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Wilson

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[54] **PATTERN MACHINING SYSTEM FOR DIE ROLLS**

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Related U.S. Application Data

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[52] **U.S. Cl.**..... **51/35,** 51/50 PC, 51/101 R, 51/281, 51/289 R, 82/19, 90/13.4, 90/62 R

[51] **Int. Cl.**..... **B24b 1/00,** B24b 17/02

[58] **Field of Search**..... 51/32, 33 R, 35, 50 R, 51/50 PC, 100 R, 101 R, 281 R, 289 R; 82/2, 18, 19; 90/13.4, 62

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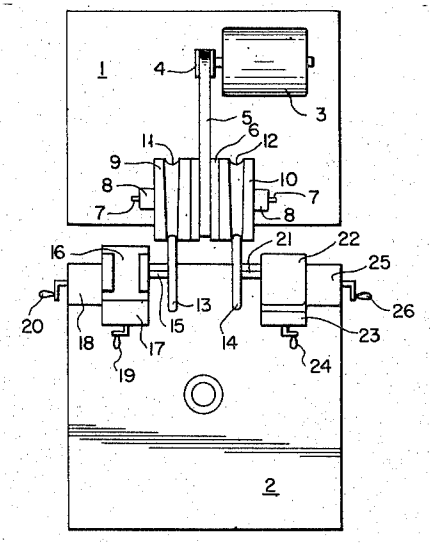
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[57] **ABSTRACT**

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 above-mentioned the abovementioned plane so that its entire three dimensional surface will be engaged by the follower.

28 Claims, 6 Drawing Figures



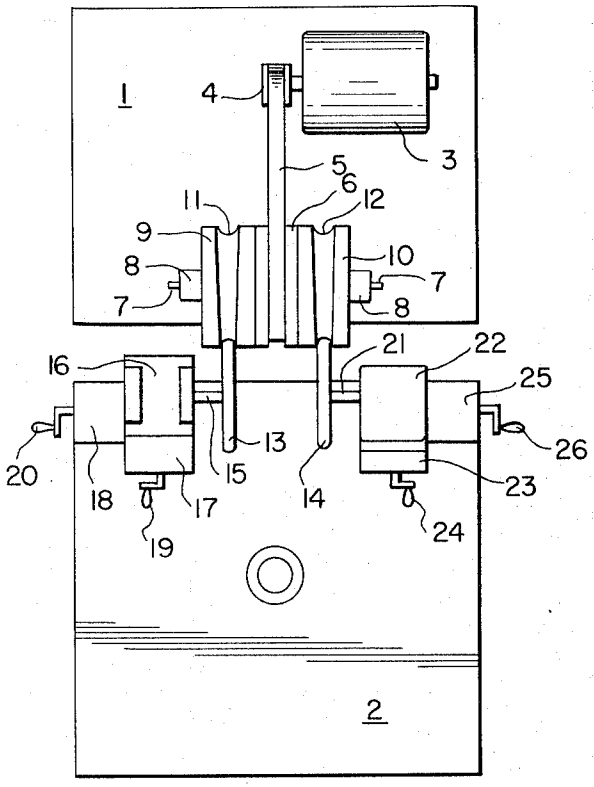


FIG. 1

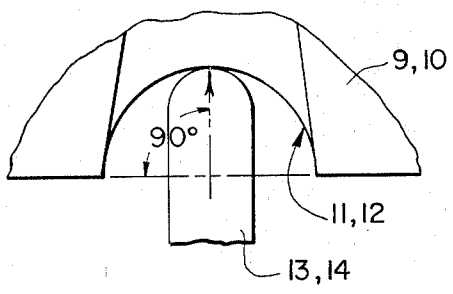


FIG. 4

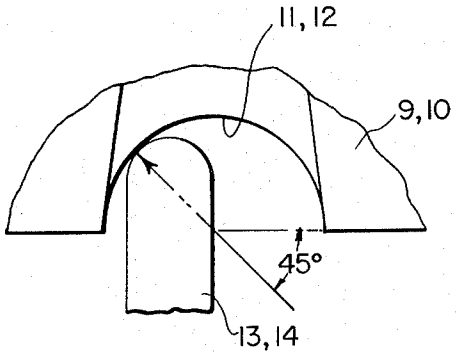


FIG. 5

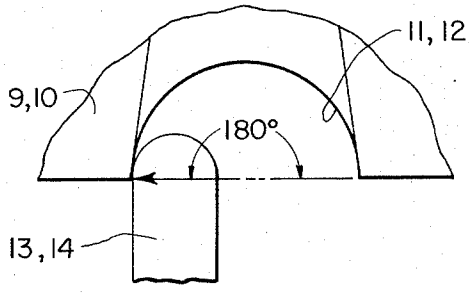


FIG. 6

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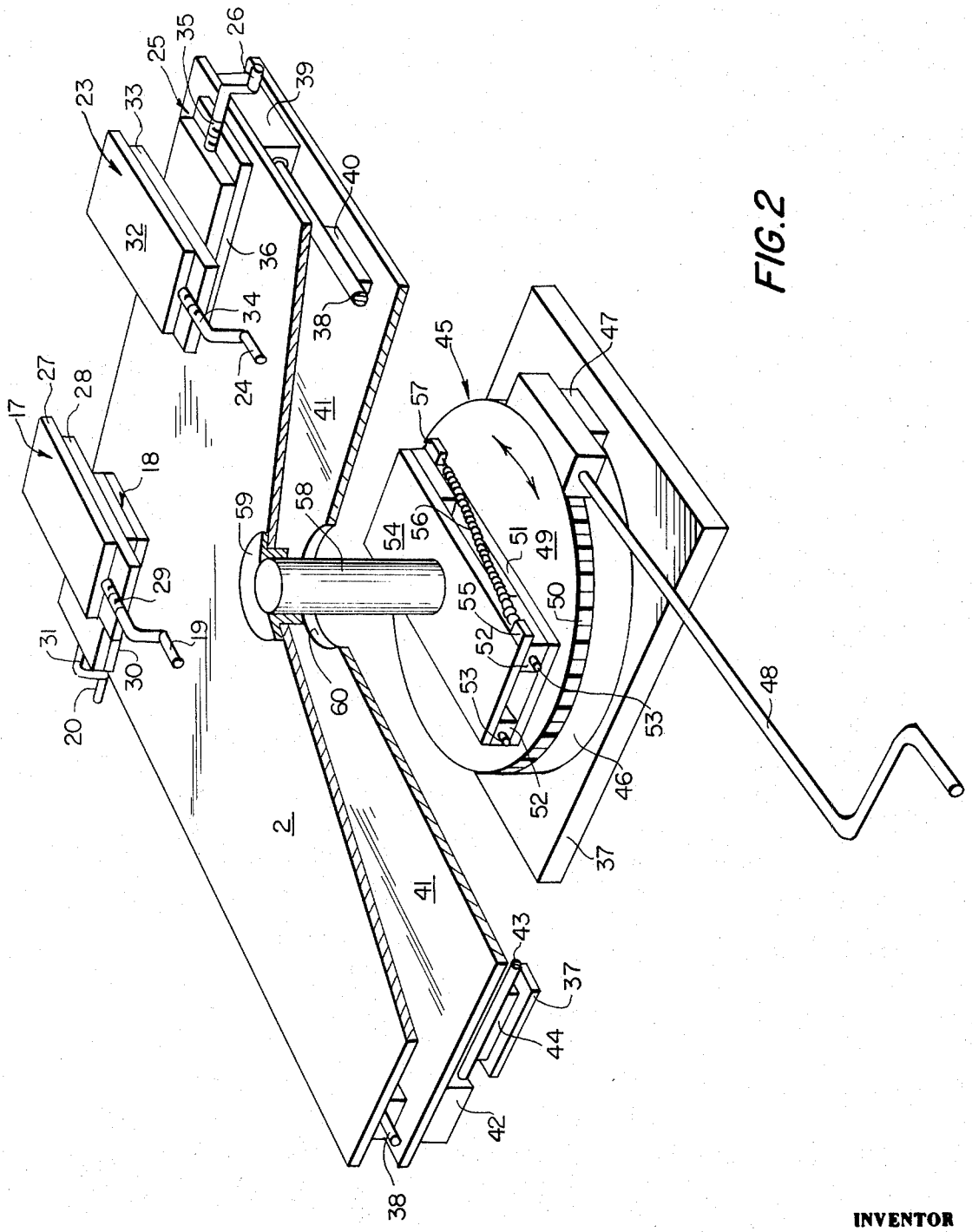


FIG. 2

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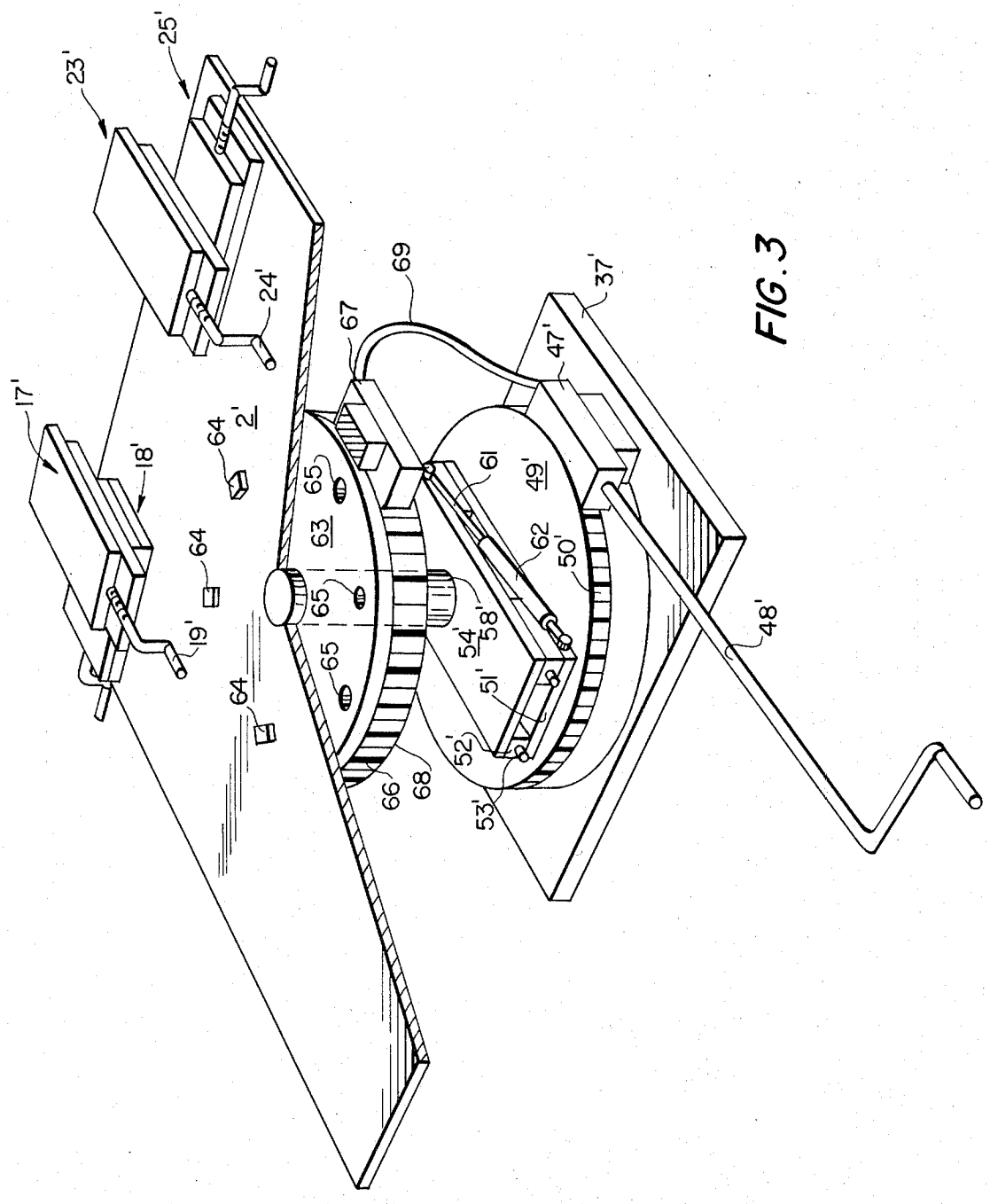


FIG. 3

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PATTERN MACHINING SYSTEM FOR DIE ROLLS

This is a continuation, of U.S. Pat. application Ser. No. 76,653 filed Sept. 28, 1970.

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 a 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, whuch 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 its 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 rotation 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 axis of rotation of 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 rigidly 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 tothe stationary base **37** about a stationary vertical axis. The peripherally arranged teeth **50** of the gear **49** drivingly interengage with the within 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** or 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 within 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 Sept. 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 is 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 now 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 be 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 form 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 perpendicular 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 follower **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 positions. 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. Pattern controlled apparatus for machining a work piece, comprising: means for holding a work piece to be machined; means for holding a master pattern having a surface configuration correlated to the configuration to be shaped upon the work piece; a follower; means for mounting a machining tool for rotation about an axis; means for guiding said tool mounting means and follower in a predetermined fixed correlation simultaneously relatively toward and away from said master holding means and work piece holding means along a single predetermined path; and means, in addition to said follower, for changing the angle of said path relative to the tool axis of rotation while maintaining the angular orientation between the tool axis of rotation and each of said follower, master holding means and work piece holding means.

2. The apparatus of claim **1**, wherein said tool holding means is rotatable at a cutting speed and said work piece holding means and said master holding means include means for respectively rotating the work piece and master about their axes at a feed speed substantially slower than the cutting speed.

3. The apparatus of claim **2**, wherein said work piece and master axes are coextensive; and said work piece and master holding means include common means for driving the work piece and master about their axes.

4. The apparatus of claim **1**, including a tool having a work piece contacting face of a specific cross-sectional configuration and wherein said follower has

a master engaging face of the same cross-sectional configuration.

5. The apparatus of claim 1, including means biasing said tool holding means toward said work piece holding means and said follower toward said master holding means, with said biasing means constituting the sole means to move the master, follower, work piece and tool relative to each other along said path.

6. The apparatus of claim 1, wherein said work piece holding means and master holding means are stationarily mounted; a common table fixedly carrying thereon said tool holding means and said follower; and said guiding means determining the path of movement of said table.

7. The apparatus of claim 6, including a fixed base; said guiding means including a slide having a first and second way for relative translation along said path; means mounting said slide first way to said base for rotation about a fixed axis perpendicular to said path; and means rotatably mounting said slide second way to said table about an axis parallel with said fixed axis.

8. The apparatus of claim 7, wherein said means for mounting said slide for rotation about a fixed axis includes means for selectively annularly driving said slide about said fixed axis; said means for rotatably mounting said slide to said table permitting free relative rotation; and means freely guiding said table for only translatory movement relative to said base.

9. The apparatus of claim 8, wherein said freely guiding means includes a mounting member having a translatory slide guide connection with said table and a translatory perpendicular slide guide connection with respect to said base.

10. The apparatus of claim 1, including a grinding wheel rotatably held by said tool mounting means; and means for facing said grinding wheel.

11. The apparatus of claim 1, including a table carrying said follower and said tool holding means; means for moving said follower relative to said table parallel to said tool axis and separate means for moving said follower relative to said table perpendicular to said tool axis; means for moving said tool holding means relative to said table perpendicular to said tool axis and separate means for moving said tool holding means relative to said table parallel to said tool axis.

12. The method of machining an annular configuration on a work piece varying in its radial dimension about an axis and varying in its axial dimension about the axis, comprising the steps of: providing a master having a configuration about an axis identical to the configuration desired to be machined; rotating the master about its axis at a feed speed; rotating the work piece about its axis at the same feed speed; rotating a machine tool about an axis at a machining speed substantially higher than said feed speed; correlating the distance of the working face of a cam follower from the working face of the tool to the distance of the control face of the master from the face to be machined of the work piece and thereafter fixing the spacing between the follower and tool and fixing the spacing between the master and work piece; effectively biasing said master and work piece relatively toward said follower and tool along a single predetermined path to engage said cam with said cam follower and said tool with said work piece; and in addition to any movement imparted by the follower engaging the master varying the angle of said path relative to all of said axes of rotation while maintaining the same angular orientation of all said axes of rotation with respect to each other until said follower engages the entire control periphery of said master and said tool machines the entire desired configuration on said work piece.

13. Pattern controlled apparatus for machining a work piece, comprising: means for holding a master pattern having a surface configuration correlated to the surface configuration to be shaped upon the work piece; a follower; means for holding a work piece to be machined in a fixed relationship with one of said means for holding a master pattern and follower as a first unit; means for mounting a machining tool for rotation about an axis in a fixed relationship with the other of said means for holding a master pattern and said follower as a second unit; means for guiding said first and second units for only translatory movement in a single plane relative to each other; means for biasing one of said units toward the other of said units along a predetermined path within said plane; and means, in addition to said follower, for sweeping the angle of said bias path within said plane relative to the tool axis of rotation without rotating any of said follower, tool axis, master holding means and work piece holding means in said plane.

14. The apparatus of claim 13, wherein said tool mounting means rotates the tool at a machining speed about said axis; and said work piece holding means and said master holding means include means for respectively rotating the work piece and master about their axes at a single common feed speed substantially slower than the machining speed.

15. The apparatus of claim 14, wherein said tool, work piece and master axes are parallel.

16. The apparatus of claim 15, wherein said tool, work piece and master axes are parallel to said plane.

17. A tool control mechanism comprising: means for holding a curved surface 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; means, in addition to said follower, for sweeping said bias path through an angle sufficient to traverse the curved cam surface by the follower without rotating the follower relative to the cam within said plane; means for holding a work piece; means for holding a tool to engage the work piece; and means interconnecting said tool holding means and said cam follower for concurrent movement along said bias path relative to said cam holding means and said work piece holding means.

18. The method of traversing a curved cam surface with a follower to reproduce the curved cam surface in a work piece, comprising the steps of: guiding the follower for only translatory movement in a plane intersecting the curved surface; biasing such follower along a path in the same plane and into engagement with said curved surface; rotating the bias path, in addition to any movement imparted by the follower engaging the curved cam surface, 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; and moving a machine tool relative to the work piece in direct proportion to the moving of the follower relative to the cam.

19. Master pattern controlled apparatus for three dimensionally shaping a work piece, comprising: means for holding a work piece to be shaped; means for holding a master pattern having a three dimensional surface configuration correlated to the configuration to be shaped upon the work piece; a master pattern follower; means for mounting a work piece shaping tool; means for guiding the movement of said tool mounting means in a predetermined correlation with the movement of the master pattern follower; means for providing a biasing force for urging the master pattern follower toward contact with the configured surface of the master pattern; and means to maintain the biasing force substantially perpendicular to the zone of contact between the follower and the master pattern.

20. The apparatus of claim 19, wherein the means for holding the work piece and the means for holding the master pattern are mounted in common on a support; and the master pattern follower and the means for mounting the work piece shaping tool are mounted in common on the means for guiding the movement of the tool mounting means.

21. The apparatus of claim 20, wherein the guiding means for the movement of the tool holding means includes a movable member upon which the tool mounting means and the master pattern follower are mounted, a base, and orthogonally related slide means which permit the movable member to move with respect to the base along mutually perpendicular lateral axes.

22. The apparatus of claim 21, including a further lateral slide means for movement of the base along the axis of said further slide means; said further slide means being rotatable with respect to the common support for the work piece holding means and the master pattern holding means about an axis normal to said mutually perpendicular axes; said means for providing a biasing force acting on said slide means to urge said master pattern follower in a direction determined by the rotational attitude of the axis of said further slide.

23. The apparatus of claim 20, including means for rotating the commonly mounted master pattern follower and means for mounting the work piece about an axis; and said means for providing a biasing force urging said master pattern follower in a direction as determined by the rotational angle of said common mounting about said axis.

24. Master pattern controlled apparatus for three dimensionally shaping a work piece, comprising: means for holding a work piece to be shaped; means for holding a master pattern having a three dimensional surface configuration correlated to the configuration to be shaped upon the work piece; a master pattern follower; means for mounting a work piece shaping tool; means for guiding the movement of said tool mounting means in a predetermined correlation with the movement of the master pattern follower; means for providing a biasing force for urging the master pattern follower toward contact with the configured surface of the master pattern; and means for varying the angle of the biasing force path with respect to the means for holding a master pattern.

25. The apparatus of claim 24, wherein the means for holding the work piece and the means for holding the master pattern are mounted in common on a support; and the master pattern follower and the means for mounting the work piece shaping tool are mounted in common on the means for guiding the movement of the tool mounting means.

26. The apparatus of claim 25, wherein the guiding means for the movement of the tool holding means includes a movable member upon which the tool mounting means and the master pattern follower are mounted, a base, and orthogonally related slide means which permit the movable member to move with respect to the base along mutually perpendicular lateral axes.

27. The apparatus of claim 26, including a further lateral slide means for movement of the base along the axis of said further slide means; said further slide means being rotatable with respect to the common support for the work piece holding means and the master pattern holding means about an axis normal to said mutually perpendicular axes; said means for providing a biasing force acting on said slide means to urge said master pattern follower in a direction determined by the rotational attitude of the axis of said further slide.

28. The apparatus of claim 25, including means for rotating the commonly mounted master pattern follower and means for mounting the work piece about an axis; and said means for providing a biasing force urging said master pattern follower in a direction as determined by the rotational angle of said common mounting about said axis.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,815,288 Dated June 11, 1974

Inventor(s) Harold R. Wilson

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Title Page and Col. 1, line 1, in the title, "PATTERN MACHINING SYSTEM FOR DIE ROLLS" should be --PATTERN MACHINING SYSTEM FOR TUBE REDUCER DIE ROLLS--.

Abstract, 3rd to the last line, after "parallel" insert --to the--; 2nd to last line, delete "the abovementioned".

Column 2, line 66, "whuch" should be --which--.

Column 5, line 44, "tothe" should be --to the--.

Column 8, line 14, "is" should be --in--.

Column 9, line 57, "form" should be --from--.

Column 11, line 65, after "and" insert a comma.

Signed and sealed this 7th day of January 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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