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Wilson

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[54] **METHOD AND APPARATUS FOR TRAVERSING A CAM FOLLOWER**

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[62] Division of Ser. No. 76,653, Sept. 28, 1970, abandoned.

[52] **U.S. Cl.** ..... **51/50 PC,** 51/101 R, 51/289 R, 82/19

[51] **Int. Cl.** **B24b 17/02**

[58] **Field of Search** ..... 51/50 PC, 101 R, 281 R, 51/289 R; 90/62 R, 13.4; 82/2, 18, 19

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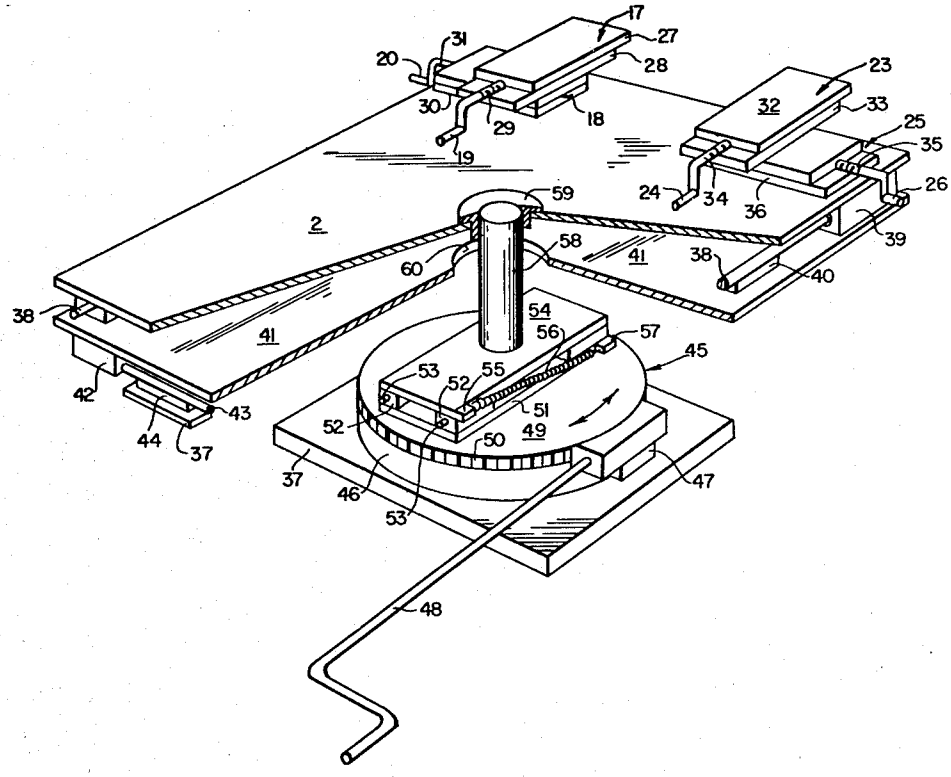
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[57] **ABSTRACT**

A system for the machining of work pieces, particularly the abrading of die rolls for a tube reducing mill, where the work piece and the master pattern or cam are mounted for rotation on a common shaft and moved relative to a master follower and rotating tool, respectively, with this relative movement being biased translation with only the angle of the translation varying with respect to the axis of rotation for causing the follower to traverse the entire control surface of the master and correspondingly cause the tool to duplicate the master control surface in the work piece. The follower and tool are mounted on a common table, which table is mounted with respect to a base for only translation, that is, the table will not rotate with respect to the separately mounted master and work piece. A slide mechanism allowing only translation of the table is rotated independently of the table to traverse the direction of table translation through an angle of 180°. Elements are provided to bias the table in the direction of translation so that with the 180° rotation of the slide, the follower will traverse the entire control surface of the master, in one plane. The master is rotated about an axis parallel to the above-mentioned plane so that its entire three dimensional surface will be engaged by the follower.

8 Claims, 6 Drawing Figures



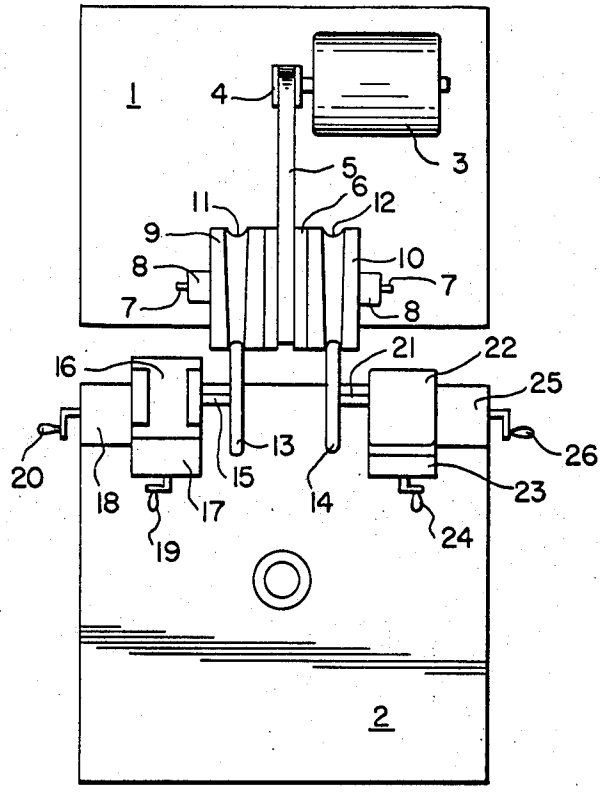


FIG. 1

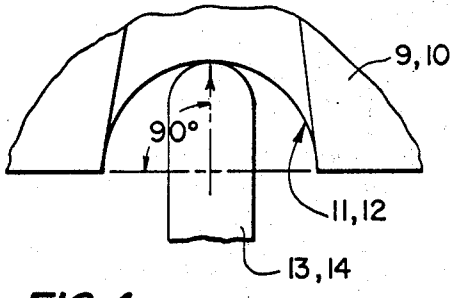


FIG. 4

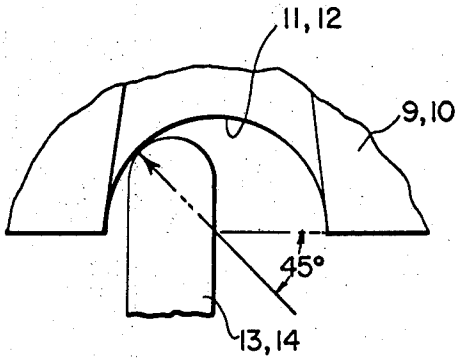


FIG. 5

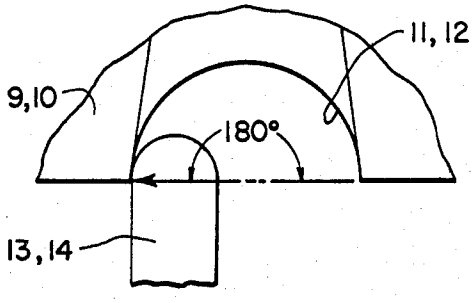


FIG. 6

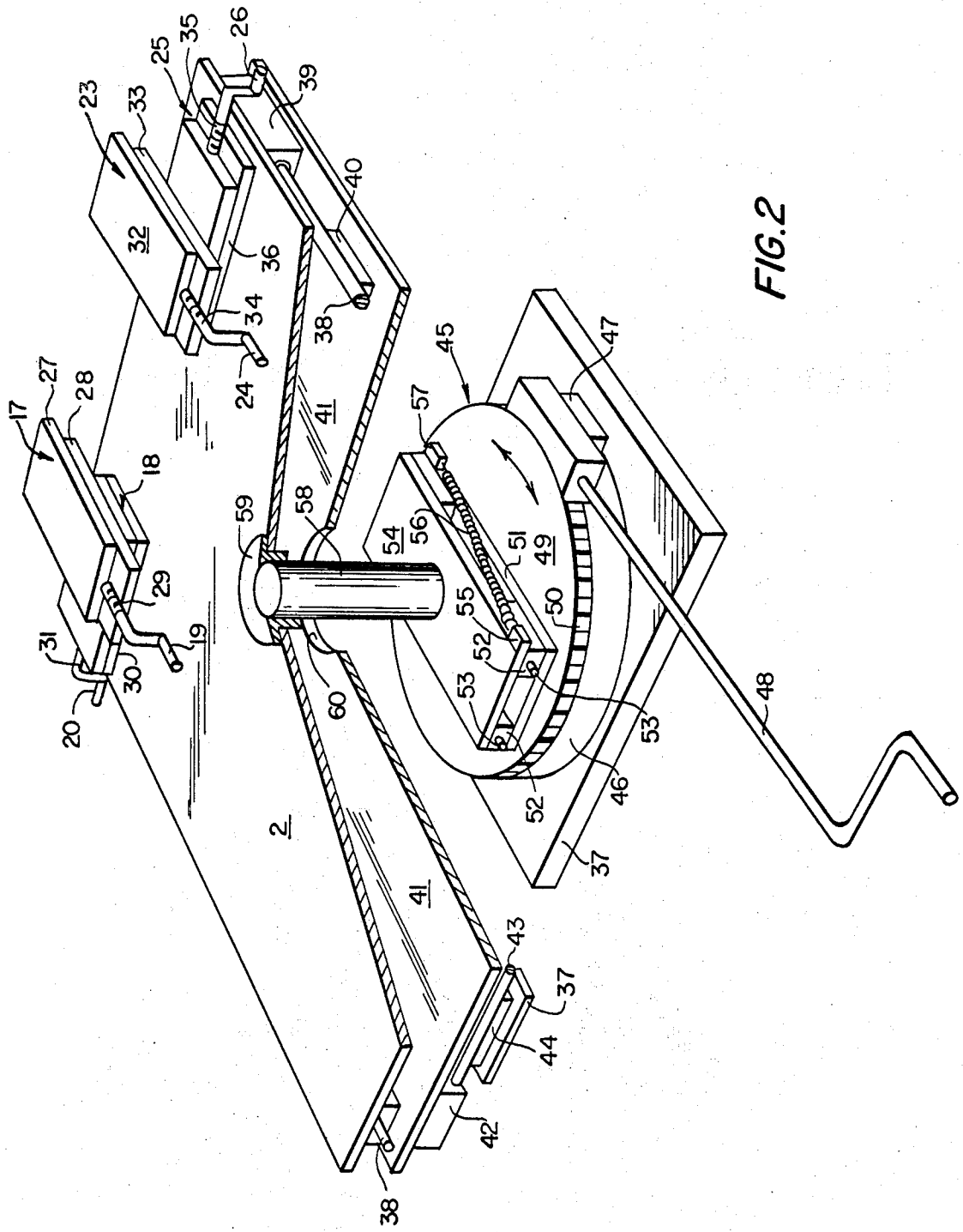

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FIG.2

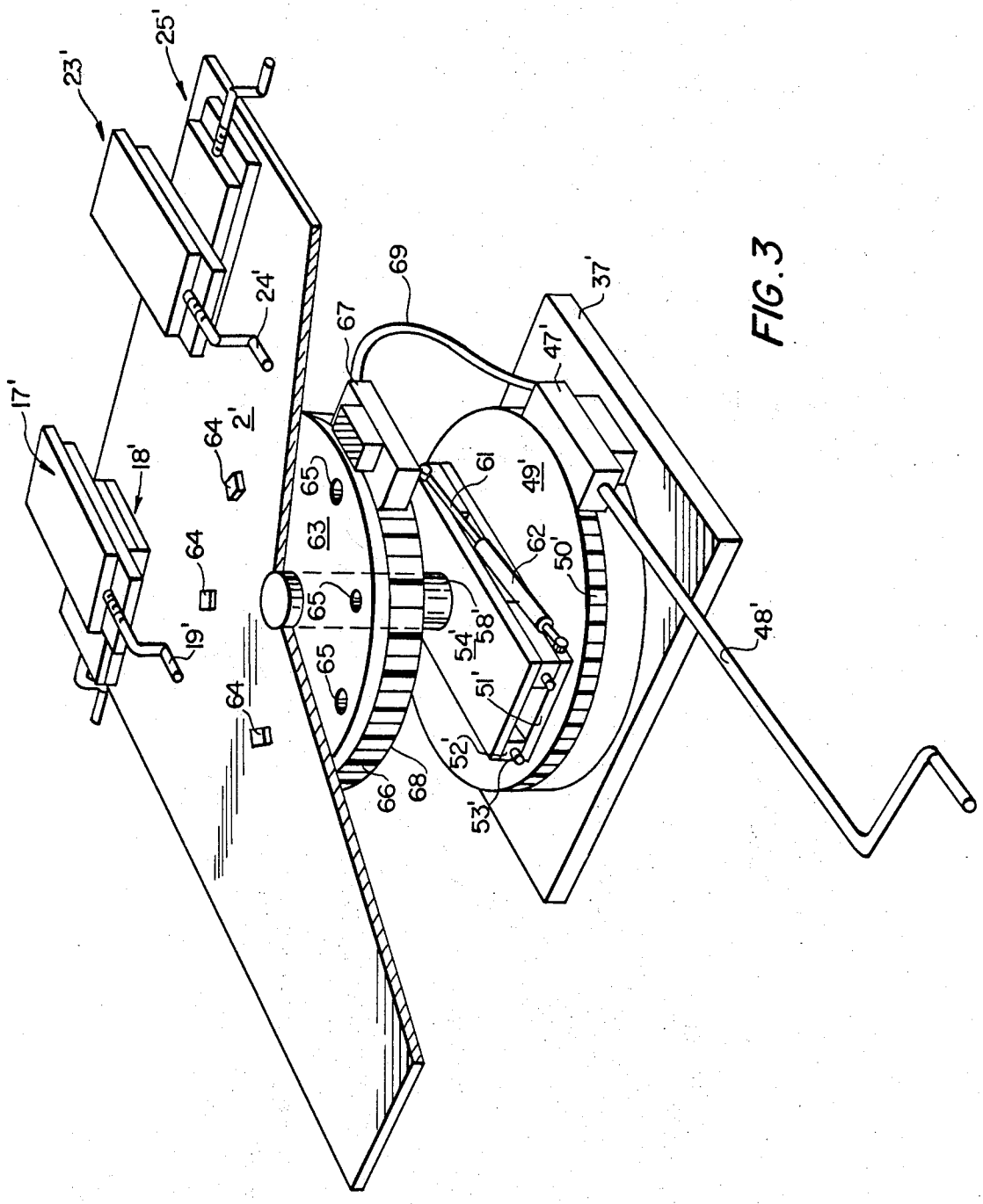

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FIG. 3

METHOD AND APPARATUS FOR TRAVERSING A CAM FOLLOWER

This is a division, of application Ser. No. 76,653 filed Sep. 28, 1970, and now abandoned.

BACKGROUND OF THE INVENTION

In a tube reducing mill, a thick walled, tube shell may be rolled into an elongated pipe. The tube reducer includes a heavy vertical roll stand having a pair of horizontal axis die rolls, with each die roll having an annular groove that varies in axial width around its entire periphery and that varies in radial depth about its entire periphery. The accurate forming of this groove is essential in that a tube shell is nipped by the die rolls and rolled forward while the tube piece resulting from the metal squeezed out is carefully smoothed in the adjacent part of the roll groove. The mill will produce a tube of relatively uniform thickness, and of very great lengths and wall thicknesses. A distinctive feature of this type of roll is the changing groove diameter. Due to the size, strength, radial and axial surface variations, and accuracy required, machining has proven to be quite difficult.

In general, machines are known for reproducing the control surface of a master in a work piece, apart from the specific application of machining Pilger rolls. The U.S. Pat. to Schiavone No. 2,754,637, which issued in 1956, is an example of this type of machine wherein a work piece is coaxially driven with a master, and wherein a rotatable tool and master follower are bodily moved radially and axially relative with respect to the rotating work piece and the master. The tool and follower tables are rotatable but to keep the tool normal to the work surface. In all machines of this type, there is considerable difficulty experienced in controlling the relative movement between the follower and master so that the follower uniformly engages the entire surface of the master for producing an accurate corresponding surface in the work piece. Difficulties of the prior art have been in part experienced due to variations in engagement pressure for different parts of the master surface, disengagement of the follower with the master, and high complexity of the mechanisms involved that produce cumulative errors, maintenance problems and high manufacturing costs.

SUMMARY OF THE INVENTION

It is an object of the present invention to produce highly efficient and accurate method and machine using engagement of a follower with a control cam surface, particularly a three dimensionally varying control surface with corresponding three dimensional relative movement between the control surface and follower. According to the present invention, this method and mechanism has been found to be particularly useful in combination with a tracing machine tool for duplicating the control surface of the master pattern in a work piece by having the work piece follow the movements of the master and the machine tool follow the movements of the follower.

A preferred embodiment of the present invention relates to a machine tool and the method of using the machine tool wherein the work piece and master are mounted for rotation about a common axis, the master follower and machine tool are mounted on a common table, each by cross slides for initial adjustment so that the relative position of the master to the follower is substantially the same as the relative position of the work piece and tool, the table has a mounting restricting its movement with respect to the master and work piece to only translation, an independently rotatable slide is adjustable through an angle of 180° in a plane substantially parallel with the axes of rotation of the work piece and master for continuously changing the angle of table translation during machining, and a bias is provided in the direction of translation so that the follower will traverse the entire axial extent of the adjacent master control surface only under the influence of the bias and rotation of the direction of translation through the required angle, for example 180°.

Thus, with the present invention, a follower engages a master under the influence of a constant bias by translating in a direction with respect to the control surface that sweeps through an angle sufficient to traverse the entire control surface. With simultaneous rotation of the master, a compound control movement will be obtained. For use in operating a machine tool, the follower moves with the tool and the master moves with the work piece for accurate duplication of the control surface of the master in the surface of the work piece. The system provides a uniform pressure and direction of relative movement between the control surface and follower that is at all times perpendicularly oriented without relative rotation therebetween.

BRIEF DESCRIPTION OF THE DRAWING

Further objects, features and advantages of the present invention will become more clear from the following detailed description of the drawing, wherein:

FIG. 1 is a plan view of a preferred embodiment of the apparatus according to the present invention, which is set up to grind the periphery of a rolling die to be used in a Pilger type of rolling mill, with the grinding being controlled by a similarly shaped master;

FIG. 2 is a partial perspective view of the preferred table construction for mounting thereon the follower and tool;

FIG. 3 shows a modification of the structure of FIG. 2;

FIG. 4 shows the engagement between the follower and master or tool and work piece when the translation and biasing force are in the direction indicated by the arrow, that is, perpendicular to the axis of rotation of the master and work piece;

FIG. 5 shows the relative positioning between the follower and master or tool and work piece when the direction of relative translation and bias is rotated 45° counter clockwise from the position of FIG. 4 to the new position as indicated by the arrow, with the intermediate positions having been traversed; and

FIG. 6 shows the relative position between the follower and master or tool and work piece when the direction of relative translation and bias has been rotated 90° in the counter clockwise direction from its position of FIG. 4 to the position indicated by the arrow, with all of the intermediate positions having been traversed.

DETAILED DESCRIPTION OF THE DRAWINGS

A preferred embodiment of the present invention is shown in FIG. 1 and takes the form of an abrading machine for duplicating the three dimensional contour of a master in a work piece, which may have the specific

application of producing rolling dies for Pilger type rolling mills or for producing a three dimensionally contoured cam from a control cam, for example. The specifically illustrated machine tool could also be a milling machine, merely by substituting a milling tool for the grinding wheel, but for purposes of a specific illustration grinding will be referred to in the following description.

A first table **1** is mounted for relative movement, to be described hereinafter, with respect to a second table **2.** For purposes of the broader aspects of the present invention, the table **1** may be stationary and the table **2** movable, or the table **2** may be stationary and table **1** movable. In the specifically illustrated preferred embodiment, the table **1** is stationary and the table **2** is mounted only for translation in any one selected direction in the plane of FIG. **1,** without relative rotation between the tables **1** and **2.**

The table **1** carries thereon an electric motor **3** that drives a pulley **4** about an axis parallel to the plane of FIG. **1.** By means of a conventional belt **5,** the pulley **4** correspondingly rotates a larger pulley **6** about an axis parallel to the axis of pulley **4;** due to the difference in size between the pulleys **4** and **6,** there is a speed reduction in the drive. The pulley **6** is keyed in a conventional manner to a shaft **7,** which is rotatably mounted within suitable pillow block bearings **8.** The shaft **7** also drivingly carries thereon a master cam or pattern **9** and work piece **10.** The shaft **7** and/or bearings **8** may be disassembled for removal and replacement of the master cam **9** and work piece **10** with similar or materially different cams and work pieces respectively. The master cam **9** has an annular groove **11** that varies in radial depth, with respect to the axis of shaft **7,** about is entire periphery and that varies in axial width, with respect to the axis of shaft **7,** about its entire periphery. The machine tool is designed for reproducing this groove configuration in the work piece **10** by machining a correspondingly shaped groove **12.**

The table **2** carries thereon the cam follower **13** and abrading wheel **14.** The cam follower **13** is a disc substantially identical to the abrading wheel **14** and drivingly carried by a shaft **15,** which shaft is rotatably mounted within a bearing **16,** so that engagement of the follower **13** with the rotating master cam **9** will cause corresponding counter roation of the cam follower **13.** Also, it is contemplated that the follower may be stationary or bearing **16** may be replaced by a motor provided with shaft **15** for driving the cam follower **13** independently of the master cam **9.** The bearing **16** is adjustably mounted with respect to the table **2** by means of a first cross slide **17** carrying thereon the bearing **16** and a second cross slide **18** mounted on the table **2** and carrying thereon the first cross slide **17.** The cross slides **17** and **18** are of conventional structure per se in that the cross slide **17** is provided with a crank **19** for adjusting the bearing **16** in a plane of FIG. **1** perpendicularly toward and away from the axis of rotation of shaft **7,** and the cross slide **18** is provided with a crank **20** for adjustment of the cross slide **17** and carried bearing **16** within the plane of FIG. **1** in a direction toward and away from the abrading wheel **14,** that is, parallel to the axis of rotation of shaft **7.**

In a similar manner, the grinding wheel **14** is mounted for rotation about an axis parallel to the shaft **7,** for adjustment perpendicular to the shaft **7** and adjustment parallel to the shaft **7.** The grinding wheel **14** is drivingly carried by the shaft **21** of an electric motor **22,** which motor **22** rotatably drives the grinding wheel **14** at a speed substantially greater than the speed of rotation of the work piece **10.** For adjustment of the grinding wheel **14** toward and away from the work piece **10,** the electric motor **22** is carried by a cross slide **23.** In a conventional manner, the handle **24** of the cross slide **23** may be operated to move the motor **22,** shaft **21** and grinding wheel **14** in the plane of FIG. **1** toward and away from the work piece **10,** that is perpendicular to the axis of rotation of shaft **7.** The slide **23** is mounted on a cross slide **25,** which cross slide **25** is of conventional construction with a crank handle **26** for movement of the slide **23,** motor **22,** shaft **21** and abrading wheel **14** toward and away from the follower **13** in the plane of FIG. **1,** that is, parallel to the axis of rotation of the shaft **7.**

In setting up the abrading machine for operation, the shaft **7** and bearings **8** are disassembled to allow mounting of the appropriate master cam or pattern **9** and work piece **10,** which work piece **10** may be cast roughly to the desired shape. The appropriate follower **13** is mounted by conventional means on the shaft **15** and the appropriate grinding wheel **14** is mounted by conventional means on a shaft **21.** At some time in the set-up procedure, the abrading wheel **14** is dressed to the exact outer contour of the cam follower **13,** in a manner that is not specifically shown. Cross slides **17** and **18** are operated to bring the cam follower **13** into a predetermined reference position with respect to the groove **11** within the master cam **9,** and the cross slides **23** and **25** are manipulated to bring the abrading wheel **14** into the same relative position with respect to the groove **12** within the work piece **10.** Thereafter during the machining operation, the cross slides **17, 18** and **23, 25** are not used, except if it becomes necessary to again dress the grinding wheel **14.**

In FIG. **2,** the cross slides are shown in greater detail, although still somewhat schematic in that their structure is conventional per se. Cross slide **17** includes upper and lower relatively movable portions **27, 28,** with the portion **27** rigidly carrying thereon the bearing **16.** The crank **19** is provided with a threaded shaft **29** for relatively moving the portions **27, 28** according to the direction of rotation. The cross slide **18** includes relatively movable portions **30** and **28,** with the crank **20** having a threaded shaft **31** for driving the portions **28** and **30** relative to each other in correspondence with the direction of rotation of the threaded shaft **31.** The upper portion **32** of slide **23** rigidly carries thereon the motor **22** and is moved relative to the lower portion **33** by means of the threaded shaft **34** that is rotated by operation of the crank **24.** Cross slide **25** similarly has a threaded shaft **35,** which can be rotated by the crank **26** for driving the portion **33** relative to the portion **36** that is rigidly mounted on the table **2.**

Movement of the table **2** relative to a stationary base **37** is limited to translation generally parallel to the extent of its top surface by means of perpendicularly oriented slide guides. On the under surface of table **2** at two diametrically opposed ends, there are rigidly mounted two parallel slide bars **38** by means of depending mounting blocks **39,** only one of which is shown, that are respectively rigidly mounted on the end portions of the bars **38** and all rigidly mounted with respect to the table **2.** The bars **38** rest in upwardly opening semicircular channels of bearing blocks **40,** which

blocks 40 are rigidly mounted on the upper surface of a support plate 41. In this manner, the bars 38 may slide with respect to the bearing blocks 40 in the direction of their axial extent and correspondingly the slide elements 38–40 support the table 2 upon the support plate 41 and permit only relative translation therebetween in one direction, that is, parallel to the axial extent of the bars 38 and perpendicular to the axis of shaft 7

In a similar manner, but perpendicularly oriented, the support plate 41 is mounted for translation only with respect to the stationary base 37 by means of slide elements. Particularly, a plurality of support blocks 42, only one being shown in FIG. 2, are mounted rigidly on the under surface of support plate 41 at its four corners and each in turn is rigidly connected to the ends of two parallel slide bars 43, only one of which is shown in FIG. 2. The slide bars 43 are respectively slidingly supported in the upwardly opening semicircular channels of bearing blocks 44, which blocks 44 are rigid with base 37 and only one of which is shown in FIG. 2. Thus, the bearing plate 41 is supportingly mounted on the base 37 for only relative translation parallel to the axial extent of bars 43 by means of the slide elements 42–44, that is, parallel to the axis of shaft 7. By the above described slide mechanisms, 38–44, the table 2 is mounted with respect to the stationary base 37 for only translatory movement in any direction parallel to the plane of its extent, which is parallel to the surface of FIG. 1. That is, the table 2 may only translate in its plane and may not rotate relative to the stationary base 37.

To limit the translation of table 2 to a single direction with respect to stationary base 37 and to determine the angular orientation of this direction, an independently rotatable slide mechanism 45 is provided, A circular bearing disc 46 is rigidly mounted on the stationary base 37 and rifidly carries on one side a gear box 47. A worm gear is rotatably mounted within the gear box 47 and driven by the coaxial crank handle 48. Suitable means, for example a stub shaft and bearing (not shown) is provided to rotatably mount a gear 49 coaxially with the bearing disc 46, for relative rotation with respect to the stationary base 37 about a stationary vertical axis. The peripherally arranged teeth 50 of the gear 49 drivingly interengage with the gear box 47 so that rotation of crank 48 will rotate gear 49 about its stationary vertical axis.

A lower slide block 51 is rigidly carried by the gear 49 and slideably mounted by means of interengaging bore bearing blocks 52 and rods 53 for relative translation with respect to an upper slide block 54. That is, the blocks and rods 52, 53 are respectively carried by the upper and lower slide blocks 54, 51. Upper slide block 54 is provided with an ear 55 at one end for mounting the adjacent end of a tension spring 56, and lower slide block 51 is provided with an ear 57 at the opposite end for mounting the other end of the spring 56 to bias the upper and lower slide blocks 54, 51 relative to each other with a constant force irrespective of the angular rotation of gear 49 relative to the stationary base 37.

The upper slide block 54 rigidly carries an upstanding bearing shaft 58, which is freely axially and freely rotatably snugly mounted within a sleeve bearing 59 rigidly carried by the table 2. The support plate 41 is provided with an oversized hole 60 for passing therethrough the shaft 58, so that the support plate 41 will not be engaged by the shaft 58 during any movement of the shaft 58 within the design range.

From the above description of FIG. 2, it can be seen that the crank 48 may be operated to rotate the gear 49 and carry slide blocks 51, 54 through any desired angle parallel to the plane of table 2. At any position to which the gear 49 is rotated, there will be correspondingly one direction within the plane of table 2 that the table 2 may be translated, as determined by the relatively reciprocating or translating slide blocks 51, 54 and the force transmitting shaft 58 and bearing 59. The slide mechanisms 38–44 will allow the translation in any direction as determined by rotation of the gear 49 while at the same time preventing rotation of the table 2 within its plane. The spring 56 will provide a constant bias force in the chosen direction.

In the embodiment of FIG. 3, like numerals have been provided for like parts, with the primes to designate the separate embodiment. Reference may be had to the above description for the structure and operation of the substantially identical parts bearing like numerals and only the variations in structure will be specifically described below. To provide the directional bias between upper slide block 54′ and lower slide block 51′ a piston 61-cylinder 62 is provided between respective ears, with the piston 61 and cylinder 62 being urged apart by an internal coil spring or internal constantly applied fluid pressure. The shaft 58′ is freely axially and freely rotatably snugly mounted within the table 2′ and a circular bearing disc 63 that is rigidly mounted on the lower surface of table 2′ by means of a plurality of peripherally arranged bolts 64 in threaded engagement within holes 65 only passing into the plate 63. A gear 66 is carried by the bearing disc 63 for relative rotation with respect thereto about the axis of the shaft 58′. A suitable key (not shown) is provided to interlock the gear 66 and shaft 58′ for rotation together. A suitable gear box 67 is rigidly mounted on the bearing disc 63 to table 2 and carries therein a worm that is mounted for rotation about a shaft parallel to the shaft of crank 48′. The worm gear within gear box 67 drivingly interengages with the peripherally arranged teeth 68 on gear 66. A flexible shaft 69 drivingly interconnects the worm gear within gear box 47′ with the worm gear within gear box 67 for counter rotation. The drive ratio between the worm gear teeth 68 and worm within gear box 67 is identical to the drive ratio between the gear teeth 50′ and worm within box 47′ so that any relative rotation between gear 49′ and 37′ will be offset with an equal relative rotation between gear 66 and table 2′, that is, the intergearing will assure that table 2′ does not rotate with respect to stationary base 37′ irrespective of rotation of the slide blocks 51′ and 54′. Thus, rotation of the handle 48′ will determine the angular direction of biased translation of the table 2′ relative to the base 37′ while at the same time preventing rotation of the table 2′ relative to the base 37′, which is the same result obtained with the table mounting mechanism of FIG. 2 Further variations in the table mounting mechanism that would produce the same result of a biased translation for table 2, 2′ without rotation, which translation may be angularly adjusted, are contemplated within the broader aspects of the present invention.

Three positions of the tool 14 relative to the work 10 or the follower 13 relative to the master 9 are shown in FIGS. 4–6, which could correspond to three rotated po-

sitions of the slide mechanism **45.** In the relative position shown in FIG. **4,** the rods **53, 53'** as shown in FIGS. **2** and **3** of the slide mechanism are in a position such that they are perpendicular to the axis of rotation of shaft **7** as shown in FIG. **1.** In such a position, it is seen that the bias produced by the spring **56** or the piston-cylinder **61, 62,** is also directed perpendicular to the axis of shaft **7.** Since the table **2** is free to translate in the direction perpendicular to the shaft **7,** the follower **13** or tool **14** will assume the deepest position in the adjacent groove **11, 12,** respectively. By operating the handle **48, 48',** the slide mechanism may be rotated continuously in either direction from the position resulting in the relationship of FIG. **4** by an angle of 90°, for example, although it is contemplated that other angular ranges may be employed.

With the follower **13** or tool **14** assuming the position of FIG. **5** relative to the master **9** or work piece **10,** the slide mechanism has been rotated in the counter clockwise direction 45° from its position of FIG. **2** and FIG. **3,** by handle **48, 48'.** It is noted that in this position the axis of the follower **13** or tool **14** has not rotated with respect to the axis of shaft **7,** although the follower or tool has taken a new position with the respective groove **11** or **12.** In the position of FIG. **5,** the force and direction of translation are aligned with the indicated arrow for corresponding engagement.

The relative position of the follower **13** and master **9** or tool **14** and work piece **10** as shown in FIG. **6** is assumed when the bars **53, 53'** are rotated by operation of the crank **48, 48'** to assume a position wherein they are parallel with the axis of rotation of shaft **7.** Correspondingly, the direction of translation of the table **2** and the direction of the constant bias force are shown by the arrow to be parallel to the axis of the shaft **7.** Rotation of the handle **48, 48'** to rotate the slide mechanism in the clockwise direction 180° from the position of FIG. **6** would produce a corresponding engagement on the diametrically opposed side of the groove **11, 12.** During the rotation of 180° all surface portions of the grooves **11, 12** would be traversed by the follower **13** and tool **14,** respectively.

The advantages of the above mechanism are seen in that the relative positioning between the tool and follower may be initially set up and then fixed throughout the entire machine operation. In contrast, with prior machines wherein the tool and/or follower must rotate to assume a wide range of positions relative to their work piece or master, the relative positioning of the tool and follower will change or at least additional errors may be introduced in their spacing by movable parts between their connections. In the present invention, the tool and follower move as a unit relative to the master and work piece without sacrifice in ability to traverse a three dimensional surface of widely varying shape. According to the present invention, it is only the direction of relative translation that changes, that is, there is no rotation between master, work piece, follower and tool axes. Additionally, uniform engagement between the master and follower, and work piece and tool is assured in that the direction of bias correspondingly changes so that the bias will be constant and generally perpendicular to the engaging surfaces. Further, it is seen that there are very few moving parts for tolerance accumulation, wear, manufacturing costs and maintenance.

In reference to the axis of rotation of the tool, it is understood that this axis may be parallel with the axis of rotation of shaft **7** or at any other angle according to the broader aspects of the present invention; for example, the tool may be of a type shown in U.S. Pat. No. 2,330,566, to Edmonds et al., issued Sep. 28, 1943. Similarly, the follower may be rotatable about an axis parallel with the axis of the rotatable tool or the follower may be rotationally stationary according to the broader aspects of the present invention. Although accuracy and set up advantages are obtained by mounting the work piece and master upon a common shaft, the broader aspects of the present invention contemplate staggering their shafts or separating them in some other manner. Further the method of the present invention could be accomplished by hand as applied to only a cam and follower or a tool and work piece or pattern tracing wherein both the follower and tool were moved simultaneously relative to a master and work piece; to accomplish this, the tool and/or follower would be grasped by hand and moved continuously through the various positions shown in FIGS. **4–6** while maintaining the engaging force and direction of movement according to the orientation of the arrows in these figures.

OPERATION

For purposes of describing the system of the present invention, let it be assumed that it is desired to final grind a previously rough cast roll die for a tube reducer rolling mill, with the final ground shape to be dictated by the configuration of a master cam having exactly the desired groove configuration. With reference to FIG. **1,** the shaft **7** and bearings **8** would be disassembled to allow mounting of the master **9** and cast work piece **10;** thereafter, the bearings would be fixed to allow rotation of the master **9** and work piece **10** about the common axis of shaft **7** under the drive of motor **3.** Thereafter, a grinding wheel **14** would be mounted on the shaft **21** and a preferably identically shaped follower **13** would be mounted on the shaft **15;** if the grinding wheel had not previously been dressed, it would not be dressed to assume as closely as possible the working configuration of the follower **13.** Thereafter, the cross slides **17** and **18** would be adjusted by their respective cranks **19** and **20** to accurately locate the follower **13** in a predetermined position relative to the master **9,** for example, the center for the working face, preferably semicircular, of the follower **13** when viewed in a cross section that would be similar to FIG. **4** would be located midway along the line joining the terminal ends of the groove **11,** which would be a position similar to that shown in FIG. **4** but with the follower withdrawn partially from the groove **11.** Most preferably, the shafts **15, 21** and **7** would be horizontally aligned.

Thereafter, the cross slides **23, 25** would be adjusted by their respective cranks **24, 26** to accurately locate the tool **14** in a corresponding position relative to the work piece **10,** which according to the above specific example would mean that the center of the adjacent semicircular surface of the tool **14** as viewed in the horizontal plane passing through the shafts **7, 15** and **21** would bisect the line drawn between the terminal ends of the groove **12.** This position would exactly correspond with the position of the follower **13** relative to the groove **11** even though the groove **12** in its cast state would be smaller than the groove **11** at corresponding positions.

Now the machine is basically set up for a machining operation. If the groove **12** is to be finally machined to the exact size of groove **11**, the cross slides **23, 25** and **17, 18** are not adjusted further. However, if it is desired to make a first machining pass to grind all but the last 0.002 of an inch, that is grind the groove **12** to a uniform 0.002 of an inch smaller than the groove **11**, the cross slides **17, 18, 23, 25** would be adjusted further. Although these adjustments may take various forms, a specific example will be given. Although the follower and tool are still held withdrawn from engagement with their respective grooves **11** and **12** throughout these adjusting steps, it will be advantageous to refer to FIGS. **4–6** for the angular orientations shown with the understanding that in fact there would be no engagement. The cross slide **17** or **23** is adjusted to relatively move the follower or tool 0.002 of an inch so that the follower will correspondingly by 0.002 of an inch closer to the axis of shaft **7.** Thereafter, the cross slide **18** or the cross slide **25** is adjusted to relatively move the tool and follower 0.002 of an inch in a direction parallel to the axis of shaft **7** away from each other. With this initial set up, the cross slides **17, 18, 23** and **25** will not be further adjusted for one-half of the machining operation. With the rods **53** arranged perpendicular to the axis of shaft **7,** the table **2** will be released to allow its translation perpendicularly toward the axis of shaft **7** until the follower **13** assumes the position of FIG. **4** relative to the groove **11** of the master **9**; the tool **14** will assume a similar position with respect to the work piece groove **12,** but will grind radially inwardly to within 0.002 of an inch of the final configuration. Thereafter, the crank **48, 48'** is rotated either manually or by automatic feed to slowly swing the rods **53** and correspondingly the force and translation direction arrow in a counter clockwise direction, as viewed in FIGS. **1–4,** continuously through an angle of 90° to the relative position of FIG. **6,** with the position of FIG. **5** having been passed. During the slow feed sweep caused by rotation of the crank **48, 48'**, the shaft **7** would be turned at a feed speed sufficient to assure that the entire periphery of one-half of the respective grooves will be traversed. In this manner, the left hand half of groove **12** would be roughed machined, as viewed in FIG. **1.**

To rough machine the other half of the groove **12,** that is the right hand half, the table **2** would be withdrawn to withdraw the follower and tool out of engagement with the master and work piece, respectively; the cranks **48, 48'** would be turned to a position wherein the rods **53** would be perpendicular to the axis of shaft **7.** Thereafter, the cross slide **18** or **25** would be adjusted to move the follower **13** and tool **14** axially toward each other the previously adjusted 0.002 of an inch and an additional 0.002 of an inch. Thereafter, the machining operations would be repeated on the right hand portion of the groove **12,** as viewed in FIG. **1** by rotating the arrow in the clockwise direction from its position of FIG. **4** to a position diametrically opposed from that of FIG. **6.** Due to the cumulative offset of 0.004 of an inch parallel to the axis of shaft **7,** the central most portion of the groove **12** would not be machined properly if the above steps were followed exactly; therefore, in machining the left hand portion of the groove **12,** it is necessary to swing the rods **53** and correspondingly the arrows shown in FIG. **4** very slightly to the clockwise direction from the perpendicualr and when machining the right hand portion of the groove **12,** it is necessary to correspondingly swing the rods **53** and arrow of FIG. **4** very slightly in the counter clockwise direction from the perpendicular position.

For final machining, the cross slides **18, 17, 23, 25** will be adjusted to the above-described initial setup position wherein their centers of curvature exactly bisect the respective lines drawn between the terminal ends of respective grooves when viewed in a plane passing through axes **7, 15, 21.** From this position, the table **2** may be released to allow engagement of the follow **13** with the groove **11** and the tool **14** with the groove **12.** Thereafter, the crank **48, 48'** would be operated to continuously swing the rods **53** through the full machining angle of 180°, for example from a position of FIG. **6** clockwise 180° to grind the final 0.002 of an inch.

With the above-described system, it is seen that the follower and tool are fixed relative to each other, and the master and work piece are fixed relative to each other whenever any material is being removed from the work piece to avoid errors inherent in changing position. This advantage is obtained simultaneously with a force and movement orientation that is at all times substantially perpendicular to the surface being machined or surface of the cam being traversed, regardless of the three dimensional configuration of the surfaces. All of the above is accomplished with a relatively simple mechanism, which would correspondingly be relatively maintenance free and inexpensive to manufacture, and can be operated by relatively unskilled personnel.

Although the specifically illustrated embodiment is highly desirable in its own right, further modifications, variations and embodiments are contemplated according to the broader aspects of the present invention as defined by the spirit and scope of the following claims.

What is claimed is:

1. Control apparatus comprising: a cam mounted for rotation about an axis and having an annular cam control surface varying in radius peripherally around said axis and varying in configuration as measured parallel to its axis about its periphery; a cam follower; means guiding said cam follower for movement relative to said cam along a single path; and means, in addition to said follower, for varying the angle of said path relative to said cam axis of rotation without changing the angular relationship between said cam axis of rotation and said follower.

2. The apparatus of claim **1** including means for mounting said follower for rotation about an axis parallel to the axis of rotation,of said cam.

3. The apparatus of claim **1** including means for biasing said cam follower against the control surface of said cam.

4. A control mechanism comprising: means for holding a cam; a cam follower; means interconnecting said cam holding means and said cam follower for only relative translatory movement within a plane; means for biasing said cam follower and cam holding means relatively toward each other along a path within said plane; and means in addition to said follower, sweeping said bias path through an angle sufficient to traverse the cam surface by the follower without rotating the follower relative to the cam within said plane.

5. The apparatus of claim **4,** wherein said cam holding means includes means for rotating a cam about an

axis lying in a plane that is generally perpendicular to a plane containing the axis about which the path is rotated.

6. A control mechanism comprising: means for holding a cam; a cam follower; interconnecting means interconnecting said cam holding means and said cam follower for relative movement toward and away from each other along a predetermined single path; adjusting means, in addition to said follower, for adjusting said interconnecting means to rotate the predetermined single path through a substantial angle to cause said cam follower to traverse a cam surface held by said means for holding a cam and said adjusting means preventing relative rotation of said cam holding means and said cam follower about an axis parallel with the axis of rotation of said path.

7. The method of traversing a curved cam surface with a follower, comprising the steps of: guiding the follower for only translatory movement in a plane intersecting the curved surface; biasing said follower along a path in the same plane and into engagement with said curved surface; and rotating the bias path through an angle sufficient to traverse the curved surface while simultaneously preventing the same rotation of said follower relative to said curved surface within the plane.

8. The method of claim 7, including the step of simultaneously rotating said curved surface about an axis lying in a plane that is substantially perpendicular to a plane containing the axis about which said path is rotated.

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