TAPERED END MILL MACHINE

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ABSTRACT

Apparatus for forming helical flutes in a tapered workpiece, and for sharpening such workpieces, especially to form and sharpen a novel tapered end mill, and employing special control over the position and feed of the workpiece relative to the machining tool.

18 Claims, 19 Drawing Figures
TAPERED END MILL MACHINE

BACKGROUND OF THE INVENTION

This invention relates to tapered end mills, and to apparatus for machining helical flutes in a tapered workpiece, especially for forming tapered end mills, and for sharpening such end mills.

Manufacture of tapered end mills having helical flutes and teeth is extremely difficult. Moreover, the inventor herein has learned through extensive experience that manufacture of a plurality of such cutters in a manner causing them to be substantially identical is almost impossible using conventional techniques. Even gradual wear of the machining tools used to form them upsets and changes the helical path formed. The problem is increased when the forming tool is dressed. And, when different size forming tools are used, the length and configuration of the helical path will vary considerably. Consequently, each of a group of end mills so formed will be a “bastard.” In fact, it has been discovered that wear of the forming tool can even cause helical paths on the same end mill to vary. As a result, not only are tapered end mills extremely expensive, but standardization is almost impossible, and even the quality of individual end mills varies. Further, since the forming tool normally requires a specially configured surface, the problem is even more complex.

When end mills become dull during usage, sharpening is also a problem. Following the helical path adjacent each cutting edge with a sharpening tool is extremely tricky. Trying to set up a machine to cause this following action is impractical using conventional technology, especially with end mills that vary from one to the next.

SUMMARY OF THE INVENTION

One object of this invention is to provide apparatus for forming tapered end mills and the like, at a fraction of the present cost. The end mills formed on the apparatus are accurate over all the flutes and teeth. A series of end mills can be formed having a standardized structure, both in flute length and also in helical path configuration.

Another very important object of this invention is to provide apparatus for forming helical flutes, including three or four flutes, into an elongated tapered workpiece, using a simple flat surfaced forming tool. No special pre-formed or specially configured tool is required. Yet the flutes can have either a 90° angle, for each of four flutes, or an obtuse angle, for each of three flutes. The width of the arcuate lands on the teeth between the flutes or grooves can be a selected amount, for ease of stock removal during subsequent sharpening. The depth of the cut and resulting flute can be controllably varied. Moreover, the depth of the flute can be varied, while still being able to roll the workpiece for relief forming to obtain a desired width land, even of narrow width.

Another object of the invention is to provide novel apparatus for machining flutes into tapered workpieces, particularly for forming end mills, wherein the resulting flutes and adjacent teeth are uniform even though the forming tool wears, even if the forming tool is repeatedly dressed, and even if different size forming tools are employed. The apparatus can be operated by the average machinist, to repeatedly produce quality, uniform products. All of this can be done with a flat wheel having no specially preformed configuration. Moreover, after forming any desired number of uniform fluted pieces, the same apparatus and forming tool can be used to sharpen these end mills, matching the helical path exactly. This is true even if, for example, 1000 or so are formed with varied diameters of flat forming wheels before any are sharpened.

Another object of this invention therefore, is to provide novel apparatus capable of machining tapered end mills, and also capable of subsequently accurately sharpening those end mills.

These and other objects, advantages, and features of this invention will become apparent upon studying the following specification in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front perspective view of the novel apparatus;

FIG. 2 is a perspective view of the apparatus in FIG. 1, shown viewed from an angle approximately 30° displaced to the right of the angle of viewing in FIG. 1;

FIG. 3 is a fragmentary perspective view of the apparatus in FIG. 1, viewed from the rear of the structure as illustrated in FIG. 1;

FIG. 4 is a perspective view of a feed control rotational cam for the apparatus in FIGS. 1–3;

FIG. 5 is a partial plan view of accommodating linkage forming a part of the feed control means for the novel apparatus;

FIG. 6 is a front elevational view of the linkage in FIG. 5 as connected to the control means cam follower device;

FIG. 7 is a diagrammatic presentation showing the differing relationships of different size cutting tools with a tapered end mill blank to be machined;

FIG. 8 is a diagrammatic illustration of part of the illustration in FIG. 7, showing the larger forming tool, and with the tapered end mill angles being exaggerated for purposes of illustration;

FIG. 9 is a diagrammatic illustration of the other part of the illustration in FIG. 7, showing the smaller forming tool, and again with the angles of the tapered end mill blank being exaggerated for illustrative purposes;

FIG. 10 is an end view taken on plane X–X of FIG. 13, and showing the small end of an end mill formed according to the invention;

FIG. 10A is an end view of an alternate form of end mill formed according to the invention;

FIG. 11 is a cross sectional view of the novel end mill, taken on plane XI–XI of FIG. 13;

FIG. 11A is a cross sectional view of the alternate end mill in FIG. 10A;

FIG. 12 is an elevational view of a tapered starting blank to form a tapered end mill;

FIG. 13 is an elevational view of a tapered end mill formed from the starting blank in FIG. 12, according to this invention;

FIG. 14 is a plan view of the novel apparatus;

FIG. 15 is a partial rear elevational view of the tilt mechanism for the work holding chuck of the apparatus;

FIG. 16 is a partial front elevational view of the limit switch mechanism for the feed control; and
FIG. 17 is a diagrammatic illustration showing the relationship of a forming tool to a previously formed end mill during a subsequent sharpening process which is a separate operation.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The invention herein will largely be explained relative to machining of end mills, and sharpening of tapered end mills having helical flutes and adjacent teeth. The formation of such end mills and the like was the basic reason this invention was developed. However, although the machine is particularly adapted for this usage and is primarily intended for it, it is conceivably that other types of tapered grooved or fluted products may be made employing the concept set forth.

Referring now specifically to the drawings, the apparatus 10 includes a conventional base 12 upon which a conventional longitudinally movable work support bed 14 is supported, as well as a vertically adjustable tool mounting head 20. On this bed 14 is a series of cooperative novel subassemblies, namely workpiece supporting and driving subassembly 22, its movable carriage subassembly 24, drive motor subassembly 26 also on this carriage, feed control camming subassembly 28, and feed accommodation subassembly 30 operably associated with said control camming subassembly 28.

The base 12 also forms a normal enclosure for power means (not shown) to advance and return rectangular bed 14 in the direction of its longest dimension past head 20 which extends upwardly adjacent the rear edge of bed 14. Bed 14 can also be manually advanced and returned by conventional hand crank 96 (FIG. 1). Subassembly 20 includes a conventional housing 40 having a horizontal drive spindle 42 protruding therefrom over bed 14 for removably mounting a rotational disc type tool 44, specifically an abrading or grinding wheel. Spindle 42 is at an angle to the direction of advance of bed 14 and of work feed carriage 24. Housing 40 and its underlying pad 46 are mounted on a platen 48 which is vertically adjustable relative to its base 50 (FIG. 3) as by a conventional internal vertical screw and sleeve (not shown) enclosed within flexible bellows 52. Spindle is rotationally powered by a conventional motor inside housing 40. The vertical screw that adjusts the position of housing 40, and thus mount 46, platen 48, and spindle 42 with its tool 44, has a rotational hand wheel 56 at its upper end. If desired, this screw may also be incrementally rotated mechanically by a ratchet wheel 58 on the screw shaft engaged by a reciprocating ratchet blade 60 operated by fluid cylinder 62.

Mounted on platen 48 is a rigid horizontal support bar 70 which has an end extending transversely over bed 14. To this extending end of bar 70 is secured an elongated horizontal reference bar member 72 extending parallel to the direction of feed of the assembly, at the rear of bed 14, (FIG. 3) for purposes to be explained hereinafter. Depending from member 72 is a special tapered stop 74 which, by virtue of its being mounted to members 72, 70 and platen 48, moves vertically with movement of the tool spindle equipment. Stop 74 is abutted on its vertically tapered surface by abutment member 76 which is adj ustably mounted on bracket 78 fixed to the rear of bed 14.

As noted, subassembly 22, 24, 26, 28 and 30 are generally supported on bed 14. However, subassemblies 22 and 26 are simultaneously movable on carriage 24 relative to bed 14 in the long dimension of bed 14. Subassembly 28 is also movable on its carriage 154 with respect to bed 14 and also with respect to carriage 24 in a specially controlled relationship therewith. The only longitudinally fixed connection of any of these subassemblies to bed 14 is a pivot connection between carriage 154 at dogleg link 180 as will be described in detail hereinafter.

The mounting of carriage 24 on bed 14 is as follows. Fixed to bed 14 is a pair of longitudinally spaced mount blocks 13 and 15 (FIG. 14). Extending between these blocks is a pair of fixed parallel, guide rods 17 and 19. These rods extend through correspondingly configured slide sleeves in a thick platform 21 which, in plan, is L-shaped in configuration and which forms the main member of carriage subassembly 24. This platform is movable longitudinally on these rods toward and away from tool spindle 42.

Affixed to and extending upwardly from platform 21, at the rear edge thereof, is a spaced pair of vertical pillars 23 (FIGS. 3, 14, 15) to which one end of chock support 138 is pivotally mounted by a coaxial pair of transversely oriented pivot pins 27 (FIG. 14) which extend through pillars 23 and through special ears 25 extending from support 138. Also fixedly mounted to this platform 21, at the extended leg of its L-shape, is an upwardly projecting support plate 100 to which is secured a drive motor 102 forming part of subassembly 26. This may be a hydraulic rotary motor driven by pressurized fluid through suitable conduits 103 connected to ports 104 in the motor. The motor has a drive shaft extending rotationally through plate 100 and to the end of which is mounted a drive gear 108. Meshing with this gear is a second gear 110 affixed to the end of rotational shaft 112 extending back through plate 100. Shaft 112 is thus supported on one end by plate 100, and is supported on the other end by one leg 114' of a U-shape mount 114 through which it extends. Bracket 114 is also mounted on platform 21. Within the recess formed between parallel legs 114 and 114' of this U-shaped bracket 114 is a drive connection formed by a pair of rotationally mounted cooperative members 116 and 118. Member 116 is attached to shaft 112 and has a tapered male axially extending nose which matingly interfits to a controlled depth with a correspondingly tapered female recess in member 118. By adjusting that axial spacing between these members, the amount of rotational "blacklash" or "play" therebetween can be regulated for purposes to be explained hereinafter. This adjustment may be made with a threaded member 120 extending between legs 114 and 114', and a threaded collar 121 which is attached to member 118. Rotation of member 120 thus varies the spacing between members 116 and 118. Threaded member 120 is rotated by a knurled knob 122 on the outer end thereof.

Also attached to shaft 112 is a pulley 130 around which a drive belt 132 passes. Belt 132 also passes around a second pulley 134 on one end of parallel shaft 136. This shaft extends through support 138 and has a workpiece receiving and securing chuck 140 on the opposite end thereof for mounting a workpiece W.
Rotational member 118 (FIG. 1), rotatably mounted in leg 114" has a chuck 144 connected therewith. This chuck removably receives and retains an elongated shaft 146 forming part of a special helical cam (FIG. 4) containing a preformed helical cam track groove 151 in its cylindrical surface. This track 151 is preformed with a helical configuration correlating with that desired to be applied to the tapered workpiece. Helical cam 148 is received in a cam follower sleeve 150 (FIG. 1) mounted by bracket 152 to carriage 154. Sleeve 150 has cam follower members 153 (FIG. 16) which project into cam track 151 (FIG. 4). This carriage is slidably mounted on a pair of parallel guide rods 156 the ends of which are supported by blocks 158 and 160. These blocks are affixed in spaced relationship to bed 14 to cause rods 156 to be aligned with the direction of the main longitudinal dimension of this bed. Integrally associated with this subassembly 28 is subassembly 30.

Subassembly 30 includes a dogleg link 180 pivotedly mounted at its apex on pin 182 to the side of carriage 154. The short leg 180' of this dogleg link 180 extends vertically downwardly from this pivot point to a pivot pin 184 parallel with pin 182 and supported by bracket 186 which is affixed to bed 14 (FIGS. 1 and 6). The long leg 180'' of this dogleg link extends longitudinally, either horizontally or at a small acute angle to the horizontal, as will be explained, along the direction of the bed. On its free end, leg 180'' includes a slide pad 190 which is slidably mounted in a slide track 192 of member 194. Member 194 is pivotally mounted at its one end overlapping leg 180'' on a pivot pin 206. Its other end is attached by fastener 200 to a mating sine plate 198. This plate has an end also pivotally supported on pin 106. The plate has a series of openings 202 in an arc having a center of radius at pin 206. Placing fastener 200 at different openings then puts track 192 at different angles of elevation as shown by the solid and phantom lines in FIG. 6, for purposes to be described.

Attached to the end of sine plate 198 opposite pin 206 is one end of a pivotal link 210. Pivotally attached to the opposite end of this link is one end of another link 212 which has its opposite end affixed to an elongated twist rod 214. Twist rod 214 extends transversely across bed 14 to the rear edge thereof. Rod 214 is rotatably supported by bearings 211 (FIG. 5) which are secured to the platform 21. To the rear end of rod 214 is affixed one end of an elongated link 216 (FIG. 3). Adjustably attached to the opposite end portion of link 216 is a follower 218. Torsion spring 215 (FIG. 5) biases link 216 upwardly, causing follower to engage the undersurface of horizontal bar 72 that is always parallel to the bed. Thus, raising and lowering of parallel bar 72 causes up and down pivoting of link 216, and hence rotation in one direction or the other of twist rod 214. Lowering of link 216 causes elevation of sine plate 198 through rod 214 and links 210 and 212, about pivot 206. This therefore increases the angle of inclination of track 192 which follower 190 follows. Likewise, raising of parallel bar 72 with raising of head 20 lessens the angle of inclination of track 192 at any particular setting of sine plate 198. Rising of follower 190 as it moves up an inclined track raises the free end of leg 180'' of dogleg 180. Raising of the free end of long leg 180'' pivots the dogleg around pivot pin 184. Since pivot pin 184 is fixed to bed 14, pivoting of dogleg 180 in a clockwise direction (as viewed from the front) shifts cam follower collar 150 to the right as the structure is viewed in FIG. 1. i.e. away from subassemblies 22, 24 and 26 as the latter advance toward the tool and toward collar 150. The purpose of this during operation will be explained more fully hereinafter.

Previously, belt 132 driving pulley 134 was noted. Attached to the rear end of shaft 31 that mounts pulley 134 (FIG. 14) and workpiece chuck 140 is a pre-settable rotational indexing means 137 for shaft 136 and chuck 140. This indexing means may be any of several conventional types in order to cause the chuck 140 to be rotated through predetermined angles for selectively positioning succeeding portions of the workpiece in functional relation to tool 44. In the embodiment shown, removable pins 37 (FIG. 14) protrude from index collar 137 to engage with a stop 39 on mount 41 on bed 14. Here three pins are used for 120° rotation increments. Obviously this may vary considerably.

As noted earlier, chuck support 138 is pivotable on a horizontal pivot axis adjacent its end away from tool 44. Specifically, a protruding ear 25 of member 138 is attached to pillar 23 with a pivot pin 27, allowing member 138 with its work chuck 140 and its workpiece W to be tilted upwardly at a small acute angle from the horizontal. This tilt is made by lifting an elongated sine bar 252 (FIGS. 1, 2, 14 and 15) having one end portion secured to the side wall of member 138. A particular tilt angle is maintained by positioning a prop stop 253 beneath a fixed protrusion 255 on the free end (FIG. 15) of sine bar 252. Prop stop is removably supported by an elongated extension 21' of carriage platform 21. Thus members 138 and 140, as well as the workpiece W can be tilted to different angles as indicated by solid and phantom lines in FIG. 15.

Means to dress the wheel 44 is also preferably provided. This constitutes a dressing tip 240 mounted to and projecting upwardly from a support dog 242 which in turn is pivotally mounted on a vertical pivot pin 244 above support 246. Support 246 is attached to bed 14. This dressing unit is preferably set up to cause tip 240 to shift transversely across the peripheral surface of wheel 44 after each pass of the wheel relative to the workpiece W. Support 242 is biased toward wheel 44 by suitable torsional biasing means (not shown) around pin 244. This movement under the bias is controlled by laterally projecting nose 250 which has oppositely positioned slanting surfaces for engaging the nose 242' on dog 242. This shifts the dressing tip 240 back and forth across the peripheral surface of wheel 44. Nose 250 is mounted on horizontally extending sine bar 252 adjacent the rear edge of bed 14. Wheel 44 may be brought down to a level of operative engagement with dressing tip 240 by lowering of the wheel using the vertical adjustment mechanism described previously relative to housing 40 and components 56, 58 and 60. As will be described, preferably the wheel is lowered a slight amount after each pass during its machining operation, to provide a true surface on the wheel for the next pass, thus causing the dressing tip to be momentarily functional after each such pass. The novel apparatus then makes accommodation in the helical machining operation for this dressing operation as will be described.
The apparatus has a forward feed action with the workpiece W moving toward tool 44, and at the end of the feed stroke, has a reverse return movement. The particular position of the workpiece where forward motion is reversed is specially controlled, as is the particular position where reverse movement is stopped. Preferably limit switches are employed for these functions. The limit switches are activated relative to the position of the carriage subassembly 24 which advances the workpiece. However, as will be understood from the operational description hereinafter, advance and reverse movement must also be governed by the position of cam follower sleeve 150 relative to tool 44. Hence, limit switches 300 and 303 (FIG. 16) are mounted to carriage platform 21 with support 305, while activators therefor, 307 and 309 are attached via rod 311 and boss 313 to cam follower carriage 154. On the feed stroke of carriage platform 21, when limit switch 303 strikes activator 309, the carriage motion is caused to reverse. On the return stroke, when limit switch 300 engages activator 307, the carriage is stopped, and if desired, reversed to re-feed, it being understood that indexer 137 is rotated prior to re-engagement of the workpiece with tool 44.

During operation, a blank 400 (FIG. 12) having a shank 402 (generally cylindrical) and a tapered frustoconical nose 404 to be machined, is inserted with its shank in chuck 140 to form the workpiece W. It is desired to form a plurality, usually three or four, (here three in number for illustrative purposes) of helical flutes or grooves 406 (FIGS. 10, 11 and 13) and adjacent teeth 408 in this workpiece. Also, a relief surface 410 is formed adjacent the bottom surface 406' of each flute 406 and the adjacent tooth. The teeth 408 of the end mill formed according to FIGS. 10 and 11 have a helical forward face 408', the portions of which are aligned with the central axis 412, and have a helical arcuate outer land 408" comprising a portion of the original outer workpiece periphery, prior to sharpening. Surfaces 408' and 408" join at the tooth cutting edge 408'". At the small end of the end mill, the teeth preferably extend to axis 412 in conventional fashion, (FIG. 10) with this face end being formed according to any conventional method. Subsequent sharpening, explained hereinafter, creates a chordable flat in place of arcuate land 408". The structure in FIGS. 10 and 11 is the usual one formed according to this invention. However, the alternative construction shown in FIGS. 10A and 11A can also be formed. Here the flute 406a again has a bottom surface 406a' which joins the front face 408a' of tooth 408a. However, in this instance the relief surface 410a on the back side of the tooth extends from flute bottom 406a' directly to cutting edge 408a'" at the apex between relief surface 410a and tooth front face 408a', rather than leaving an arcuate land.

With this invention, both of these alternative end mills can be formed using a simple flat wheel. This is a very important factor.

During the machining operation, the diameter of the machining wheel will normally vary, specifically will decrease, sooner or later due to wear of the wheel and/or dressing of the wheel. Further, it may sometimes be necessary or desirable to employ a different wheel diameter size while still desiring to produce a standardized end mill. These changes in wheel diameter can have serious consequences for the machining operation since it will change significantly the length and configuration of the helical flute and groove being machined. This will be explained initially with respect to wheels that vary substantially in size to enable the complexities to be clearly understood. The same factors apply, but to a lesser degree, when the wheel size varies in small increments due to wheel wear and/or dressing. Reference will be made first to FIG. 7 relative to two different wheel diameters and subsequently to FIGS. 8 and 9 showing these wheel diameters taken separately. It is notable that this novel apparatus accommodates any one or more of the three noted reasons for wheel diameter change, and because of this, the novel apparatus allows both initial forming of the special end mill, and subsequent sharpening thereof, using a simple flat wheel for both operations.

Referring now to FIG. 7, the blank is shown at 400a in the position where it first engages the larger tool 44a, and is shown at 400b which is its position generally after it has been fed into the tool a substantial distance. The blank is also shown at 400c which is its position when it first engages a smaller wheel 44c and at 400d which is its position after being fed substantially into the smaller wheel.

The radius designated 302a is that radial line of the larger tool drawn to the point 304a of initial engagement of the blank with the outer periphery of the larger tool. The radius designated 302b is that radial line drawn to the point of contact 304b between the periphery of the larger tool and the blank when in position 300b. The radius designated 302c is that drawn to the point of engagement 304c of the blank at 300c with the smaller tool 44c, and the radius designated 302d is that drawn to the point of contact 304d of the smaller tool periphery with a blank at 300d. It will be seen that the angle between the vertical radius 302 of both of these wheels and any one of the radii 302a, 302b, 302c and 302d is different. As will be understood more fully from the following explanation, the function of the tapered stop member 74 (FIG. 3) is to cause the starting radii i.e. 302a and 302c to coincide regardless of the cutting tool diameter, by controlling the position of bed 14 before it stops at the point where the feed of the blank then starts into the wheel due to carriage movement on bed 14. By causing these radii to be coincident regardless of the tool diameter, the accommodating subassembly can regulate the feed to a standardized value.

In FIGS. 8 and 9, the relationships between the forming tools and the workpieces are individually depicted, but showing the larger forming tool in FIG. 8 and the smaller one in FIG. 9, and also showing the tapered workpiece with an exaggerated angle of taper for illustrative purposes. Separation of these enables the concept to be more readily understood.

Specifically, referring to FIG. 8, it will be noted that the line representing the shortest distance between point 304a and vertical radius 302 is represented as 306a, while the line representing the shortest distance between point 304b and vertical radius 302 is designated 306b. Referring then to FIG. 9, and evaluating the relationship of the workpiece at 400c and 400d relative to the smaller diameter tool 44c, the line representing the shortest distance between point 304c...
and the vertical radius 302 is 306c, while the line representing the shortest distance between point 304d and radius 302 is 306d. Let it be assumed for the moment that it is desired to produce the same tapered end mill with like helical flutes using both wheels, one end mill formed by each. Since the radial distance from the common center point 301 for the two respective wheels 44a and 44c (i.e. and of the spindle 42) to the periphery will be substantially different, that for 44c being substantially larger, an equal linear movement of the workpiece generally tangentially of the two respective wheels will cause the total distance along the tapered workpiece traveled by the periphery of the wheels to be greater for wheel 44c than 44c. By triangulation techniques, this difference in distance (designated Y) can be calculated. Specifically, it amounts to the difference between distances 306a and 306b (which will be designated X as in FIG. 8) minus the difference between distances 306d and 306c (which will be designated X' as in FIG. 9) i.e. \( X - X' = Y \). Now the problem is, if these two different size wheels are going to be used to form like tapered end mills with flutes that have the same length, the workpiece must be advanced or fed a further distance into the smaller tool an amount which equals \( X - X' \) or \( Y \). Since the determination of this value for any particular wheel size is most readily made using one particular wheel size as a standard, and since a 6 inch diameter wheel is a common size, calculations are made using a 6 inch wheel as larger wheel 44a. Such a 6 inch wheel would of course have a 3 inch radius. For purposes of illustration, smaller wheel 44c is taken as a 4 inch wheel i.e. having a 2 inch radius.

As noted, the radial lines 302a and 302c drawn to the initial points of engagement for the two tools are caused to geometrically coincide, angularly. In order to get radial lines 302a and 302c to coincide, bed 14 is advanced a controlled amount with lowering of tool 44 to the level of engagement with the workpiece. This is done with tapered stop 74. That is, stop 74 is lowered automatically with lowering of tool 44, and since stop 74 is tapered at an angle equal to the difference in the angles of radii 302a and 302c, the angles of the points of contact coincide relative to vertical. When radii 302a and 302c are caused to coincide, the distance \( Y \) can be trigonometrically calculated for each one inch difference of tool radius. The value for \( Y \) for the one inch difference in radius of the wheels (i.e. 6 inch wheel to 4 inch wheel) was found to be 0.0194 inch. Therefore, accommodation must be made to cause the blank to be advanced further into the wheel at the rate of 0.0194 inches per inch difference in radius of the forming tool. Moreover, not only must this difference in feed be caused to occur so that the flutes are of equal length, but also, this difference must be incrementally caused to occur during the progressive feed of the blank into the cutting tool so that the helical paths of the two different workpieces formed by the two different wheels will be identical. The novel apparatus does this in a manner to be explained hereinafter. It should also be realized that not only will there normally be a difference in the required amount of feed of the workpiece relative to the tool when using these very different sized wheels, but there also will be a relatively smaller difference in the amount of feed even when using a nominal size wheel, such as the 6 inch wheel, to accommodate for wear of the wheel and for dressing of the wheel which causes a small decrease in diameter. Once the apparatus is set up to accommodate for the larger difference, on a per inch basis, the novel apparatus also achieves the smaller proportionate accommodation in a manner to be described hereinafter.

Accommodation is achieved through subassemblies 28 and 30 which control the advancement of the workpiece W (FIG. 1) with subassemblies 22 and 24. The basic mode of advance of the workpiece with its carriage is by power rotation of helical track cam 148 in cam follower sleeve 150. If the 6 inch diameter tool is used as a standard, the machine is set up so that cam follower sleeve 150 remains stationary when the workpiece is advanced into a 6 inch cutter, and moves a controlled amount away from the advancing carriage and relative to the cutting tool when the workpiece is advanced into a cutting tool which is smaller than 6 inches in diameter. This cutting tool smaller than 6 inches will be involved either because it is purposely chosen as a smaller wheel e.g. four inches, or because its original 6 inch diameter has decreased because of wear and/or wheel dressing.

This type of action is achieved as follows. Firstly, referring to FIG. 6, when a 6 inch wheel is used, member 194 containing track 192 is caused to be horizontal i.e. parallel with the bed of the machine, as is leg 180° of dogleg member 180, so that advancement of track 192 with the carriage 24 causes follower 190 to ride horizontally along in this track and keep leg 180° horizontal. Thus, dogleg 180 will not pivot about pivot pin 184 which is the only fixed connection of the operating subassemblies to the bed of the machine. Obviously, if member 180 is not pivoted about pin 184, no movement of the type indicated by the arcuate arrow adjacent pin 182 in FIG. 6 will occur and thus, support 154, brackets 152, and cam follower sleeve 150 will remain stationary. However, any tilting of track 192 in the manner indicated by the arcuate arrow adjacent sine plate 198 in FIG. 6 will cause follower 190 to follow an upwardly inclined path 192. Thus, for example, if a 4 inch wheel is substituted and head 20 is lowered to place the tool at the level of the same workpiece, the first thing that will happen is that bed 14 will advance a small amount toward tool 44 due to the angle of tapered stop 74 to control the point where machining starts. Also, lowering of head 20 will tilt track 92 upwardly through elements 70, 72, 218, 216, 214, 212, 210, and 198 in the manner previously described. Then, feeding of workpiece W to the tool by its carriage and movement of follower 190 causes elevation of the free end of leg 180° with this advancement of the carriage toward the cam follower and toward the cutting tool, to cause pivoting around fixed pivot pin 184. This causes shifting of assembly 28 gradually away from the advancing carriage a much smaller amount. The exact angle of elevation of track 192 is previously set so that lowering the cutting tool spindle 42 one inch causes this angle to be such that cam follower 150 retreats from the advancing carriage the controlled amount of 0.0194 inch. This retreat of cam follower sleeve 150 is gradual over the entire feed stroke, causing the greater amount of travel to be gradually applied, which causes the helical path machined to match...
that machined by the larger tool, as well as being as long as that of the larger tool. The end of the feed stroke in either case is when limit switch 303 strikes actuator 309. It will be realized that since actuator 309 is attached to carriage 154, it will also retard the controlled amount when using the smaller tool, to extend the feed the controlled amount. On the return stroke, engagement of limit switch 301 with actuator 307 stops the feed carriage. When the smaller tool is used, support bar 311 for the actuators also returns over the longer stroke length.

Moreover, if either wheel is dressed, requiring tool 44 and head 20 to be lowered a small amount to obtain engagement of the tool on the blank, the accommodation subassembly will adjust the feed stroke a proportionate amount. Consequently, no matter what the reason for lowering spindle 42 and cutting tool 44 to the work, the slope of track 192 will be automatically regulated to cause retraction of cam sleeve 150 the appropriate amount during the feed stroke. Retraction of sleeve 150 of course causes the carriage to advance this additional amount until the limit switch is activated which reverses the feed carriage.

Actually, when positioning the workpiece W to be machined, it is not normally put with its axis horizontal. Rather, support 138 is placed at an acute angle with sine bar 252 and prop stop 253. This is done because, if it were left horizontal, the depth of the cut into the workpiece at its larger diameter portion would normally be deeper than desired to leave too small a support core for the end mill. The flute is preferably deeper at the larger end of the blank than at the small end of the blank. Hence, the angle of the axis of the blank to the horizontal is preset to be not as great as the angle of taper of the blank, usually about one half of this angle of taper.

The return stroke of the mechanism also results in an important machining step being performed on the blank. Specifically, tool 44 forms relief surface 410 (FIGS. 10 and 11) as the blank returns to its starting position for the next feed stroke. To achieve this machining step on the return stroke, blank 400 is rotated through a small angle, usually around 17° when forming a three flute mill, to shift the portion of the blank vertically aligned with tool 44 from the zone of surface 408 to the zone of surface 410. This controlled rotation is achieved with reversal of drive motor 102, by rotating workpiece chuck 140 through this angle prior to rotation of cam chuck 144. This occurs as a result of the “back lash” or “play” in the drive connection to chuck 144 as a result of the spacing between male and female members 116 and 118 of the coupling formed thereby. Since there is no appreciable back lash in the drive train to chuck 140, it will reverse immediately with reverse of motor 102, whereas cam 146 will not begin reverse rotation until the play in its drive train is eliminated. When cam 146 does begin rotating in reverse, however, the reverse motion of the chucks and carriages will cause tool 44 to follow the same helical path configuration as the just formed flute and adjacent tooth, but adjacent to the flute, so that helical relief surface 410 will be formed adjacent to and at the controlled angle to surface 408. Obviously, the angle between surfaces 408 and 410 can be varied simply by adjustment of the play between members 116 and 118 with members 120, 121 and 122.

The novel tapered end mill formed according to this invention has helical surfaces, any cross section of which is flat except for the arcuate land. The end mill is symmetrical about its axis of rotation. Helical relief surface 410 is generally chordal of the original body portion periphery, at any cross sectional portion, and forms an obtuse angle to the adjacent helical recessed surface 408°. Its purpose is to cause the arcuate land to be sufficiently narrow for sharpening.

This construction is in contrast to that of the conventional tapered end mill with helical flutes, wherein at least two and usually three back off or relief surfaces are formed on the back side of each flute, with each usually being a curved surface. Needless to say, these conventional structures require considerably more machining steps for each tool. Any attempts of automated sharpening of conventional end mills are almost futile, considering these multiple surfaces, particularly in view of the basic non-uniformity of the helical paths of such end mills as conventionally formed.

A most important feature of the novel end mill and the novel apparatus is the ease and accuracy of automated sharpening the end mill. To do this, the cylindrical shank 402 of the end mill is placed in chuck 140, and the chuck and end mill are tilted by tilting support 138 by lifting up sine bar 252 until the angle of tilt equals the angle of taper of the end mill. The sine bar and end mill are retained at this angle with a suitable stop prop under the sine bar. The end mill is placed at this angle so that the wheel 44, acting as a sharpening tool, will engage the arcuate land 408° adjacent cutting edge 408°. The flat grinding wheel is caused to travel along the outer arcuate land portion of the original blank periphery to remove material from the land generally chordal of the arc. The resulting chord may extend clear across the arcuate land as represented by phantom line 500 in FIG. 11, or across a portion of this arc. To sharpen the preformed tool, the same cam 146 will be used as was used during its formation. Now however, since tool 44 will travel along the periphery of the tool, rather than into its depth as during forming, accommodation must be made to cause the tool to travel farther along the end mill surface than it did when it cut into the end mill blank during "slashing" i.e. forming of the end mill. Further, the accommodation must cause the tool to follow an exactly correlative helical path or else one pass of the sharpening tool will ruin the end mill. Reference is made to FIG. 17 for an explanation. The end mill 400 there generally depicted is tilted at the angle it would take when being sharpened. Wheel 44 is shown in broken lines where it would be during the start and completion of sharpening. However, the wheel is also depicted in solid lines to illustrate its positions relative to the workpiece during forming, (realizing that in the latter instance the axis of the workpiece would normally be almost horizontal and the axis of the wheel would stay in a constant horizontal plane). The point on wheel 44 where it first engages and starts the flute on the end mill blank during forming is designated "sf" (start forming), and the point on the wheel where it ends the helical flute is designated "ff" (finish forming). The point on the wheel where it first engages the end mill during sharpening is designated "is" (start sharpening), and the point where the wheel would last engage the end mill, if no accommodation were made,
Likewise, sharpening has been explained using retreat of cam follower 150 from the advancing feed carriage for accommodation of the greater travel required over the tooth edge. If, however, sine plate 198 were modified to extend below the horizontal as noted above, to enable track 192 to tilt downward, the relative difference between horizontal and decline could be employed for this accommodation too, in place of the present relative difference between incline and horizontal. That is, the cam follower would advance toward the workpiece during machining when the workpiece axis is level, using a standard wheel, and would stay relatively constant or advance less or retreat slightly, as necessary, during sharpening where the workpiece is on an angle and the tool movement, relatively speaking, is along the workpiece surface.

It is also conceivable that the ingenious concept set forth herein could be embodied in apparatus which might differ considerably from that depicted herein, once the concept is understood. It is therefor intended that the invention is not to be limited solely to the preferred illustrative embodiment of the invention set forth herein, but only by the scope of the appended claims and the reasonable equivalents thereto.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows.

1. Apparatus for machining helical flutes in a conical workpiece comprising: tool mounting means rotational on an axis, adapted to support a rotational tool having both an axis of rotation and also peripheral material removing means; rotational workpiece supporting chuck means having an axis of rotation; carriage means mounting said rotational workpiece supporting chuck means, and movable therewith substantially tangentially toward and away from the periphery of a tool in said tool mounting means; regulated feed means operably associated with said chuck means to advance said chuck means on said carriage, and any workpiece supported thereby, toward said tool, while controllably rotating said chuck means; and accommodating means operably associated with said regulated feed means to controllably alter the amount of linear advancement of said chuck means in response to change of dimension between said tool mounting means axis and said chuck means axis.

2. The apparatus in claim 1 wherein said accommodating means is operably associated with said regulated feed means in a manner to also controllably alter the amount of rotation of said chuck means in relation to the amount of linear advancement of said chuck means, in response to said change in dimension between said tool mounting means axis and said chuck means axis.

3. The apparatus in claim 2 wherein said accommodating means decreases the amount of rotation of said chuck means in relation to the amount of linear advancement of said chuck means, in response to a decrease in said dimension.

4. The apparatus in claim 1 wherein said accommodating means includes cam and cam follower means.

5. The apparatus in claim 4 wherein said feed means includes cooperative helical cam and cam follower means, and said accommodating means is adapted to alter the cooperative relationship between said cam and cam follower means with change in said dimension.
6. The apparatus in claim 1 wherein said feed means includes helical cam means and cam follower means, one of which is associated with said carriage and the other of which is mounted on a support that is movable relative to said carriage, and said accommodating means includes adjustment means between said support and said carriage allowing controlled relative movement therebetween and relative to said tool mounting means to govern the advancement of said carriage and said chuck means relative to said tool mounting means.

7. The apparatus in claim 2 wherein said feed means includes helical cam means and cam follower means, one of which is associated with said carriage and the other of which is mounted on a support that is movable relative to said carriage, and said accommodating means includes adjustment means between said support and said carriage allowing controlled relative movement therebetween and relative to said tool mounting means to govern the advancement of said carriage and said chuck means relative to said tool mounting means.

8. The apparatus in claim 7 wherein said adjustment means is variable to enable variation of the amount of said relative movement between said carriage and said support.

9. Apparatus for machining helical flutes and adjacent teeth in a conical workpiece and for sharpening the teeth so formed comprising: tool mounting means rotatable on an axis, adapted to support a rotational tool having both an axis of rotation and also peripheral material removing means; rotational workpiece supporting chuck means having an axis of rotation; carriage means mounting said rotational workpiece supporting chuck means, and movable therewith substantially tangentially toward and away from the periphery of a tool in said tool mounting means; regulated feed means operably associated with said chuck means to advance said chuck means on said carriage, and any workpiece supported thereby, toward said tool, while controllably rotating said chuck means; and accommodating means operatively associated with said regulated feed means to controllably alter the amount of rotation of said chuck means relative to linear advancement thereof.

10. The apparatus in claim 9 wherein said feed means includes cooperative helical cam and cam follower means, and said accommodating means is adapted to alter the cooperative relationship between said cam and cam follower means with change in said dimension.

11. The apparatus in claim 9 wherein said feed means includes helical cam means and cam follower means, one of which is associated with said carriage and the other of which is mounted on a support that is movable relative to said carriage, and said accommodating means includes adjustment means between said support and said carriage allowing controlled relative movement therebetween and relative to said tool mounting means to govern the advancement of said carriage and said chuck means relative to said tool mounting means.

12. The apparatus in claim 10 wherein said adjusting means includes second cam and cam follower means between said support and said carriage means.

13. The apparatus in claim 11 wherein said helical cam means is associated with said carriage means, and including interconnecting rotational drive means to said chuck means and to said helical cam means to operate them in synchronism, said drive means to said helical cam means including a controlled backlash such that, on advancing said chuck means with a workpiece therein toward said tool mounting means and a tool thereon, a helical flute will be cut into the workpiece, and, on reversing of said drive means with withdrawal of said chuck means from said tool mounting means, the tool will controllably remove material from the workpiece adjacent said flute.

14. The apparatus in claim 1 wherein said chuck means is shiftable to positions with its axis moving through acute angles, to enable a workpiece to be shifted relative to a tool for both cutting flutes into the workpiece and also sharpening teeth along the workpiece periphery.

15. The apparatus in claim 9 wherein said chuck means is shiftable to positions with its axis moving through acute angles, to enable a workpiece to be shifted relative to a tool for both cutting flutes into the workpiece and also for sharpening teeth along the workpiece periphery.

16. The apparatus in claim 1 including means to controllably govern the point of engagement of a tool on said tool mounting means with a workpiece in said chuck means with a change in said dimension.

17. The apparatus in claim 9 wherein said accommodating means controllably alters linear advancement of said chuck means while altering the amount of rotation of said chuck means relative to linear advancement thereof.

18. Apparatus capable of machining helical flutes to form adjacent teeth into a tapered end mill blank, and also capable of sharpening the flutes of the formed tapered end mill, comprising: tool mounting means rotatable on an axis, adapted to support a rotational tool having both an axis of rotation and also peripheral material removing means; rotational workpiece supporting chuck means having an axis of rotation; carriage means mounting said rotational workpiece supporting chuck means, and movable therewith substantially tangentially toward and away from the periphery of said tool; regulated feed means operably associated with said chuck means and said carriage means to advance said chuck means on said carriage, and any workpiece supported thereby, toward a tool on said tool mounting means, while controllably rotating said chuck means; accommodating means operatively associated with said regulated feed means to controllably alter (a) the amount of linear advancement of said chuck means, and (b) the amount of rotation of said chuck means relative to linear advancement thereof; and said chuck means being shiftable with its axis moving through acute angles to accurately shift a tapered workpiece therein relative to said tool mounting means to enable machining at one position of said chuck means and sharpening at a second position of said chuck means.