with even force and impact upon the whole width of the belt in a narrow zone in the direction of belt movement as suggested by the arrows *b*. A bracket 93 is provided to locate the nozzle relative to the backing plate 17. Compressed air from a pump, not shown, is led to the nozzle through a hose 94 in which is interposed a throttling, pressure controlling valve 95 with a conveniently disposed knurled hand-wheel 96 for regulating the flow of air through the valve and nozzle and, ergo, the air velocity of the nozzle orifice and the deflection of the belt A toward the work W and/or the limiting pulley 77. Subject to as much or little limiting effect as may be sought and had by the positioning of the pulley 77, the air blast from the nozzle can be conveniently supplied and controlled to exert as much or little pressure between the abrasive face of the belt A and the surface of the work W as may be necessary or desirable to accomplish the objects and purposes of my invention. Incidentally, I have found it of advantage on occasion to restrict the outlet orifice of the nozzle Z, as by closing of part or all but a part as viewed in FIG. 13, and/or substitute a nozzle having a small transverse dimension in the direction of the width of the belt A, so that the essential force of the air jet may be confined to one edge or the other of a limited middle part of the belt whereby to confine the pressure between the belt and the work to an edge or fraction of the width of the belt. This is a facility which may be of particular advantage as in finishing the end of the cylindrical surface of a shaft or journal adjacent an enlargement or hub or integral gear or the like.

As shown in FIGS. 9, 10 and 11 the shaft 71 and pulley 77 may be raised and lowered to lift the belt A out of contact with the work, on the one hand, or, contrary-wise, the pulley 77, etc. may be lowered to be entirely out of contact with the belt even with maximum air pressure exerted thereupon from the nozzle Z, on the other hand. Between these extremes any desired, determinable and/or selected pressure may be created and maintained between the belt and the work, and also the extent of arcuate contact between the belt and the work for different desired and selected pressures of contact between the belt and the work can be had. In furtherence of this latter facility the nozzle Z can be inclined from approximate normalcy to the belt as shown in solid lines in FIG. 12 to such a position as suggested in part in dotted lines at 97 and 98 whereby to change the place of application of the force of the air jet more or less proximate the work W. A collateral advantage of the air jet over the pressure pulleys is its less unyielding contact with the belt and its relative insensitivity to bumps and unevenness in the interior surface of the belt. A relative disadvantage is the cost of consumption of compressed air, the significance of which increases with the pressure that is desired to be maintained between the belt and the work. It sometimes follows that the advantages of the air jet for deflecting the belt upon the work may be more abundantly enjoyed to effect light abrasive cuts and to promote cleaning and polishing passes on and over the surface of the work; these preferably with increasing areas of contact between the belt and the work as less abrasion and more cleaning and polishing is done.

My teaching on present experience also includes the use of an air jet as a second or supplemental means or as an independant "downstream" means for exerting pressure between the belt and the work, as shown for convenient example in FIG. 3. Here the nozzle ZZ, its relation to the belt and backing plate, may be the same as the nozzle Z and is similarly and/or conveniently supplied with air, preferably under the control of a separately controlled valve like the valve 95, not shown in FIG. 3, but all corresponding to FIG. 13, except for the disposition of the nozzle ZZ downstream of the work, between the work and the driving pulley 25. As shown in FIG. 3 an air jet from nozzle ZZ may be used to exert much or little pressure upon the belt A downstream of the work while the pressure pulley 61 is exerting similarly directed pressure in any desirable amount and/or sharing of the burden upstream of the work. It follows that the nozzle ZZ may not be employed at all while the pulley 61 functions alone as was assumed in the description of the apparatus of FIG. 3 in the first instance, and it follows that the pulley 61 can, if desired, be raised from contact with the belt A and the whole burden of urging the belt toward and/or upon the work to be borne by the jet from the nozzle ZZ. My teaching thus also comprehends the employment of a "downstream" air jet or (equivalent including a pressure pulley) in juxtaposition to, and/or used in simultaneous or intermittent cooperation and coaction with, any of the means herein disclosed for urging the belt toward the work and disposed and working "upstream" or ahead of the work, see also FIGS. 8 and 12.

While I have illustrated and described preferred and particularly modified forms of methods and machines comprising and embodying my invention, it is not my intention to limit the scope of my patent to the specific forms and exemplary teachings hereof nor in any other manner inconsistent with the progress in the art that has been promoted by my invention.

I claim:

1. A machine for finishing the surface of a workpiece having a hard microscopically rough, cylindrical surface, which surface comprises elongated microscopic ridges rising above and between microscopic valleys whose bottoms are proximate the smoother and truer finished surface that is sought, said machine comprising means for rotating the work about a fixed axis with its surface coaxial thereof a light, flexible, abrasively charged belt for conveying abrasive particles across said surface in a plane approximately tangent to said intended finished surface and in clean cutting engagement with only the ridges of the rough surface and at high speeds as from about 8,000 to 12,000 feet per minute and in a substantially straight line and in a plurality of angular relations to said axis and with selectably restrained radial pressures upon and controlled engagement with said surfaces, means for supporting, tensioning and driving said belt with its work engaging strand held taut and substantially planar and engageable with said surface of the work tangentially thereof in approximately a line of contact parallel with the

axis of the work, means for supporting said belt for pivotal movement about an axis parallel to said axis of the work about which said strand may be adjustably inclined and for pivotal movement about an axis normal to the path of said strand and about which the path of said strand may be adjustably rotated, means for moving said belt bodily toward and away from the work, and means spaced remotely ahead of said line of contact, in the sense of belt travel, for deflecting said strand from its said planar predisposition toward the work, and means disposed between said last named means and said line of contact for selectively restraining said deflection.

2. The machine of claim 1 with said means for limiting the degree of engagement between the said strand of said belt and the work engageable with said strand of said belt on the abrasive side thereof which is also engageable with the work comprising a driven pulley driven at a peripheral speed equal to the speed of the belt, and means for so driving said pulley.

3. The machine of claim 2 wherein said means for deflecting said strand toward the work is pivotally supported to swing about the axis of said driven pulley.

4. The method of reducing microinch roughness in the hard, rounded, external surface of a workpiece which surface comprises microscopic ridges standing between microscopic valleys, said method comprising moving said surface continuously in one direction, moving discrete, abrasive cutting particles at high velocities in the same sense of direction as the motion of said surface and in straight lines with momentum sufficient to shear through the said microscopic ridges and remove minute bits thereof therefrom, moving said particles toward the said surface of the workpiece in said lines in a plane which is tangent to said surface approximately at a line of tangency that intersects said ridges above the bottoms of said valleys and shearing out said bits from the ridges and guiding said particles to clear the bottoms of said valleys, and moving said particles at high velocity away from said surface and beyond said line of tangency in substantial lineal extensions of said straight lines, and driving said bits of the ridges away from the work in the direction of motion of said particles.

5. The method of reducing microinch roughness in the hard, rounded, external rough surface of a workpiece which surface comprises elongated microscopic ridges rising above microscopic valleys whose bottoms are proximate the smoother surface that is desired to be formed, said method comprising moving said rough surface continuously through a line which is substantially fixed in space and is common to said desired smoother surface and a plane tangent thereto and which common line intersects said ridges and clears the bottoms of said valleys, moving small, hard, discrete, abrasive particles at high velocities in said tangent plane and in straight lines transverse to at least certain of said ridges with force, direction and momentum sufficient to shear through the said ridges and remove minute bits thereof therefrom without gouging the bottoms of said valleys, moving said particles through said common line in said straight lines and shearing out said bits of said ridges and avoiding cutting into the bottoms of said valleys, and moving said particles at high velocity away from said common line in substantial lineal extensions of said straight lines and driving said bits of the ridges away from the work.

6. The method of reducing microinch roughness in the hard, round, external rough surface of a workpiece to provide a smoother desired surface which rough surface comprises elongated microscopic ridges standing between microscopic valleys, said method comprising moving said rough surface continuously through a line which is common to the desired more smooth surface and to a plane tangent thereto and which common line intersects said ridges and clears the bottoms of said valleys, moving small, hard, discrete, abrasive, cutting particles at high velocities and in the same sense of direction as the motion of said surfaces and in said plane and in straight lines transverse to at least certain of said ridges with momentum sufficient to shear through the said ridges and remove minute bits thereof therefrom, moving said particles toward the said common line in said straight lines and shearing out said bits, preserving said particles from forces and influences tending to drive them below said desired smoother surface, and moving said particles at high velocity away from said common line in substantial lineal extensions of said straight lines and driving said bits of the ridges away from the work.

7. The method of reducing microinch roughness in a hard cylindrical surface of a workpiece comprising microscopic ridges standing between microscopic valleys said method comprising rotating the work about a fixed axis and giving said surface motion at a uniform slow speed in one direction, moving discrete abrasive particles at high velocities in straight lines with momentum sufficient to shear through the ridges and cut minute bits thereof therefrom and with direction to avoid cutting the bottoms of said valleys, and moving said particles toward the work in said lines in the same general direction as the motion of said surface in a plane which is tangent to the workpiece approximately in a line parallel to said axis that intersects said hills above bottoms of said valleys, moving said particles through said ridges and shearing out said bits, and moving said particles and said bits away from the work and from said line of tangency in substantial lineal extensions of said straight lines.

8. The method of reducing microinch roughness of not more than about 18 microinches in the hard, rounded, external surface of a workpiece which surface comprises elongated microscopic ridges rising above microscopic valleys whose bottoms are proximate the smoother surface with roughness less than about 2 microinches that is desired to be formed, said method comprising moving said rough surface continuously through a fixed line which is substantially common to said desired smoother surface and to a plane tangent thereto and which common line intersects said ridges and clears the bottoms of said valleys, moving a belt charged with discrete cutting particles of not more than about 60 microns in size at from about 8,000 to 12,000 feet per minute approximately in said plane and moving said particles on said belt in straight lines transverse to at least certain of said ridges with force, direction, and momentum sufficient to shear through the said ridges and remove minute bits thereof therefrom without gouging the bottoms of said valleys, moving said particles on said belt through said common line in said straight lines and shearing out said bits of said ridges and driving said bits away from the work while avoiding cutting into the bottoms of said valleys, moving said particles on said belt away from said common line in substantial lineal extensions of said straight lines, and repeating the said steps with progressively smaller particles down to about 3 or 4 microns in size and moving the same transverse to different ridges at different angles to said fixed line and thereby reducing the roughness of the desired surface to less than 2 microinches.

9. The method of reducing microinch roughness of not more than about 18 microinches in the hard, rounded, external surface of a workpiece which surface comprises elongated microscopic ridges rising above microscopic valleys whose bottoms are proximate the smoother surface that is desired to be formed, said method comprising moving said rough surface continuously through a fixed line which is common to said desired smoother surface and to a plane tangent thereto and which common line intersects said ridges and clears the bottoms of said valleys, moving a belt charged with small, discrete, cutting particles at speeds not substantially less than about 8,000 feet per minute closely adjacent said plane and moving said particles on said belt in straight lines transverse to at least certain of said ridges with force, direction, and momentum sufficient to shear through the said

ridges and remove minute bits thereof therefrom without gouging the bottoms of said valleys, moving said particles on said belt through said common line in said straight lines and shearing out said bits of said ridges and driving said bits away from the work while restraining said particles from cutting below the bottoms of said valleys, and moving said particles on said belt away from said common line in substantial lineal extensions of said straight lines.

10. The method of reducing microinch roughness of not more than about 18 microinches in the hard, rounded, external surface of a workpiece which surface comprises elongated microscopic ridges rising above microscopic valleys whose bottoms are proximate the smoother surface with roughness less than about 2 microinches that is desired to be formed, said method comprising moving said rough surface continuously through a fixed line which is common to said desired smoother surface and to a plane tangent thereto and which common line intersects said ridges and clears the bottoms of said valleys, moving a succession of belts in the same directional sense as said surface is moving, said belts being charged progressively with smaller and smaller discrete cutting particles of from about 60 to 3 microns in size at no less than about 8,000 per minute, all approximately in said plane and moving said particles on said belts in straight lines and selectively different angles to said fixed line and transverse to certain of said ridges selectively with force,

direction and momentum sufficient to shear through the said ridges and remove minute bits thereof therefrom without gouging the bottoms of said valleys, moving said particles on said belts through said fixed line in said straight lines and shearing out said bits of said ridges and restraining said particles from cutting into the bottoms of said valleys, and moving said particles on said belts away from said common line in substantial lineal extensions of said straight lines and driving said bits of the ridges away from the work.

References Cited by the Examiner

UNITED STATES PATENTS

1,768,339	6/30	Stevens	51—145
1,939,674	12/33	Elskamp	51—145
2,176,163	10/39	Zimmerman	51—273
2,224,423	12/40	Binns	51—103
2,241,568	5/41	Yetter.	
2,396,505	3/46	Gumper	51—289
2,418,535	4/47	Wild	51—259 X
2,489,811	11/49	Perkins	51—147 X
2,594,647	4/52	Hendrickson	51—266
2,697,900	12/54	Lewis	51—289
2,883,804	4/59	Hjelstrom et al.	51—141

LESTER M. SWINGLE, *Primary Examiner.*

FRANK E. BAILEY, FRANK H. BRONAUGH, *Examiners.*