PATENT SPECIFICATION

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(54) TOOTHED CLUTCH RING AND METHOD OF FORMING THE TEETH

(71) We, BROWN & SHARPE MANUFACTURING COMPANY, a corporation organized under the laws of the State of Delaware, United States of America, of Precision Park, North Kingstown 02852, Rhode Island, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a toothed clutch ring which provides increased load carrying ability by having substantial face to face contact of the teeth during a partial engagement of the clutch teeth. Such clutch rings are particularly useful in positive drive clutches or index couplings requiring high accuracy and where the parts undergo frequent engagement and disengagement. For example, tooth index couplings are used to obtain angularly spaced positions on rotary tables and tool index turrets. Such a coupling type is shown in United States Patent to Muller 2,202,117.

In use, the coupling members are tightly held in mesh by heavy springs or by hydraulic or pneumatic cylinders. To accomplish indexing the coupling members are axially separated and moved in some manner to a new location where the two coupling members are again squeezed tightly together. In general, the mechanism used to obtain the relative rotation is only approximate and as the coupling is engaged, there must be a slight rotation caused by the coupling teeth to reach the exact final location.

Very high accuracy is often required of these devices with some grades offered with less than 3 seconds of arc error. To retain this high accuracy, the prior art couplings for accurate indexing are made of hardened steel. Two such coupling designs are widely used. One is the "Curvio" curved-tooth coupling, and the other is the straight sided Hirth design. Neither of these couplings make use of the helicoid tooth form to obtain the desired accuracy. Both designs require a grinding operation after the coupling members are hardened. The hard surfaces are necessary, because as the teeth engage, there is only a theoretically very small area of contact and therefore, high stresses especially if fast operation and many operations are required.

To obtain better contact conditions on engagement coupling devices have been made which have a helicoid tooth form. For instance, Wildhaber shows in patent No. 2,654,456 a helicoid form of tooth chamfering. The clutch tooth design disclosed by Zieher in patent No. 2,950,797 attempts to improve conditions by combining a narrow band, which has flat engaging areas like the Hirth coupling with curved portions blended thereto. However, even with this design, there is still only contact at the extreme outside radius until the final engagement is reached. Moosmann, patent No. 3,820,412, shows a tooth form where the shape in the fully seated area is of helicoid form.

The term helicoid surface means a surface generated by a radial line which rotates about its axis and advances along the axis with a fixed relation between the two rates of motion.

We find that the helicoid tooth forms of the prior art are not suitable for a high accuracy coupling. The machinery necessary to produce the Moosmann design makes it very difficult to achieve the high precision required.

In accordance with this invention therefore we provide a clutch ring for a positively acting clutch, said clutch ring being adapted to cooperate with a cooperating clutch ring of identical construction, said clutch ring having clutch teeth, each tooth lying substantially on a radial plane that is perpendicular to the axis of rotation of said ring and having a form profile which is of substantially exponential shape with the faces of each tooth having a helicoid surface with constant lead at the pitch plane.

The helicoid shape in the working area of the tooth can be provided in a very simple manner. A form cutter machines the teeth and a subsequent coining operation achieves the desirable helicoid form at the mating areas. The tooth contact area is progressively enlarged to carry the service load and during continued use the indexing accuracy actually improves.

The present invention involves a tooth shape where the slope of the face of the tooth is cut with a form cutter which produces a form wherein the cross section thereof is of exponential shape. To achieve a helicoid shape in the working area of the tooth along the pitch line a cutter is utilised which cuts the form that can be defined generally by the formula $X=Ke^{ky}$ where X is the distance from the center line, e is the base of natural logarithms and y is the height of the tooth face. The exponential curve is chosen so that the mating contact areas are at the flat mid-plane between the coupling teeth. Also the mating contact areas line in mutually shared helicoid surfaces. The tooth form is machined by a cutter which has the desired cross section, the cutter moving on an axis perpendicular to the rotational axis of the clutch and being traversed in a plane which passes through the axis of the clutch and is slightly inclined to the pitch plane. For example, as the cutter is traversed outward cutting the tooth form, it traverses slightly downward so that the width at the pitch plane is just correct for mating with another member of the same shape. The cutter form is such that the slope is inversely proportional to the radial distance from the center of the coupling and, since the width of the tooth space is proportional to the radial distance from the center, the cutter cuts an exponential shape utilizing a simple cutting action to generate the teeth. Some residual errors do exist after the tooth cutting and accordingly a coining process is used to remove these residual errors and at the same time develop an essentially constant width band of contact to give adequate load carrying capacity. It has been shown, for example, in a coupling with 120 teeth having an outside diameter of 175 millimeter and mid size diameter of 134 millimeter and a material having a Rockwell "C" hardness of 27 to 32, that a coining force of 100 tons is satisfactory to produce a contact area approximately one-half a millimeter wide.

In the accompanying drawings:

Fig. 1 is a perspective view of a portion of a clutch coupling illustrating the tooth arrangement;

Fig. 2 is an enlarged section taken through partially and fully engaged clutch teeth;

Figs. 3 and 3A are respectively enlarged sectional elevational views through a tooth and top view of a tooth illustrating the area of contact engagement;

Figs. 4 and 4A are respectively top views and sectional views of a clutch coupling illustrating the manner of generating the teeth with a simple cutter.

Referring to Fig. 1 there is shown a portion of a clutch tooth coupling which is substantially a cylindrical plate member having a plurality of teeth on the face of the plate equally spaced around the periphery thereof. The teeth extend above and below a pitch plane P and the dimension H is the theoretical height of the tooth if the teeth were fully warped surfaces extending to sharp corners; R_1 is the radius at the inside of the teeth and R_0 is the radius at the outside of the teeth. R_b is the base radius for a normal pressure angle. θ is the pressure angle of the tooth and X will be the horizontal distance from the center of the tooth space to the tooth contour and Y is the distance above the mean plane (see Fig. 2); Z is the distance of the cutter axis of rotation above the mean plane required at the base radius location (see Fig. 4); N equals the number of the teeth of the coupling; e is the base of natural logarithm.

To simplify the computations two approximations are made which do not substantially affect results for couplings having at least 120 teeth. First the distances across the tooth space are taken as equal to the developed arc length and secondly, although the tooth path is at a small angle, the vertical distances are taken to be the same as if the path were flat.

In order to use a single cutter to generate the tooth space in one pass the cutter half width at the mean plane at any radius "R" must correspond to the necessary space width

1.
$$X=\frac{\pi\cdot R}{2\cdot N}$$

The pressure angle or slope also required from the cutter must be given by

2.
$$\frac{dx}{dy}=\frac{\pi\cdot R}{N\cdot h}$$

The single cutter must have both relations 1 and 2 together which requires that

$$\frac{dx}{dy}=\frac{2X}{h}$$

The above differential equation has the well known solution

$$x=Ke^{2y/h}$$

The unknown constant k must be

$$\frac{\pi R_b}{2N}$$

to give the correct result when "Y" is zero at the base radius location. Then

$$x=\frac{\pi R_b}{2N}e^{2y/h}$$

also since

$$h=\frac{\pi R_b}{N\tan\theta_b}$$

We have the slope to be generated by the cutter as

3.
$$X=\frac{\pi R_b}{2N}e^{\left(\frac{2N\tan\theta_b}{\pi R_b}\right)y}$$

To generate the required tooth form along the entire tooth length the cutter must travel along a path inclined slightly to the line perpendicular to the coupling axis. To find the amount, "Z", above the mean plane of the cutter axis of rotation, we note that for the cutter space, equation 3 must hold while on the tooth at the same radius, equation 1 is true. To have a match, "Z" must equal the negative of "Y" or

$$\frac{\pi R}{2N}=\frac{\pi R_b}{2N}e^{\left[-\left(\frac{2N\tan\theta_b}{\pi R_b}\right)Z\right]}$$

or
$$Z=\frac{2N\tan\theta_b}{\pi R_b}\ln\left(\frac{R}{R_b}\right)$$

or
$$Z=\frac{2N\tan\theta_b}{\pi R_b}\ln\left(\frac{R_b}{R}\right)$$

To illustrate the derivation of tooth cutting data for the 120 tooth coupling with 25 degree pressure angle at 80 mm base radius:

$$H = \frac{\pi \cdot 80}{120 \tan 25°} = 4.4915$$

and

$$X = 1.0472\ e^{\frac{y}{2.2457}}$$

To make the cutter it is convenient to have a tabulation of the form to be cut and to help in fabrication and inspection, the radius of curvature, ρ (see Fig. 2), at various points is also calculated using the formulae

$$\rho = \frac{\left[1 + \left(\frac{dx}{dy}\right)^2\right]^{3/2}}{\frac{d^2x}{dy2}}$$

and

$$\frac{dx}{dy} = \frac{X}{2.2457}$$

and

$$\frac{d^2x}{dy2} = \frac{X}{5.0432}$$

For 120 tooth example coupling the nominal depth of the tooth engagement is 2 mm with 1 mm of each member beyond the mean plane. The cutter is made to cut 1.6 mm below the mean plane at the base radius to allow for tooth end clearance and for the amount the cutter is raised in cutting at the inside radius. Also the shape is extended up beyond the working range to a practical width. Below is a tabulation of the cutter work form data. That is, the shape of the space actually generated by the cutter.

Y, mm	X, mm	Radius, ρmm
2.4	3.049	7.93
2.0	2.552	6.85
1.4	1.953	6.01
1.0	1.635	5.84
0.6	1.368	5.92
0.2	1.145	6.23
0.0	1.047	6.47
–0.2	.958	6.76
–0.6	.802	7.53
–1.0	.671	8.55
–1.4	.561	9.84
–1.6	.514	10.60

In cutting the tooth form the theoretical cutter path should follow the formula

$$Z=2.2457 \ln \left(\frac{80}{R}\right)$$

The tabulation below shows the theoretical cutter path data:

Radius	Cutter height above mean plane at Base Radius
67	0.398
70	0.300
75	0.145
80	0.0
85	–0.136
87.5	–0.201

The above line of cutter travel deviates only slightly from a straight path inclined at an angle of 1 degree and 36 minutes. Because of this, the teeth can be cut on a standard machine with a simple wedge under the rotary table used to hold the coupling for machining.

The error caused by this procedure is less than 1/100th of a mm which is accommodated by the coining process.

As seen in Fig. 4 and Fig. 4A, the cutter is shown in the cutting cycle of moving on the path designated by the line 20. As the cutter generally designated 21 revolves on its axis, it moves progressively through the points marked B, C, D and E which causes a depthwise feed component. This results in different angles of contact zone changes, the contact zones being cross hatched in Fig. 3. For example, near the inner radius of the tooth which would be in the position B, the contact angle to give an example would be 21.62° and at point D as seen in Fig. 4 the contact zone would be an angle of approximately 26.62°, the angle of the mating helicoidal surfaces varying constantly from the end of the space and then it is moved back to point A and the work is indexed seven teeth and the process of cutting another tooth continues and this is continued until all 120 teeth were cut as shown in the example. Indexing by the prime number of teeth not evenly divisible in the total number of teeth insures that all teeth are cut and that effects of cutter wear is evenly distributed around the clutch. It is, however, not always necessary to index by a prime number. Suppose a clutch had 11 teeth, which is a prime number; then indexing by four, (not prime), secures the proper result. Accordingly, if the number of teeth in the clutch is prime, just about any number above three will distribute the wear very adequately.

The clutch member 25 will have teeth in which the height will vary from the base radius to the outer radius as seen more particularly in Fig. 3. The tops of the teeth are plane surfaces perpendicular to the clutch axis and as seen more particularly in Fig. 2, there will be produced between lines 30 and 31 and dotted lines 30a and 31a substantial helicoid surfaces with a constant lead and which with a coining operation produces a substantial contact area for the engaging clutch rings. As will be seen in Fig. 2 and Fig. 3 the contact area is of substantial extent and fairly uniform from the base radius to the outer radius of the clutch ring. In Fig. 2 the teeth are shown in a position where they might very well engage in broken lines in an indexing type of operation, it being desired to achieve the engagement on the substantialy helicoid surfaces which have been generally designated 32. This means that when full engagement is reached as shown in solid lines that engagement will take place with the substantially helicoid surfaces 32 facing each other in the same fashion that they do in a coining operation. To illustrate how the angle of the contact zone changes as the radius is varied, reference might be had to Fig. 3 where two sections labeled B and C are drawn. Section BB′ is near the inner radius of the tooth where the contact angle, that is the angle, θ, is 21.62° while at section CC the tooth angle is 26.26°. It will therefore be seen that the angle of the mating helicoid surfaces varies constantly from inner to outer radius of the tooth in the clutch coupling.

It will therefore be seen that the clutch teeth are made with very inexpensive cutting processes and allow a subsequent coining operation which develop a mating area of contact along a pitch line which lies in a truly helicoid surface. As can be seen in Fig. 2, as the teeth engage the contact area progressively enlarges to full contact of the area developed in the coining process as a result of the tooth form that is developed. The accuracy of the engagement actually improves with use.

WHAT WE CLAIM IS:—

1. A clutch ring for a positively acting clutch, said clutch ring being adapted to cooperate with a cooperating clutch ring of identical construction, said clutch ring having clutch teeth, each tooth lying substantially on a radial plane that is perpendicular to the axis of rotation of said ring and having a form profile which is of substantially exponential shape with the faces of each tooth having a helicoid surface with constant lead at the pitch plane.

2. A clutch ring as in claim 1 wherein the exponential shape is defined by the formula $X=Ke^{ky}$, where X is the distance from the tooth centre line, e is the natural base logarithm, y is the height of the tooth face and K, k are constants.

3. A clutch ring as in claim 1 wherein said substantial helicoid surface with constant lead at the pitch plane is formed by flattening out the contact area at the mid plane.

4. The method of producing the teeth of the clutch ring claimed in claim 1

which comprises moving a cutting tool having an exponential shape on a radius of said clutch member and in a path extending downwardly towards the periphery of the clutch member, and indexing the clutch member by a prime number not evenly divisible in the total number of teeth and thence cutting another tooth.

5. A clutch ring substantially as hereinbefore described with reference to the accompanying drawings.

6. A method of producing a clutch ring substantially as hereinbefore described with reference to the accompanying drawings.

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1585913 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

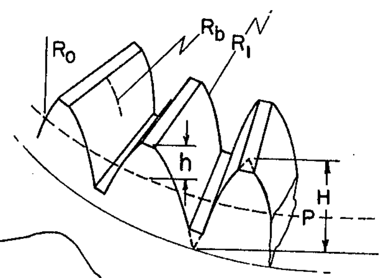

FIG. 1

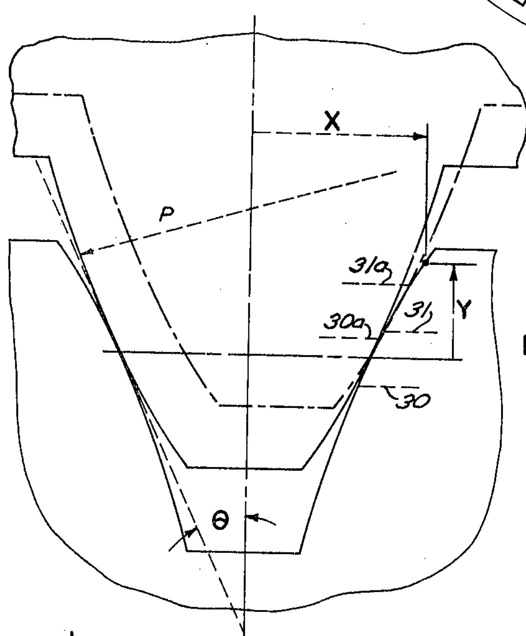

FIG. 2

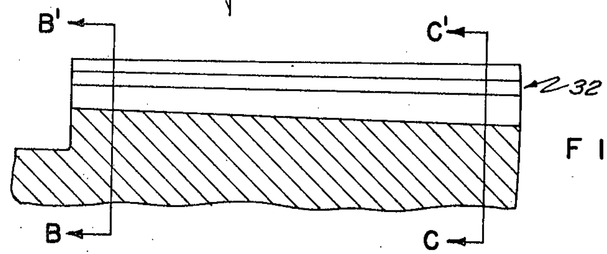

FIG. 3

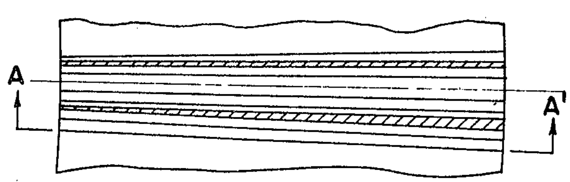

FIG. 3A

1585913 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

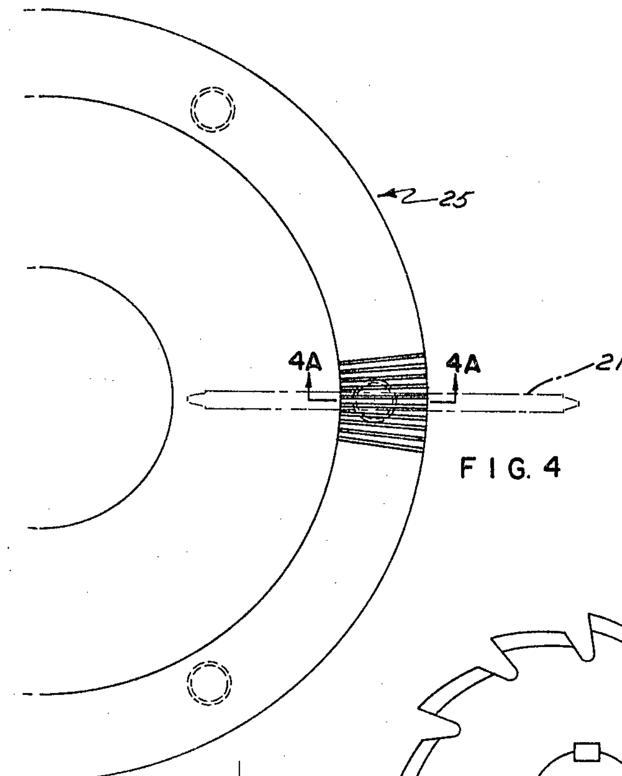

FIG. 4

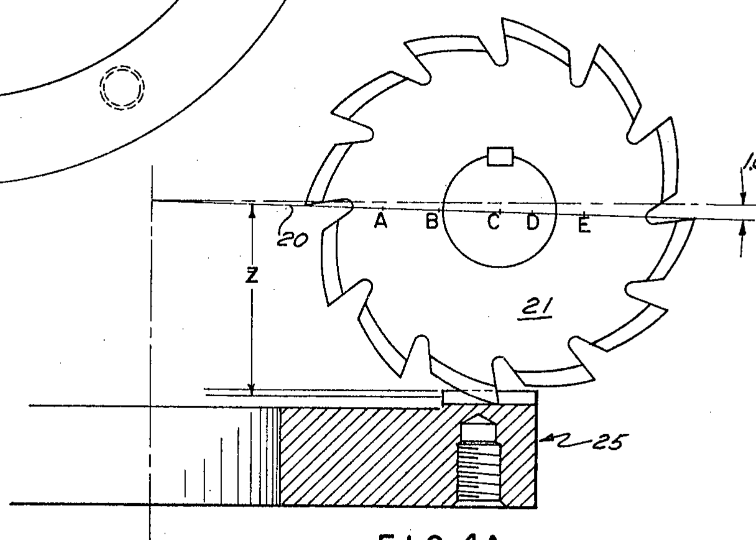

FIG. 4A