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3,233,372

SURFACE FINISHING IN HIGH SPEED GYRATING BARRELS

Filed May 13, 1963

FIG. 1
PRIOR ART

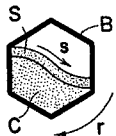


FIG. 2
PRIOR ART



FIG. 4

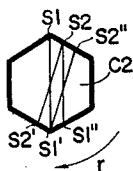


FIG. 5

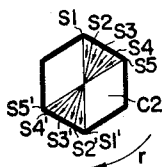


FIG. 6

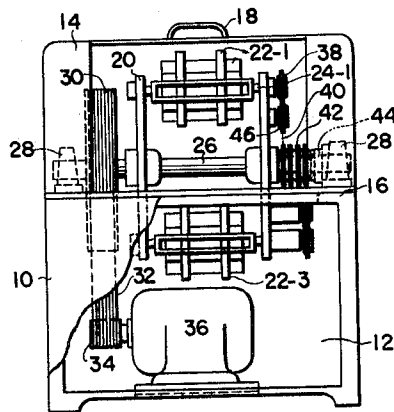


FIG. 7

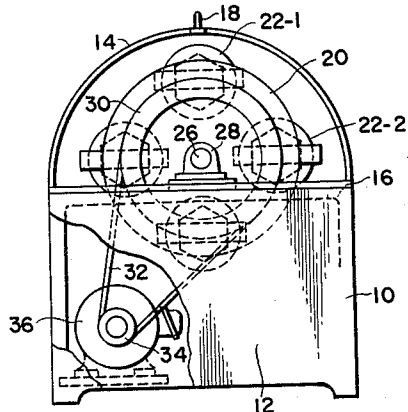


FIG. 9

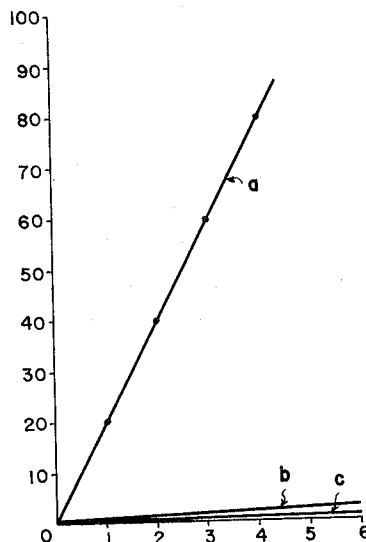


FIG. 3

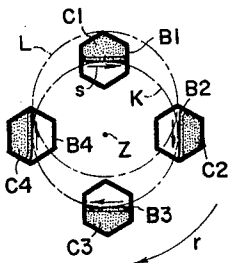
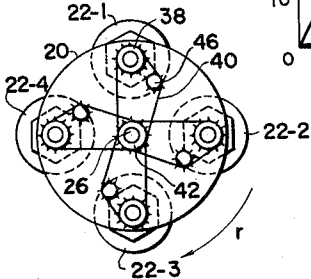


FIG. 8



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SURFACE FINISHING IN HIGH SPEED
GYRATING BARRELSHisamine Kobayashi, 13 Kikuzono-cho 3-chome,
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37/20,682

5 Claims. (Cl. 51—313)

This invention relates generally to improvements in finishing technique and more particularly to a method of surface finishing workpieces within a barrel having an equilateral polygonal cross-section gyrating at a high speed.

Heretofore,, numerous attempts have been made to surface finish workpieces made of metals or ceramics. For example, the rotary barrel process is typical of barrel finishing processes known for long time and actually carried out in a variety of fields of the finishing art. According to the rotary barrel finishing process, a mixture of workpieces to be finished and abrasives which may include admixed therein any suitable lubricant or any suitable surface activator tumbles in a barrel rotating at a relatively low speed about its longitudinal central axis to contact and scrub the workpieces with the abrasives to thereby finish the workpieces. This process, however, consumes a long period of time before the completion of the finishing operation and it is impossible to perform finishing of minute workpieces thereby because a mixture of workpieces and abrasives tumbles due to its weight alone.

Also it is well known that, by using any cylindrical pot mill or crushing mill, workpieces can not be subjected to a surface finishing treatment. If such a mill is used to finish the workpieces, the workpieces including admixed therewith suitable abrasives normally slips down along the internal surface of the mill as a unitary mass resulting in greatly uneven scrubbing-off of the workpieces. Alternatively, a mass comprising the workpieces and the abrasives admixed therewith may be forced to slide on the internal surface of the vessel resulting in rubbing-out and crushing of the workpieces.

Accordingly, it is a general object of the invention to eliminate the abovementioned disadvantages of and objections to the prior art practice.

Another object of the invention is to provide an improved method of efficiently surface finishing workpieces in a barrel effecting planetary gyration at a high speed in order to utilize a high centrifugal effect.

It is a further object of the invention to provide an improved method of surface finishing workpieces which meets operational requirements exceeding those imposed on the conventional type of finishing processes.

An additional object of the invention is to provide an improved method capable of heavily cutting, abrading polishing and burnishing very minute workpieces such as parts of wrist watches, pen points of fountain pens or small jewels which could not be previously subjected to such actions.

With the above objects in view, the invention resides in a method of surface finishing workpieces, comprising the steps of loading a mixture of the workpieces and substantially spherical grains of abrasives in each of a plurality of barrels or drums each having its internal cross-section in the shape of an equilateral polygon, causing said barrels with the loaded mass to gyrate about an axis of a shaft spaced away from the barrels and disposed parallel to the longitudinal axes of all the barrels at a high speed while maintaining said barrels in a fixed orientation, said gyrational movement of the

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barrels being such that only the free surface layer of said loaded mass flows down successively in the direction of gyration of the barrel without tumbling movement whereby only the workpieces within the free surface layer are surface finished with the abrasives.

An apparatus suitable for use in carrying out the method of the invention may preferably comprise at least two barrels or drums each having the internal cross-section in the shape of an equilateral polygon, a mass of workpieces and substantially spherical grains of abrasives loaded in each of said barrels, a shaft, a pair of spaced rotary discs rigidly secured to said shaft for rotatably supporting said barrels in symmetry-of-rotation relationship, drive means for effecting gyration of said barrels about the axis of said shaft in one direction, a stationary sprocket wheel device with a plurality of rows of teeth secured to a base block and loosely fitted onto said shaft, a sprocket wheel mounted coaxially to each of said barrels to be operatively coupled with different ones of said rows of teeth on said sprocket wheel device through an endless chain, a tensioning wheel for maintaining the associated endless chain in its tensioned state, said sprocket wheel device said sprocket wheel, said tensioning wheel and said endless chains being arranged to rotate each of said barrels with respect to said pair of discs in the direction oppositely to said one direction in such a manner that each of said barrel effects one complete rotational movement relative to said pair of discs during one complete rotational movement of the latter to gyrate about said axis of said shaft while the same is maintained in the fixed bearings, the gyrational movement of each barrel being such that said mass includes on its free surface layer a sliding layer flowing in the direction of gyration of said barrel without tumbling movement, said flowing movement of said sliding effecting circulation of said mass within said associated barrel.

The invention as to both its organization and the manners of operation and practice together with other objects and advantages thereof, will be more readily apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagrammatic sectional view of a prior art rotary drum showing in which a mass loaded in the drum partially flows, while tumbling, in the rotating drum.

FIG. 2 is a diagrammatic sectional view of the drum illustrated in FIG. 1 and showing the charge cohered on its internal surface due to the centrifugal effect provided by the drum being rotated at a high speed exceeding its critical speed;

FIGURE 3 is a diagrammatic representation useful in explaining the principle of the invention and illustrating, in cross-section, the manner in which a mass loaded in each of the drums having an equilateral polygonal cross-section is positioned in the drum while the drum is gyrating at a high speed and in the direction that the free surface layer of the mass flows within the drum;

FIGS. 4 and 5 are diagrammatic cross-sectional views illustrating in more detail the manner in which the mass loaded in the drum illustrated in FIG. 3 flows within the same gyrating at a high speed;

FIG. 6 is a front elevational view, partly broken away, of an apparatus constructed in accordance with the teachings of the invention;

FIG. 7 is a side elevational view of the apparatus illustrated in FIG. 6;

FIG. 8 is a plan view of a mechanism for effecting gyrational movement of a plurality of drums illustrated in FIGS. 6 and 7; and

FIG. 9 is a graph useful in explaining the results of the invention.

Through the several figures like reference numerals designate similar components.

In order to aid in fully understanding the invention, the prior art type of barrel finishing methods will now be described.

In the past, numerous barrel finishing methods and apparatus have been proposed in order to finish a variety of workpieces made of either metals or ceramics. All of them, however, have advantages and disadvantages and are presently in a stage where they are still required to be largely improved. For example, the rotary barrel finishing method which is typical of the barrel type well known and widely used for along time is to load a charge including proper proportions of workpieces to be finished, any suitable abrasives, water, and, if desired, a lubricant or a surface activator into a barrel and to slowly rotate the barrel with the mass about its longitudinally central axis with the barrel maintained in its horizontal position. Under these circumstances, the mass within the barrel tends to be raised in the direction that the barrel is rotating. FIG. 1 illustrates this tendency of the mass. A barrel B is rotating about its longitudinal axis horizontally disposed, in the direction of the arrow r and has loaded therein a suitable amount of a mass C such as that above described. As shown, the mass C includes its upper or free surface layer S raised in the direction of rotation r . Due to its weight the free surface layer S tends to slide down along the tilted surface in the direction s opposite to the direction of rotation whereby the same flows and tumbles. Within the free surface layer S thus flowing and referred to hereinafter as a sliding layer, workpieces and abrasives are rubbed against each other and finished. Water functions to prevent any violent impact between the components of the mass and also any collision of the mass against the internal wall of the barrel.

If the rotary barrel finished method as above outlined is used to finish very minute workpieces, the same will be only subject to very low pressure or stress which is caused by their contact with the abrasives used, because of their light weight and hence they are only slightly abraded. For example, when such workpieces were finished in a rotating barrel for scores of hours, the thickness removed from the surface of the workpieces was only a few microns. To increase the thickness of the surface removed from the workpiece the barrel may be speeded up. Alternatively, the finishing time may be increased. As is well known, however, the number N of rotations per minute of a barrel has a practical upper limit defined by the expression $N=32/\sqrt{d}$ where d designates the diameter of the barrel of circular cross-section in meters. If the barrel is rotated at a speed exceeding this upper limit then a mass within the rotating barrel will be raised too high along the internal surface of the barrel until the same will fall down from adjacent the uppermost portion of the interior of the barrel. Thus workpieces forming a part of the mass may be dented upon falling down leading to the impossibility of smooth finishing. If the number N of rotations per minute of the barrel exceeds a magnitude defined by the expression $N=42/\sqrt{d}$ then the centrifugal effect due to the rotation of the same will cause the mass to cohere to the entire internal surface of the rotating barrel as shown in FIG. 2 whereby the mass loses its fluidity with the result that no finishing is performed.

Further, there is the prior art method of finishing workpieces in a vibratory barrel. In this case, it is required to correlate the frequency of vibration with its amplitude such that they should be inversely proportional to each other. In general, the maximum amplitude of vibration should be decreased as its frequency is increased. It is well known that the barrel should be vibrated at a frequency between 1500 and 1800 cycles per minute for

the maximum amplitude of 8 mm. and between 3000 and 3600 cycles per minute for the maximum amplitude of 1 mm. which is the lower limit for practical purposes. If the barrel is vibrated outside of the range just specified then a finishing operation is not performed. It has been found that whether a barrel is rotated or vibrated within either of the practicable operating ranges as above pointed out respectively does not greatly affect either the distance through which a mass can flow in the barrel or its flow rate.

The finishing methods utilizing rotating and vibrating barrels respectively rely upon an intermittent frictional motion between workpieces and abrasives which form a sliding layer of mass in the barrel, that motion being a tumbling and contacting motion of the mass intermittently effected within the sliding layer. It will therefore be apparent that such methods are low in efficiency of finishing by a value as high as or even exceeding 90% as compared with the case in which a frictional motion was continuously effected between the workpieces and the abrasives. In addition, the force between the workpieces and the abrasives is a pressure under which they collide with each other when they slide down in a sliding layer such as that previously described in conjunction with FIG. 1 and hence such force results principally from their weights. For this reason, the force between the workpieces and the abrasives as they contact each other will be very low resulting in a great decrease in finishing power. This means that it is fundamentally impossible to finish extremely minute workpieces in a rotation barrel. The same is true of a vibrating barrel.

Since workpieces to be finished are of a wide variety the operational conditions for finishing them have in the past been critical. In other words, those conditions were previously required to be selected in accordance with the specific gravity, configuration, dimension and material of the workpiece and the degree of finishing such as rough grinding or abrasion, cutting-down, polishing or burnishing. Therefore, for each kind of workpiece, it was necessary to select the material, configuration and dimension of abrasives, proportions of workpieces, abrasives, water and a lubricant or activator, an amount of a mass loaded in a barrel, a speed of rotation of the barrel dependent upon the dimension and configuration of the workpieces, etc. Consequently, a series of experiments had to be, as a matter of course, conducted to grope and establish the critical operational conditions for the purpose of satisfactorily finishing the workpieces.

It is now been found that the utilization of the centrifugal effect which was heretofore objectionable in rotary barrel-finishing methods leads to an increase in finishing speed and hence in efficiency of the finishing operation. Thus the invention is based upon the fact that barrels into which workpieces and abrasives are loaded effect planetary gyration about an axis of a shaft spaced away from the barrels and disposed in parallel to the longitudinal axes of all the barrels at a speed far exceeding the speed of rotation which was heretofore its upper limit for the purpose of avoiding an excess of the centrifugal effect as previously described in conjunction with FIG. 2. In this way, the invention can utilize the centrifugal force amounting up to several hundred times the centrifugal force corresponding to said upper limit for the speed of rotation of the barrel.

Referring now to FIG. 3 of the drawings, there is illustrated the principle of the invention. Plural pairs in this case two pairs of barrels or drums B1, B2, B3 and B4 having an equilateral polygonal cross-section, in this case an equilateral hexagonal cross-section, are disposed such that their respective longitudinal axes are positioned at substantially equal angular intervals on a circular cylindrical surface represented by a circle K having a center Z. In other words, the barrels are disposed in symmetry-of-rotation relationship. All the barrels are adapted to effect planetary gyration at a high

speed about an axis passing through the center Z and parallel to the respective longitudinal axes of the barrels by a drive to be described later. With the arrangement illustrated any edge or vortex line of each barrel will depict a locus of circular shape such as a locus L which the uppermost edge of the barrel B1 depicts while the barrels are always maintained in the fixed bearings in a fixed orientation. The barrels should be driven at a speed exceeding 180 gyrations per minute and preferably at a speed on the order of 200 gyrations per minute. In general, the barrels should be advantageously driven at a speed on the order of $165/\sqrt{D}$ gyrations per minute where D represents the diameter of the circle K or L shown in FIG. 3.

Thus it will be seen that during such gyration of the barrels each mass C1, C2, C3 and C4 composed of workpieces, abrasives, water and the like and loaded in the associated barrels B1, B2, B3 or B4 is accumulated on that portion of the internal wall of the associated barrel positioned outside of the locus such as the locus K by the action of a high centrifugal force exerted on the same and that the mass thus accumulated is displaced with respect to the associated barrel as the latter is gyrated about the axis of revolution Z in the direction of the arrow *r* in FIG. 3. For example, as the barrel which starts at the uppermost position represented by the barrel B1 successively gyrates through its positions represented by the barrel B2, B3 and B4 respectively, the mass C1 accumulated in the upper half portion as viewed in FIG. 3 flows successively into the positions represented by the masses C2, C3 and C4, respectively while the free surface of the mass remains substantially smooth as seen in FIGS. 3-5 rather than undulated as in the rotary driven process shown in FIG. 1.

As shown by the arrow *s* within each barrel in FIG. 3, this relative displacement of the mass is effected such that breaking of the mass begins with the free surface portion of the same and proceeds progressively into the interior of the mass whereby the same flows smoothly and is displaced to its next position while the free surface remains smooth.

Referring now to FIGS. 4 and 5 of the drawing, there is illustrated by way of example the manner in which the mass C2 in the barrel B2 flows and is displaced to its position represented by the mass C3 in the barrel B3. In order to displace the smooth free surface S1-S1' of the mass C2 to a new smooth free surface S2-S2', a stratified zone or layer between lines S1-S1' and S2-S1' forming the upper layer portion of the mass is moved, as a sliding layer to form another sliding layer S2-S2'-S1'-S2'' which will be subsequently moved to the next position for the sliding layer. More specifically, as shown in FIG. 5, the free surface S1-S1' of the mass C2 is displaced to a line S5-S5' through lines S2-S2', S3-S3' and S4-S4' while the surface layer of the mass is sliding in the direction of the arrow *s*. During this sliding successive portions of the mass are brought into the surface layer at the right hand end and other portions are successively moved from the surface layer into the mass at the left hand end. Thus the mass C2 tends to be accumulated on the portion of the interior of the barrel represented by the mass C3 during a quarter of the gyration of the barrel with the result that all portions of the mass are uniformly displaced.

Results of experiments have indicated that the thickness of the sliding layer flowing smoothly in this way or the spacing between the lines S1-S1' and S2-S1' (see FIG. 4) designated by "*l*" corresponds approximately to an eighth of the diameter *d* of a circle inscribed about the polygonal cross-section of the barrel. Therefore, as in the rotary barrel method, the dimension of a workpiece or abrasive should be less than *l* for satisfactory results. If a mass includes admixed therewith workpieces or abrasives having their dimensions ex-

ceeding *l* then the latter may be forced out of the sliding layer to collide against the internal wall of the barrel. For this reason, any workpiece or abrasive whose dimension is greater than *l* should not be used. However, any workpiece in the form of either a sheet or a wire has been found to be satisfactorily finished according to the invention provided that the same has its maximum length ranging from two times from five times the depth *l* of the sliding layer. It has been found also that a mass comprising workpieces and spherical abrasives less than *l* in size and even as small as on the order of 0.01 mm. or less can smoothly flow within the aforesaid sliding layer by the action of high centrifugal force without the same cohering to the internal wall of the barrel, whereby the finishing operation is performed with a high efficiency of finishing.

Under these circumstances, the mass is always drawn toward the outside of a locus such as the locus K by the high centrifugal effect and is accumulated in that place without intermittent contacting and jostling occurring between the workpieces and the abrasives. At the same time, only the sliding layer forming the stratified free surface zone of the mass flows in the direction of the arrow *s* illustrated in FIG. 3. Thus the workpieces and abrasives within the sliding layer effect completely continuous frictional movement but are not separated from each other at all. It is to be noted that during flowing movement as above described, the greater part of that portion of the mass accumulated in a region other than that of the sliding layer and more particularly that portion of the mass contacting the internal wall of the barrel is not moved at all with respect to the latter but gyrates together with the barrel. Therefore, the internal wall of the barrel is not damaged. It is also to be noted that any portion of mass not moved with respect to the gyrating barrel is gradually changed in its position relative to the barrel for the reason that the sliding layer of the mass is successively displaced in the manner as previously described until the same reaches the interior of the sliding layer. At that time, the position of the mass having reached the interior of the sliding layer flows for the first time within the layer without tumbling. Thus all the workpieces in the mass are repeatedly subjected to a finishing operation due to their flowing movement within the sliding layer and after the expiration of a predetermined operating period they will have been finished homogeneously and uniformly.

According to the teachings of the invention a mass is preferably loaded into a barrel in an amount on the order of from 50 to 60% by volume of the barrel as in the conventional type of rotary barrel finishing methods and workpieces should be admixed with abrasives in a range of from one to two parts of the abrasive for each part of the workpiece. It is noted that this proportion of the mixture is higher than in the conventional finishing methods. Further, the results of experiments indicated that during one complete gyration of a barrel according to the invention a sliding layer of a mass flows through a distance and in an amount equal to a distance and an amount which a sliding layer of a mass flows while tumbling within a rotating barrel having the same dimension during complete rotation of the same.

Any of the rotary barrel finishing methods can actually use the maximum number of rotations of a barrel not exceeding $25/\sqrt{d}$ r.p.m. where *d* is the same as that previously defined whereas the present barrel can normally gyrate at $165/\sqrt{D}$ r.p.m. where D is the diameter of the circle K shown in FIG. 3. If it is assumed that the barrels have the same dimension in both cases when a locus of any barrel such as the locus K for the barrel B1 (see FIG. 3) always has its average radius equal to approximately 3.3 times the radius of rotation for a rotating barrel from the standpoint of design and construc-

tion. This results in a great radius of gyration with which the barrel can gyrate.

Thus it will be appreciated that the pressure appearing between workpieces and abrasives during their flowing movement is enhanced by the high centrifugal effect whereby a finishing operation such as heavily cutting-down or a polishing operation is greatly improved. In fact, the pressure under which workpieces effect continuous frictional movement relative to the abrasives at high speeds is substantially equal to several hundred times the pressure under which workpieces intermittently contact abrasives by the action of their weights within the rotating barrel. In addition, the invention permits the barrel to gyrate at a speed at high as desired provided that a device used for carrying out the same has a mechanical strength sufficient to withstand such high speed of gyration.

Referring now to FIGS. 6, 7 and 8 of the drawings, there is illustrated an apparatus suitable for use in practicing the method of the invention as above described. The apparatus illustrated comprises a rigid enclosure 10 including a lower portion of square cross-section 12 having a thick wall, an upper portion covered by a dome-shaped cover 14 and a thick horizontal partition 16 for dividing the interior of the enclosure into the lower and upper portions. The dome-shaped cover 14 is provided on its top with a door handle 18 serving to open and close a door (not shown) forming a part of the cover. When the door is open, components to be described are accessible. Within the upper portion of the enclosure there are vertically disposed a pair of rotary discs 20 in opposed relationship and including a plurality of barrel cages 22 rotatably carried therebetween on a circle concentric to the same at substantially equal angular intervals. The apparatus is shown as including four barrel cages or drum cages 22-1, 22-2, 22-3 and 22-4 spaced from each other at an angular distance of 90 degrees but a greater or lesser number of the barrel cages may be used if desired. Each barrel cage 22-1, 22-2, 22-3 or 22-4 is provided on both ends with a pair of trunnions 24-1, 24-2, 24-3 or 24-4 rotatably journaled on the associated vertical discs 20 respectively and includes a barrel or drum having an equilateral polygonal cross-section B1, B2, B3 or B4 coaxially disposed therein for rotation with the same. The pair of rotary discs 20 are secured to a main horizontal shaft 26 rotatably supported at both ends by a pair of bearings 28 which, in turn, are rigidly secured to the horizontal partition 16. Mounted on the horizontal shaft 26 on one end portion, for example, the lefthand end portion as viewed in FIG. 6 is a multi-grooved pulley 30, which, in turn, is operatively coupled through a plurality of endless belts 32 to a multi-grooved pulley 34 rigidly secured to a driving shaft on an electric motor 36 rigidly secured to the bottom of the lower portion 12 of the enclosure 10.

In order for the barrels B1, B2, B3 and B4 to gyrate about the axis of the horizontal shaft 26, one of the trunnions 24 for each barrel cage 22 can include a sprocket wheel 38 mounted on its extension projecting beyond the associated rotary disc 20 in this case the righthand disc. Then the sprocket wheels 38 are operatively coupled through the respective endless chains 40 to different ones of the plurality of sprocket wheels composing a sprocket wheel device 42 loosely fitted onto the main shaft 26 and supported by base block 44, which, in turn, is rigidly secured to the horizontal partition 16. It is noted that the sprocket wheels 38 for the barrels are the same both in number and diameter as the central sprocket wheels 42. In order to maintain the chains 40 in their tensioned state one tensioning sprocket wheel 46 is rotatably mounted on the rotary disc 20 at any suitable position to engage each chain 40. It is noted that the central sprocket wheel assembly 42 is rigidly secured to the base block 44 on the horizontal partition 16 and loosely fitted onto

the shaft 26 independently of the rotational movement of the latter.

The arrangement thus far described is operated as follows: The energization of the motor 36 causes the rotational movement of the rotary discs 20 in one direction, for example, in the direction of arrow *r* illustrated in FIG. 8 through the components 34, 32, 30 and 26. As the rotary discs 20 are rotated about the axis of the main shaft 26 in the clockwise direction as viewed in FIG. 8 the cages 22 and hence barrels B will be rotated in the counterclockwise direction or in the direction opposite to the direction in which the discs are rotated with respect to the discs by virtue of the endless chains 40 connecting the stationary central sprocket wheels 42 to the associated sprocket wheels 38. Because the sprocket wheels 38 and the central sprocket wheels 42 have a common diameter as previously pointed out, the cages and the barrels will effect one complete rotational movement relative to the supporting discs 20 during one complete rotational movement of the same. Thus it will be appreciated that the barrel can effect gyrational movement about the axis of the main shaft 26. In other words, during gyrational movement each barrel is maintained in the fixed bearings. After a charge composed of workpieces and abrasives, in their proportions as previously specified has been loaded in an amount as previously specified into each of barrels while they are dismounted from the barrel cages, the loaded barrels are again mounted in place within their respective cages whereby the apparatus is ready for a finishing operation.

As previously pointed out, the barrels used in the invention have an equilateral polygonal cross-section for the reason which will be apparent later and it has been found that a hexagonal cross-section is suitable for a smaller barrel including a pair of opposite sides of its polygonal cross-section separated from each other by an inside length less than 200 mm., and an octagonal cross-section suitable for a larger barrel greater than 200 mm. in an inside length between a pair of opposite sides of its polygonal cross-section produces satisfactory results. It is to be understood that the cross-section of the barrel means the internal cross-section of the same. Therefore, if desired, a barrel may be advantageously used having any desired outer configuration such as a circularly cylindrical surface so long as it has an internal cross-section of an equilateral polygon.

In order to minimize dynamic unbalance of the apparatus as above described, at least two barrel cages can preferably be mounted on the rotary discs with the trunnions for the cages disposed on a circle having its center on the axis of the main shaft 26 at substantially equal angular intervals, that is, in symmetry of rotation relationship. In addition, it will be understood that the charge should be loaded in the respective barrels in amounts as equal as possible.

As an example, the apparatus illustrated in FIGS. 6, 7 and 8 was operated to surface finish needle rollers each having a diameter of 2.5 mm. and a length of 1.7 mm., with abrasives preshaped in spheres whose diameter was 15 mm. The results are illustrated in FIG. 9 wherein the abscissa represents the treading time in hours and the ordinate the polished-out thickness in thousands of one millimeter. A curve *a* illustrates the results of the invention and curves *b* and *c* were obtained with the use of vibratory and rotary barrels respectively. From the curves shown in FIG. 9, it can be seen that the invention can improve the finishing efficiency over the conventional vibratory and rotary barrel methods by a factor of several tens. The smaller the workpieces the higher this factor will be and in fact the value of the factor may reach to approximately a thousand.

In addition to the great increase in the finishing speed just described, the invention is advantageous in that very thin articles such as diaphragm sectors for photographic

cameras which may be 0.04 mm. thick and the second hands of wrist watches can be satisfactorily finished without the development of strains in the articles because of the frictional finishing operation not accompanied by tumbling movement.

The invention is also notable in that the requirements for selecting the type of abrasives used are largely alleviated. In other words, all the types of finishing operations involving heavy cutting and polishing require only the use of spherical type bonded chip stones or nearly spherical grains of abrasives for the reason that no tumbling movement is effected in practicing the present method. It is well known that the spherical chip stones or nearly spherical shape of grains are most suitable for flowing movements at higher speeds. In sharp contrast to the invention, the conventional type of rotary or vibratory barrel methods has predominantly used abrasives pre-shaped into a triangular or rhombic shape for the purpose of suppressing tumbling movement of a sliding layer as previously described to thereby prevent reduction or loss because of jostling and finishing forces. It has been found that the use of triangular or rhombic abrasives in practicing the present invention results in a sharp decrease in the operational efficiency due to their resistances to flowing movement of the abrasives and articles to be finished and thereby to the difficulty of effecting smooth flowing movement. Thus it will be appreciated that, as chip stones or abrasives used in the invention should be of spherical or nearly spherical shape, the selection of abrasives will have been completed by selecting only the material and size of the same in accordance with the particular application.

Finally, it is to be noted that, if mills of cylindrical cross-sectional shape were caused to gyrate about an axis such as the axis Z (see FIG. 3) with the same maintained in the fixed bearings, then the results of the invention as previously described are never achieved. More specifically, when such a mill including a proper amount of a mass loaded into it is gyrated in the same manner as in the invention, the free surface layer of the mass tends to slide in the same direction as the direction of gyration of the mill. However, before a small amount thereof has moved in such a direction most of the mass will slip down along the internal cylindrical surface of the mill in the direction of gyration with the mass maintained in a semi-circularly cylindrical shape in which the same was initially accumulated upon loading it into the mill. The repetition of these slipping motions of the mass causes repeated frictions to take place between the internal surface of the mill and the adjacent portion of the mass resulting in both damage of that surface and generation of heat on the same as well as scratching of workpieces to be finished. Thus the workpieces can not be surface finished with satisfactory results.

What I claim is:

1. A method of surface finishing minute workpieces, comprising providing at least one elongated drum having

an internal cross-sectional shape of an equilateral polygon having from five to eight sides, filling about one half of said elongated drum with a mixture of the workpieces and substantially spherical grains of abrasives, and rubbing the grains of abrasives and workpieces in only a surface layer of the mixture together and bringing successive portions of the mixture into the surface layer while successively moving other portions from the surface layer into the remainder of the mixture and keeping the free surfaces of the mixture substantially smooth by rotating the drum about an axis parallel to the direction of elongation of the drum and spaced laterally of the drum at a speed of rotation such that the centrifugal force is greater than the force of gravity and while holding the drum in the same orientation with respect to a horizon.

2. A method as claimed in claim 1, wherein the abrasives are spherical type bonded chip stones.

3. A method as claimed in claim 1, wherein the mixture comprises one part by weight of the workpieces and from one to two parts by weight of the abrasives.

4. A method as claimed in claim 1, wherein said mixture fills the drum in an amount equal to from 50 to 60% by volume of the drum.

5. A method as claimed in claim 1, wherein said drum is rotated at a speed of the order of $165\sqrt{D}$ r.p.m. where D represents approximately 3.3 times a diameter of circle inscribed about said equilateral polygonal cross-section of said drum.

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