Jan. 2, 1962 J. C. DRADER 3,015,243

TOOL FOR PRESSURE FORMING TOOTHED ELEMENTS

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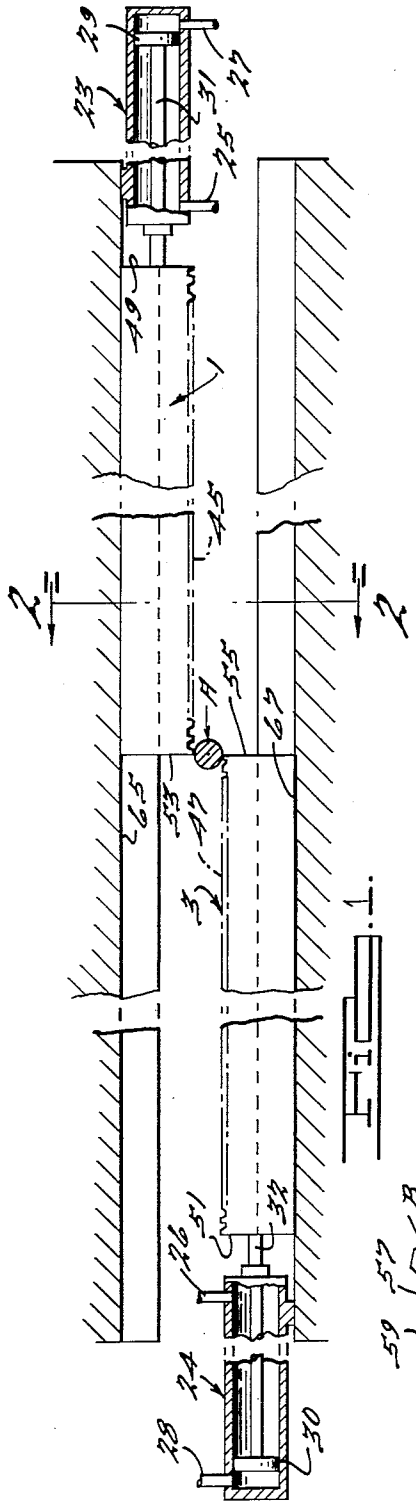


Fig. 1.

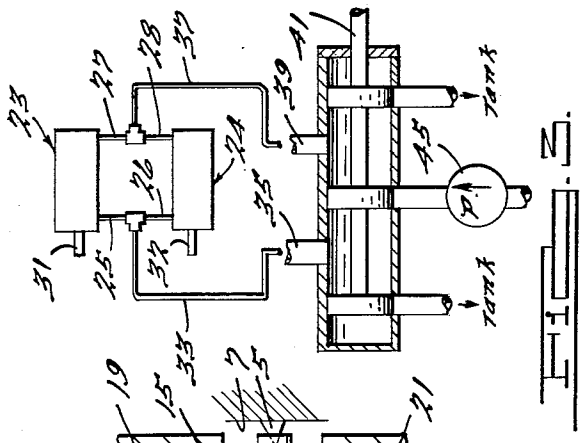


Fig. 3.

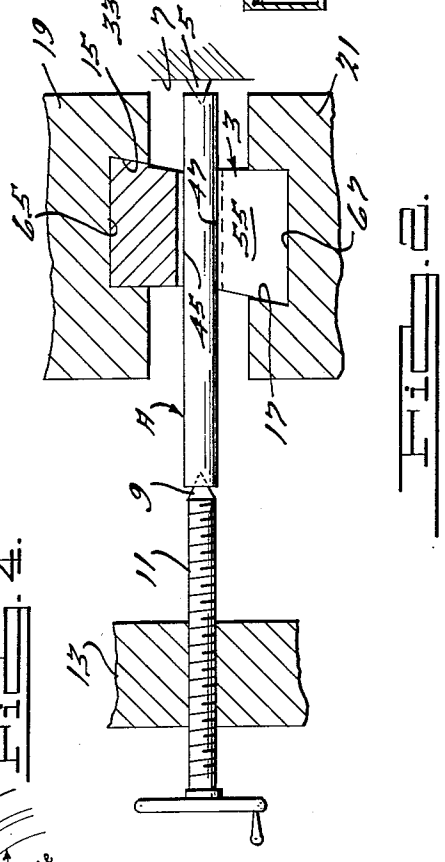


Fig. 2.

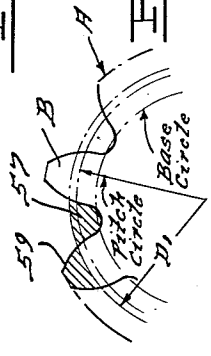


Fig. 4.

INVENTOR.
Joseph C. Drader
BY
Harness, Dickey & Pierce
ATTORNEYS.

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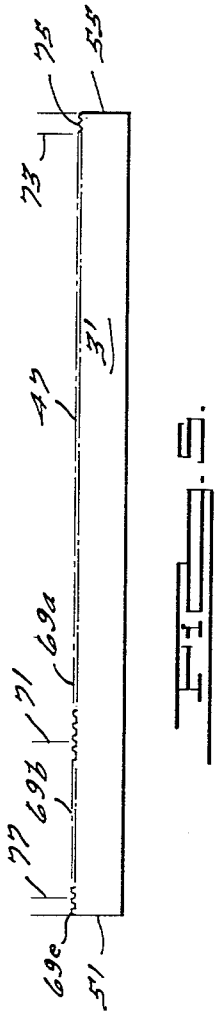


Fig. 5.

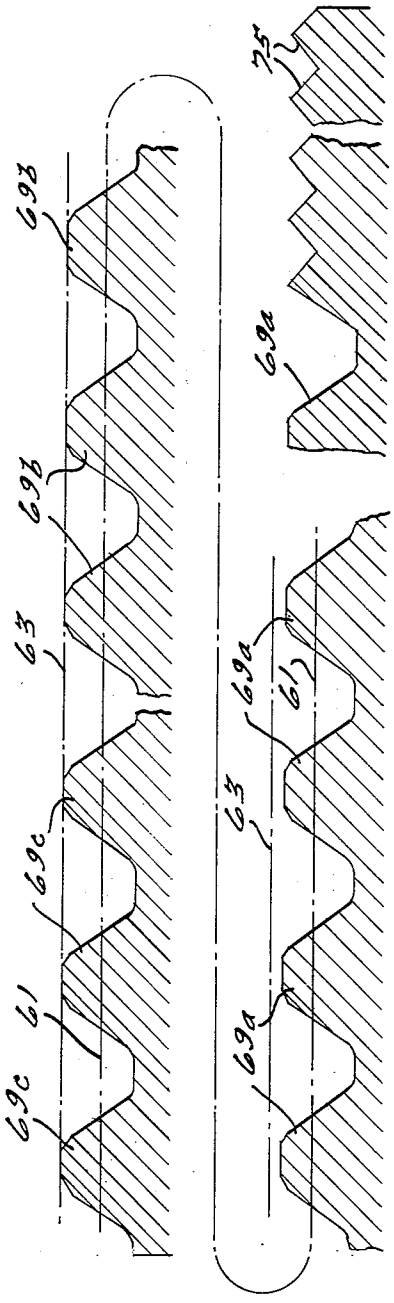


Fig. 6.

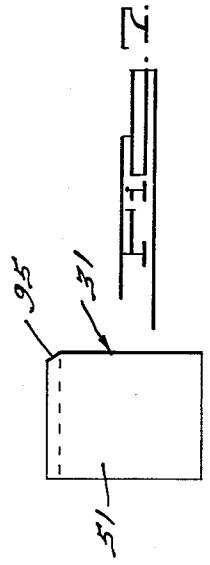


Fig. 7.

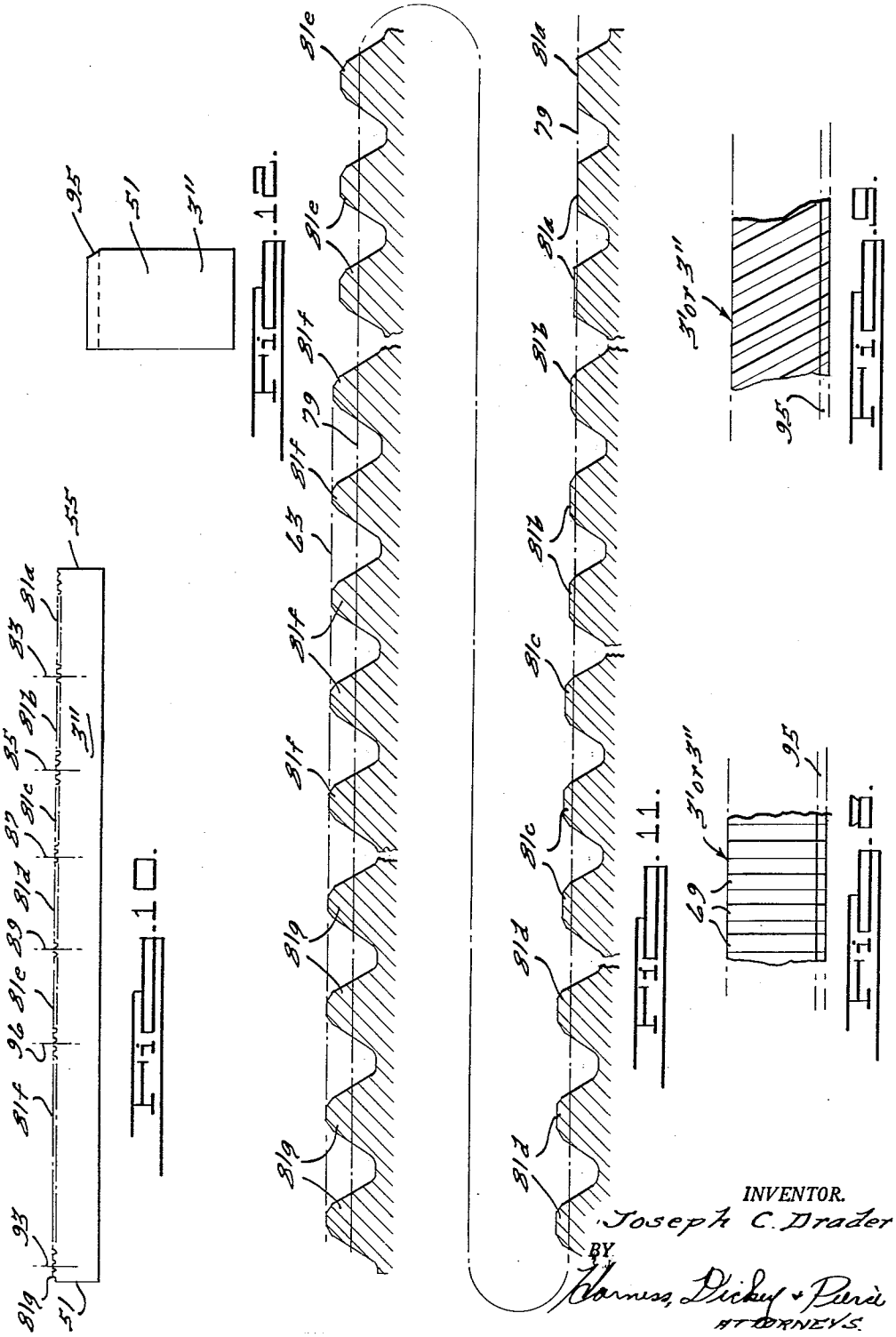
INVENTOR.
Joseph C. Drader.
BY
Harness, Dickey & Pierce
ATTORNEYS.

Jan. 2, 1962 J. C. DRADER 3,015,243

TOOL FOR PRESSURE FORMING TOOTHED ELEMENTS

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4 Sheets-Sheet 3



INVENTOR.
Joseph C. Drader
BY
Harness, Dickey & Pierce
ATTORNEYS.

Jan. 2, 1962 J. C. DRADER 3,015,243

TOOL FOR PRESSURE FORMING TOOTHED ELEMENTS

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4 Sheets-Sheet 4

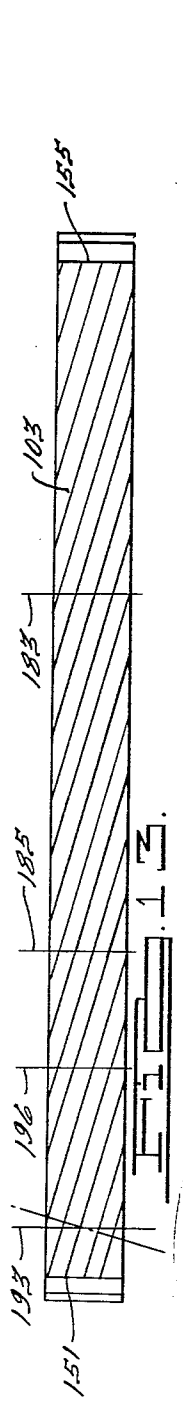


FIG. 12.

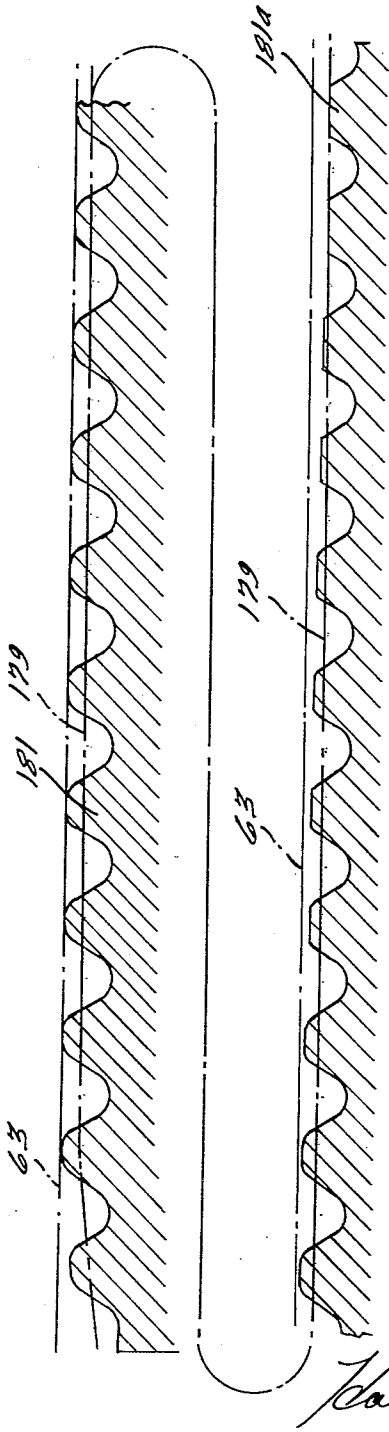


FIG. 15.

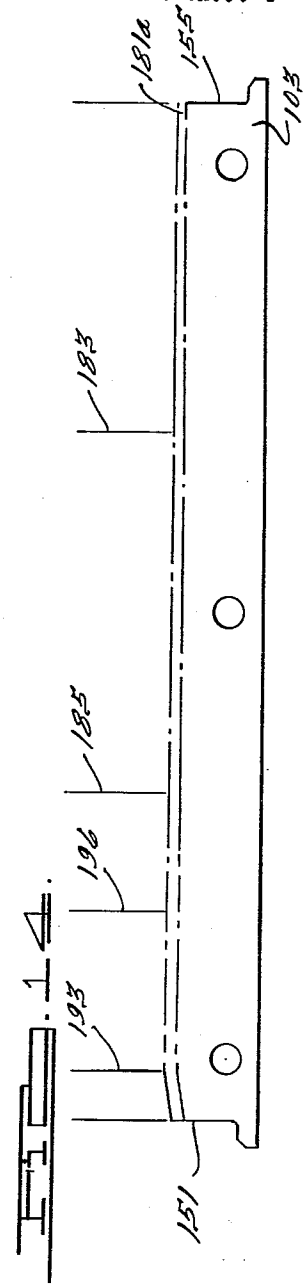


FIG. 14.

INVENTOR.
Joseph C. Drader.
BY
Harness, Dickey & Pierce.
ATTORNEYS.

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3,015,243
TOOL FOR PRESSURE FORMING TOOTHED ELEMENTS

Joseph C. Drader, Ormond Beach, Fla., assignor to Michigan Tool Company, Detroit, Mich., a corporation of Delaware

Filed Jan. 6, 1958, Ser. No. 707,244
1 Claim. (Cl. 80—20)

The invention relates to the cold rolling of external teeth on articles such as spline shafts, worms, gears, and the like and, more particularly, to improved tools for pressure forming such teeth. This application is a continuation-in-part of the applicant's co-pending application, Serial No. 461,178, filed October 8, 1954, now abandoned, and assigned to the assignee of the present application.

It is an object of the invention to provide improved means for pressure forming teeth on toothed parts which will reduce the cost of manufacturing the toothed parts, increase the speed of production, and improve the quality of the parts.

These and other objects and features of the invention will become evident upon consideration of the accompanying drawings which serve to illustrate the principles of the invention and in which

FIGURE 1 is a schematic and simplified illustration, in side elevation and with parts removed, of apparatus embodying the invention;

FIG. 2 is a section taken on line 2—2 of FIG. 1;

FIG. 3 is a simplified and schematic circuit diagram with the control valve enlarged and the direction of one of the rack moving pressure cylinders reversed;

FIG. 4 is a fragmentary view of a typical involute spline that can be formed by means of the invention;

FIG. 5 is a side elevation of a bottom rack type tool;

FIG. 6 is an enlarged fragmentary and diagrammatic side section of the teeth shown in FIG. 5, with sections broken away;

FIG. 7 is an end view taken from the left of FIG. 5;

FIG. 8 is a plan view of a rack for rolling spur teeth;

FIG. 9 is a plan view of a rack for rolling helical teeth;

FIG. 10 is a side elevation of a modified form of tool;

FIG. 11 is an enlarged fragmentary and diagrammatic side section of teeth of the rack of FIG. 10;

FIG. 12 is an end view taken from the left of FIG. 10;

FIG. 13 is a plan view of another form of the invention;

FIG. 14 is a side elevational view of the tool illustrated in FIG. 13; and

FIG. 15 is an enlarged, fragmentary and diagrammatic side section of the teeth of the tool of FIGS. 13 and 14.

One embodiment of the invention is schematically illustrated in FIGS. 1 and 2 wherein the part A is shown in position between the upper and lower tools 1 and 3 embodying the invention, the tools being shown at the beginning of the operation which will form splines on the surface of the part A. The part A is supported by means which permit it to rotate freely on a fixed axis when urged to do so by the tools 1 and 3. To illustrate such means there is shown a fixed center pin 5 depending from the surface 7 which may be considered as a part of the apparatus or machine which carries the tools 1 and 3. The part supporting means is shown as also including an adjustable center pin 9 on the end of an axially adjustable member 11, shown as a handwheel-operated, screw threaded shaft, that is carried by a support 13 which may also be considered a part of the apparatus on which the tools are mounted. The support 13 may be made slidable along the axis of member 11 so as to provide an additional adjustment whereby varying lengths of parts A can be handled by the machine.

The upper and lower tools 1 and 3 are shown as identical rack bars with teeth on their inside faces that engage the surface of part A. The bars are movable lengthwise by suitable means and are illustrated herein as being slidable in dovetail ways 15 and 17, as shown, that are formed in the head 19 and bed 21, respectively, of the machine which carries the tools. Those in the art will recognize that members 7, 13, 19, and 21 may all be made parts of the frame of a machine embodying the necessary elements to carry out the invention and that variations in structure may be employed to perform the functions indicated.

Means are provided to simultaneously slide the tools 1 and 3 in opposite directions. This means is illustrated as a pair of identical pressure cylinders 23, 24 having pressure ports 25, 26 at one end and pressure ports 27, 28 at the opposite end. Working in the cylinders are pistons 29, 30 having rods 31, 32. The rod 31 is affixed to the trailing end of tool 1 and the rod 32 is affixed to the trailing end of tool 3. Suitable valving can be used with the cylinders 23, 24 to actuate and synchronize their operation so that the rack bars 1 and 3 move at the same instant and with the same velocities in opposite directions. To illustrate this, FIG. 3 shows the cylinder ports 25, 26 joined together by a T and connected by line 33 to valve port 35 while the cylinder ports 27, 28 are joined together by a T and connected by line 37 to valve port 39. A three land spool valve 41 in valve casing 43 can be shifted to the right to connect ports 25, 26 to pressure from pump 45 and ports 27, 28 to tank; and by shifting to the left, the reverse condition is obtained wherein ports 25, 26 are connected to tank and ports 27, 28 to pressure.

The operation of the apparatus is evident from the above description. With the tools in the positions shown, the part A is mounted on supports 5 and 9 which permit it to be rotated by the tools. The valve 41 is moved to the left to connect ports 27 and 28 to pressure and ports 25 and 26 to exhaust so that tool 1 moves to the left and tool 3 to the right. The spacing between the working faces 45 and 47 of the tools 1 and 3 is less than the diameter of part A, hence the shape of the faces 45 and 47 is impressed or conjugated on the periphery of the part. The end of the stroke is reached when the trailing ends 49 and 51 of the tools pass over the part A at which point the part A may be removed from centers 5 and 9, and the valve 41 moved to the right in FIG. 3 to return tools 1 and 3 to the starting positions shown in FIG. 1 wherein the leading ends 53 and 55 thereof are adjacent the part A. A new part A can then be inserted in the apparatus and the cycle repeated.

In rolling grooves of the desired shape into the surface of part A, the material from which part A is made (ordinarily wrought steel) will flow adjacent the surface in radial and tangential directions so that there are grooves of less than the original diameter of the part and ridges of greater than the original diameter. Where the final form of the part is known and must be accurately maintained, this flow of material should be taken into account in selecting the diameter of that portion of part A which is subjected to the action of tools 1 and 3.

To illustrate by consideration of a common but very important shape that may be rolled by means of the invention there is shown in FIG. 4 a portion of a cross section of part A in finished form in which the part has involute teeth or splines B. Since no metal is removed in

the cold rolling operation, the diameter of the part prior to rolling cannot be either the final O.D. or the root diameter and it is only by chance that it can properly be the pitch diameter. The rolling diameter D_1 of the part A is selected so that the area **57** of removed tooth material below the D_1 periphery is equal to the area **59** of tooth material on a greater diameter than D_1. The diameter D_1, or substantially this diameter, is taken as the tool pitch diameter in the case of gear-like tools and defines the pitch line for rack type tools such as tools **1** and **3**. The pressure angle of the teeth of gear type tools at diameter D_1 and the pressure angle or obliquity of the teeth of rack type tools is the angle whose cosine is D/D_1 times the cosine of the pressure angle at pitch diameter of teeth B where D is the pitch diameter of part A. The base pitch of the tools and the part are identical. With such a construction, the circular pitch of the teeth on the tool, as measured on the pitch line thereof, corresponds with the circular pitch of the teeth on the workpiece, as measured on a circle having the diameter D_1 of the workpiece. The whole depth of at least some of the last teeth in the tool which engage the part A is preferably the same as that of the part, i.e., these tool teeth are fully conjugate to the part. The tools **1** and **3** are spaced apart so that at least near the trailing edges **49** and **51** thereof their working faces **45** and **47** provide a clearance equal to the root diameter of the part A less about three to four thousandths to take up elasticity of the members and compression of oil films under rolling pressure. At the present time a linear pitch line velocity for rack type tools of about 300 to 450 inches per minute of each tool is thought to be proper, 375 inches per minute being preferred. For rotary tools, the velocities may be substantially greater, for example up to ten times as much. If it is desired to positively drive the part A through gearing, etc., other than by the tools, though this is not preferred, the velocities of the part and tool should, of course, be the same. Only one pass of the tool with no reversal of direction during the working stroke is preferred.

The spacing of the working faces **45** and **47** of the tools **1** and **3** is regulated so that the depth of the impression made in part A gradually increases as the rolling operation proceeds. In other words, the faces **45** and **47** approach closer together in a plane through centers **5** and **9** as the length of stroke increases. At present it is preferred that the amount of such approach be within the range of .0015–.004 inch per inch of linear tool movement, with about .002 preferred. (This "approach" may also be regarded as a .0015–.004 inch total feed of the part across its diameter per inch of tool movement relative thereto.) This convergence of the tool faces toward each other with increasing length of stroke is preferably accomplished by tapering each tool uniformly, e.g., about .001 inch per inch per tool, though it is within the broad purview of the invention to provide the taper in other ways such as tapering only one tool and suitably mounting the part A to avoid eccentricity. The taper can be obtained by inclining the pitch lines of the tool teeth, by gradually increasing the height of the tool teeth while holding the pitch line level, or by a combination of the two methods.

FIGS. 5–9 illustrate a bottom tool **3'** in which the pitch line **61** is tapered, it being understood that the tooth formation of the upper tool will be substantially identical. The line **63** is a reference line that shows a "no taper" condition. If the bottoms **65** and **67** of upper and lower tool ways are considered parallel, the line **63** may be considered parallel to them, so that if the tops of the tool teeth remained parallel to line **63** there would be no change in spacing between faces **45** and **47** as the tools moved in the ways. The teeth of the tool **3'** are designated generally by the reference numeral **69** and it will be seen from FIG. **6**, however, that the pitch line **61** and the teeth **69*a*** of the tool **3'** do taper down and away from the line **63** as you move from the vertical reference line **71** to the vertical reference line **73** near the leading end **55** of the rack bar. The total amount of this taper is preferably just about equal to the addendum of the teeth **69*a*** (the taper angle preferably being as indicated hereinbefore) so that assuming the upper tool **1** to be substantially identical to tool **3'** the upper tool surfaces **45** and **47** are spaced apart when teeth adjacent planes **73** are above and below the part A by a distance substantially the same as the diameter D_1 of the part A. Between plane **73** and the leading end **55** the tool working surface may be provided with sharp file-like teeth **75** which tend to give the tools a grip on part A and start its rotation. The teeth **75** in the upper and lower tools would be spaced apart by about the diameter D_1 of the part A, and there being preferably about three or four such teeth per circular pitch with the number of circular pitches that are used depending upon the pitch of the part A, ordinarily around one-third the number of teeth being the number of circular pitches of teeth **75** to use. The teeth **69*b*** between plane **71** and plane **77** are fully conjugate to the splines or teeth to be formed on part A and between these planes the tops of teeth **69** on tools **1** and **3** (surfaces **45** and **47**) are spaced apart by a distance equal to the root diameter of the teeth on part A less three or four thousandths as previously mentioned. In other words, the pitch lines **61** of the upper and lower tools when the portions between planes **71** and **77** overlap will be spaced apart by the distance D_1 less three or four thousandths. It will be seen that the teeth in portions **7** to **77** are parallel to the reference line **63**, i.e., there is no taper of the pitch line **61** over this length of the tool and it is these teeth which give final form to the teeth on part A. The portion **71—77** is long enough to provide at least one-half revolution of the part A when two toothed tools are used and preferably contains two to three times as many teeth as are formed on the part A; e.g., if a 20 tooth spline is to be formed, the tool would preferably have 40–60 teeth in portion **71—77**. Between the trailing end **51** of the tool and the reference plane **77**, the teeth **69*c*** are relieved on the sides or flank faces (see FIG. 6) so that they are slightly thinner than teeth **69*a*** or **69*b***, this decrease in thickness preferably increasing toward the end of the tool from .0005" to .003". The pitch line of the relieved teeth is parallel to the reference line **63**, i.e., the teeth are not formed on a taper. This relief of the last four or five teeth eliminates seams, lines, or errors that may be formed in the part A teeth at the end of the stroke due to the decreased total area of contact between tools and part and resulting tendency to increase or unbalance forces on the part. It will be noted that the teeth **69*a*** and **69*b*** are substantially identical to each other (any difference due to the circular pitches of teeth **69*a*** being on a slight taper instead of on a parallel being negligible) and to relieved teeth **69*c*** except for grinding off of the sides of the latter. As a modification, the teeth **69*a*** could be formed with a larger pressure angle (a more pointed tooth) near the leading end and this angle would be gradually reduced toward the trailing end to equal the proper pressure angle at teeth **69*a***. In other words, the teeth **69*a*** would have varying pressure angles which decrease, preferably uniformly, going from the plane **73** to plane **71**. The pressure angle of each tool tooth would preferably be chosen so that considering the depth to which the tooth penetrated and pitch diameter on which the tooth is working the tool teeth are conjugate to the teeth to be formed on part A.

FIGS. 8–12 show an alternative form of bottom tool **3"**, it being again understood that the upper tool is preferably identical to it. In this tool, the pitch line **79** is parallel to the reference line **63** along the entire length of the tool and the taper is provided by gradually removing the addendum of the teeth **81** (as for example by grinding them on a uniform taper). The end tooth of the teeth **81*a*** between leading edge **55** and reference plane **83** may

be located right on the pitch line as shown or, say, a half to a few thousandths inch above it. The teeth **81***a* are relatively shallow but rather wide and have sharp corners. The teeth **81***b* between plane **83** and plane **85** are preferably provided with a small chamfer on the corner, e.g., .003" on 30 degrees to the horizontal or length of the tool. The chamfer may be gradually increased as the height of the teeth increases to a size which is somewhat larger than the final chamfer, e.g., between planes **85** and **87** (teeth **81***c*) it may be .005" on 30 degrees; between planes **87** and **89** (teeth **81***d*) it may be .006" on 30 degrees; and between planes **89** and **91** (teeth **81***e*) it may be .007" on 30 degrees. The teeth in each of these groups may be approximately equal in number, the number of course depending upon the total taper and the circular pitch required. The teeth **81***f* between planes **96** and **93** give final form to the spline teeth on part A and are full size or fully conjugate but have a chamfer of .005" on 30 degrees. The number of teeth **81***f* is the same as in the case of tool **3'**. The teeth **81***g*, four or five in number, may be relieved as before by grinding the flank faces off a total of from .0005 to .003 per tooth as compared with teeth **81***f*, moving from plane **93** to end **51**. The tool **3"** has certain advantages over tool **3'** in that the sharp corners on teeth **81***a* tend to grip the part A and rotate it and the changing shape of the teeth corresponds rather well to the progressive changes to be made in the surface of part A as the splines are formed.

Both tools **3'** and **3"** are shown with a chamfer or bevel **95** of suitable shape along a top corner thereof. This will eliminate sharp corners between the roots of the spline teeth and adjacent metal of the part. It will be noted that the tool will form splinies right up to a shoulder, no undercutting being necessary, and the bevel corner **95** on the tool may be used to control build-up of metal at the shoulder by being made of the desired shape for that purpose. The opposite corners of the tools are illustrated as square and such corners are ordinarily used only when it is not necessary to bevel the roots of the spline, e.g., when the splines run off an O.D. smaller than the root diameter. The end views of FIGS. 7 and 12 do not show the dovetail taper of FIGS. 1–3 (though, obviously, they could be provided with them) as it will be understood that there are various other ways of mounting and moving the tools.

FIG. 8 is a plan view of either tool **3'** or **3"** when the teeth are intended to generate spur teeth on the part A. It will be seen that the tool teeth are perpendicular to the sides of the tool, i.e., perpendicular to the direction of tool movement.

FIG. 9 is a plan view of either tool **3'** or **3"** when the teeth are designed to generate helical teeth on part A and it will be seen that the tool teeth are inclined to the sides of the rack bar or direction of tool movement. The pitch line of the tool is, as before, determined by the diameter D_1. In this case the pressure angle of the teeth as determined in the manner described above is taken as lying in the plane of rotation, i.e., parallel to sides of tools **3'** or **3"** or to the direction of their operating movement. The helix angle of the part teeth at diameter D_1 is taken as the angle of the tool teeth with a normal to the sides of the tool or direction of movement—where D_1 is greater than the pitch diameter, the helix angle will increase and where D_1 is less than the pitch diameter the helix angle will be less. Herringbone teeth can obviously be generated by placing two racks of the type shown in FIG. 9 side by side with the teeth converging toward the plane of contact between the tools.

Another embodiment of the invention is illustrated in FIGURES 13 through 15, this embodiment of the invention having inclined teeth **181** whch are particularly adapted to generate a worm. In FIGURES 13 through 15, a lower tool **103** is shown by way of illustration and it will be understood tha the upper tool is preferably substantially identical to the lower tool. In this embodiment of the invention, the pitch line **179** of the tool teeth **181** is parallel to the reference line **63** from the leading end **155** of the tool **103** to the reference plane **193**, and the pitch line of the tool teeth **181** tapers downwardly away from the reference line **63** from the reference plane **193** to the trailing end **151** of the tool. The top lands of the portions of the tool teeth **181** between the reference plane **196** and the leading end **155** of the tool tapered downwardly toward the leading end of the tool while the pitch line remains parallel to the reference line **63** as previously mentioned, the taper being provided by gradually removing the addenda of the teeth in such zone, as by grinding them on a taper. The top lands of the portions **181***a* of the tool teeth adjacent the leading end **155** of the tool may be located substantially at the pitch line as shown, or may, for example, be disposed a half to a few thousandths of an inch above the pitch line. The portions of the teeth between the reference plane **183** and the leading end **155** are relatively shallow, relatively wide, and have sharp corners as shown in FIGURE 15, the sharp corners serving to grip the workpiece and initiate rotation thereof. The portions of the teeth between the plane **183** and the plane **185** are provided with a small radius on the tips of the teeth. By way of example, the radius on the tips of the portions of the teeth between the reference plane **183** and the reference plane **185** may be .008 inch. The portions of the teeth between the reference plane **185** and the trailing end **151** have a slightly larger radius on the tips of the teeth, such radius being for example .011 inch. The portions of the teeth **181** between the reference plane **196** and the reference plane **193** are full sized and fully conjugate to the teeth on the workpiece, such portions of the tool teeth between the reference plane **196** and **193** thus giving the teeth on the workpiece their final form.

As previously mentioned, the pitch line of the portions of the teeth **181** between the reference plane **193** and the trailing end **151** tapers downwardly away from the reference line **63**, and such portions of the teeth between the reference plane **193** and the trailing end, while substantially full sized, are also relieved on the sides or flank faces thereof. This relief eliminates seams, lines or other errors that might otherwise be formed on the teeth of the workpiece at the end of the stroke due to the decreased total area of contact between the tool and the workpiece.

The pitch line of the teeth on the tool **103** is determined by the diameter D_1 of the workpiece in the manner previously described so that the circular pitch of the teeth on the tool, as measured on the pitch line **179** thereof, corresponds with the circular pitch of the teeth on the workpiece, as measured on a circle having the diameter D_1 of the workpiece. The pressure angle of the teeth of the tool **103** is also determined in the manner previously described and is taken as lying in the plane of rotation, i.e., parallel to the sides of the tool **103** or in the direction of operating movement. The helix angle of the teeth of the workpiece at diameter D_1 is taken as the angle of the tool teeth with a line perpendicular to the sides of the tool or direction of tool movement.

If desired, one or both of the top corners of the tool **103** may be provided with a chamfer or bevel, as shown in FIGURES 8 or 9, to eliminate the necessity of undercutting the workpiece.

It may be noted that in setting up the tools embodying the present invention, that they will be in a direct vertical line with one another when forming an even number of teeth but one half pitch apart when forming an odd number of teeth. In the latter case, one half pitch may be easily ground off the trailing end of the tools without affecting the action of the tool, to simplify the use of gauges for properly setting up and aligning the tools.

The invention may be used to generate various other

tooth forms, serrations, oil grooves for example, by following the principles disclosed above. In some cases where extreme accuracy is not needed, e.g., knurling, the part may not be placed on fixed centers but may be allowed to roll loose. More than one set of splines or teeth can be rolled simultaneously on each part by using pairs of tools such as **1** and **3**. The rolling in all cases can be carried out with the part at room temperature and the part can be made of various materials capable of being rolled. By far the greatest usage is in rolling steel bars, these preferably being at Rockwell "C" hardness 20–30, though harder and softer stock can be rolled. The tools themselves are, of course, preferably formed from high grade tool steels and have a hardness above Rc–60.

While certain specific constructions have been disclosed herein to illustrate the invention, it will be understood that other embodiments are within the spirit and scope of the invention.

What is claimed is:

A tool for pressure forming teeth on the periphery of a cylindrical workpiece, said tool being provided with a working face having teeth thereon and including a leading tooth and a trailing tooth, a first multiplicity of said teeth between said leading tooth and said trailing tooth being fully conjugate to the teeth to be formed on said workpiece and having a pitch line, the circular pitch of said first multiplicity of teeth measured on said pitch line being equal to the distance, measured on a circle having a diameter D_1, between corresponding points on said circle of adjacent workpiece teeth where D_1 is the diameter of a circle which encompasses a cross sectional area of the interdental space between the teeth of the workpiece equal to the cross sectional area of the portions of the teeth of the workpiece outside the circle, the tips of said first multiplicity of teeth being equally spaced from said pitch line, the pressure angle of the teeth in said first multiplicity being the angle whose cosine is D/D_1 multiplied by the cosine of the pressure angle at the pitch diameter D of the teeth of the workpiece, and a second multiplicity of teeth between said first multiplicity of teeth and said leading tooth being formed so that the tips thereof lie on a line which slopes toward said leading tooth so as to intersect an extension of said pitch line adjacent said leading tooth.

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