The present invention relates to hypoid gears and to a method of producing such gears and particularly to a method of producing hypoid gears which have longitudinally inclined teeth.

The primary object of this invention is to provide a method whereby the side tooth surfaces of each member of a pair of hypoid gears, having longitudinally inclined teeth, may be cut two sides simultaneously in a generating operation in such manner that the gears themselves will mesh with theoretical accuracy. The primary aim of this invention, is therefore, to speed up the production of hypoid gears without in any way affecting their running qualities.

The present invention is particularly applicable to the production of hypoid gears having longitudinally curved teeth. With the present invention the tooth surfaces of each member of such a pair may be cut two side faces simultaneously on existing machines and without requiring any additional adjustment or added motion.

In the accompanying drawings, I have illustrated two different embodiments of my invention. It will be understood, however, that this invention is not restricted to the forms shown, but capable of further modification within its scope and the limits of the appended claims.

In the drawings:

Figure 1 is a plan view of a pair of longitudinally curved tooth hypoid gears, such as may be produced in accordance with the present invention;

Figure 2 is a front elevation, partly in section, of the gears shown in Figure 1;

Figure 3 is a diagrammatic view of the pitch surfaces of the gears shown in Figures 1 and 2, the plane of the drawing being a plane tangent to the pitch surfaces of the two gears;

Figures 4 and 5 are a front elevation, partly in section, and a plan view, respectively, of a pair of hypoid gears, constructed according to this invention, whose tooth surfaces are derived from straight tooth basic members;

Figure 6 is a diagrammatic view showing the pitch surfaces of the gears of Figures 4 and 5, in which the plane of the drawing is a plane tangent to said pitch surfaces;

Figures 7 and 8 are diagrammatic views illustrating certain principles underlying the production of gears according to this invention;

Figures 9 and 10 are a side elevation, partly in section, and a plan view, respectively, illustrating diagrammatically the preferred method of producing with this invention the gear or larger member of a pair of longitudinally curved tooth hypoid gears;

Figure 11 is a plan view illustrating diagrammatically the preferred method of generating the pinion to mesh with the gear produced according to the process of Figures 9 and 10; and

Figure 12 is a plan view illustrating diagrammatically the preferred method of producing with this invention, gears such as the gears shown in Figures 4 and 5 which are conjugate to a basic gear having straight inclined teeth.

With the present invention each member of a pair of hypoid gears is generated conjugate to an offset crown gear or basic gear, that is, is produced in a generating operation in which in addition to the cutting motion of the tool an additional relative motion is imparted between the tool and blank corresponding to that of a gear meshing with a crown gear or basic gear whose axis is offset from the axis of the blank. A principal advantage of the present invention is that it enables both members of a pair of hypoid gears to be cut two side faces simultaneously in such manner that the gears will run together without "bias bearing" or a tooth surface contact which extends diagonally across the faces of the mating teeth. This invention is particularly applicable to the production of hypoid gears in which both members of the pair have longitudinally curved teeth and in general is especially adapted for use in the generation of hypoid gears conjugate to basic gears having teeth which are inclined longitudinally to the straight generatrices of their pitch surfaces.

Figures 1 and 2 show a pair of hypoid gears such as might be produced according to one embodiment of this invention and Figures 4 and 5 show a pair of hypoid gears produced according to another embodiment of this invention. In each case, both members of the pair are provided with teeth which are longitudinally inclined, that is inclined against the straight generatrices of the pitch surfaces of the gears. The gears of Figures 1 and 2 are provided with longitudinally curved teeth and are derived from basic gears having longitudinally curved teeth. The gears of
Figures 4 and 5 are derived from basic gears having teeth which are straight, but non-radial or skew.

In Figures 1 and 2, 10 indicates the gear or larger member of the pair and 11 the pinion or smaller member of the pair. These two gears mesh together with axes non-intersecting and non-parallel, the axis 13 of the gear being offset from the axis 14 of the pinion. In the shown embodiment, the axes 13 and 14 of the gears are disposed at right angles to each other. The gears mesh together with a combined rolling and sliding action. The gears are provided with conical pitch surfaces, the pitch cone apexes of gear and pinion being at 15 and 16, respectively. Each member of the pair has, as stated, longitudinally curved teeth. In the preferred construction, the spiral angle or tooth inclination angle of the teeth 19 of the pinion will be larger than the spiral angle or tooth inclination angle of the teeth 18 of the gear, as with this construction it has been found that the pinion can be made larger and stronger than bevel pinions of corresponding ratios. The tooth surfaces of each member of this pair are derived from, that is, generated conjugate to basic crown gears having longitudinally curved teeth. The tooth surfaces of each member of the pair are cut preferably two sides simultaneously being conjugate, thus, to basic gears whose adjacent tooth surfaces are concentric surfaces of revolution.

In Figures 4 and 5, 20 indicates the gear or larger member of the pair and 21 the pinion. The gear axis is at 22 offset from the pinion axis 23. In the shown embodiment, the two axes are arranged at right angles. The pitch cone apex of the gear is at 24 and the pitch cone apex of the pinion is at 25. Each member of the pair is provided with teeth which are longitudinally inclined to the straight generatrices of its pitch surface, the teeth 27 of the pinion being, preferably, more inclined than the teeth 28 of the gear. Each member of the pair is generated from an offset basic gear having teeth which are non-radial or skew.

Figures 9, 10 and 11 illustrate diagrammatically the method of producing longitudinally curved tooth gear pairs such as shown in Figures 1 and 2 and Figure 12 shows how the members of the pair shown in Figures 4 and 5 may be generated according to this invention. Longitudinally curved tooth gears will be cut according to this invention preferably with rotary annular face mills. Each member of the pair is generated conjugate to an offset crown gear. Figures 9 and 10 illustrate the generation of the gear or larger member of the pair. Here, the gear blank is indicated at 30. Its axis is at 31 and its apex at 32. The tool used, a rotary annular face mill, is shown at 34. It is provided with a plurality of cutting blades which represent a tooth surface or tooth surfaces of a basic gear, such as indicated in dotted lines at 35, whose axis 36 is offset from the axis 31 of the gear blank during generation. In the form shown, the basic gear 35 is a true crown gear, that is, has a plane pitch surface 37. Preferably, two side tooth faces of the blank will be cut simultaneously and for this purpose the tool 34 will be provided with cutting blades 38 having cutting edges which are adapted to finish cut adjacent side tooth faces of a blank. The blades 38 may be so arranged that alternate blades will finish cut opposite side faces of the tooth of the blank, or each blade may be provided with a pair of finish cutting edges so that each blade finish cuts simultaneously on two adjacent side tooth faces of the blank. The tool 34 will be so positioned relative to the blank that it represents adjacent tooth surfaces of the basic gear 35. In the generating operation, the tool 34 is rotated on its axis 39 in engagement with the blank, while simultaneously a relative motion is produced between tool and blank corresponding to that of a gear meshing with the basic gear 35 with its axis offset from the axis of the basic gear 35. In this relative motion, the blank will preferably be rotated on its axis 31 while a relative movement is produced between the tool and blank about the axis 33 of the basic gear 35, which axis 33 is offset from the axis 31 of the blank. The apex of the basic gear 35 is indicated at 40. After two adjacent tooth surfaces of the blank have been completely generated in the manner described, the tool and blank are withdrawn relatively to each other and the blank indexed, then the tool and blank are returned into engagement and another pair of tooth surfaces of the blank generated. The alternate cutting and indexing will continue until the blank is completed.

The pinion which is to mesh with a gear generated in the manner just described will be cut in a similar fashion. Figure 11 illustrates diagrammatically the method of producing the pinion. 42 designates the pinion blank, whose axis is at 43 and whose apex is 115 at 44. A rotary annular face mill is again preferably employed and this face mill 45 is again preferably provided with cutting blades 46 which are provided with cutting edges adapted to finish cut adjacent side tooth faces of a blank. As before, alternate blades may be provided with finish cutting edges for finish cutting adjacent side faces of the teeth of the blank, or each blade may have two side finish cutting edges and finish cut simultaneously the two adjacent tooth faces of the blank. The finish cutting edges of the tool again represent coaxial longitudinally curved tooth surfaces of a basic gear such as indicated in dotted lines at 48 whose
axis 49 is offset from the axis 43 of the blank. The tooth surfaces of the blank are generated by rotating the tool 45 on its axis 50 in engagement with the blank, while simultaneously producing a relative motion between the tool and blank corresponding to that of a gear meshing with a basic gear whose axis is offset from the axis of the blank. This relative motion will preferably be effected by rotating the blank on its axis 45 and simultaneously moving the tool and blank relatively to each other about an axis 49 representing the axis of the basic gear 43. After two tooth surfaces of the blank have been completely generated it will be indexed and alternate cutting and indexing will proceed until the blank is finished. The relationship between the basic gears 35 and 48 from which gear and pinion are generated, respectively, can be determined as described hereinafter.

When the gear and pinion are cut in the manner just described, each of them may be generated upon a machine such as described in my copending application No. 77,510, filed December 23, 1925. In this machine, the axis of the cradle or carrier will represent the axis of the basic gear to which the gear being cut is generated conjugate and the blank axis may be offset any desired distance from the axis of the cradle.

Both members of the pair shown in Figures 4 and 5 may be generated according to the method illustrated diagrammatically in Figure 12. Here, a pair of planing tools 52 and 53 are employed, representing side tooth surfaces of the basic gear 54. The teeth of this basic gear are straight and inclined to the generatrices of its pitch surface, that is, they are non-radial or skew. The blank 55 to be cut is positioned with its axis 56 offset from the axis 57 of the basic gear 54. In the generating operation, the tools 52 and 53 are reciprocated across the face of the blank 55 in paths converging in a point 58, representing the point of convergence of the side tooth faces of the teeth of the basic gear 54, which point 58 lies on a circle circumscribed about the basic gear center or apex as a center. Simultaneously, a relative movement is imparted between the tools and blank in the manner of a gear meshing with the basic gear 54 with its axis 53 offset from the axis 57 of the basic gear. This additional motion is preferably effected by rotating the blank on its axis and by simultaneously moving the tools and blank relatively to each other about an axis 57 representing the axis of the basic gear. After two side faces of the blank have been cut in the manner described, the tools and blank are withdrawn relatively to each other and the blank indexed. The alternate cutting and indexing will proceed until the blank has been completed. The mating gear is cut conjugate to an offset basic gear in a similar manner. The relationship between the two basic gears to which the two members of the pair are generated conjugate is described more completely hereinafter.

Preferably, the basic gears to which the two members of a hypoid pair are generated conjugate, by the process of this invention, are true crown gears, that is, gears having plane pitch surfaces. Usually, the crown gear to which the gear or larger member of the pair is generated conjugate is different from the crown gear from which the pinion or smaller member of the pair is derived. Preferably, however, both crown gears have the same tooth inclination or spiral angle at a mean point of contact between the crown gear and the respective gears which are generated therefrom.

Figures 3 and 6 are diagrammatic views showing the pitch surfaces of the gears of Figures 1 and 2 and of Figures 4 and 5, respectively, in relation to the planes 60 and 61 respectively, tangent to the pitch surfaces of the respective pairs at the respective mean points of contact 62 and 63 between the gears of the respective pairs. The planes 60 and 61 may also be considered the pitch planes of crown gears from which the members of the respective pairs are generated and 62 and 63 would be mean points of contact between the crown gears and the respective members of the respective pairs. 18' and 14' are the projections of the axes of the gear 10 and pinion 11, respectively, to the plane 60 and 22' and 23' are the projections of the axes of the gear 20 and pinion 21, respectively, to the plane 61.

As stated, preferably, the crown gears or basic gears from which the two members of a pair are derived have the same tooth inclination or spiral angle at the mean point of contact. In other words, the centers of the two crown gears from which the two members of a pair are derived are located on the same line which passes through the mean point of contact. Thus the centers 63 and 66 of the crown gears from which the gear 10 and pinion 11 are derived, respectively, are located on the line 67 passing through the mean point of contact 62 (Figure 3). Likewise, also, the centers 68 and 69 of the crown gears to which the gear 20 and pinion 21 are generated conjugate, respectively, are located on the same line 70 passing through the mean point of contact 63. For gear pairs of the proportions shown, the lines 67 or 70, as the case may be, are situated between the projected gear and pinion axes and nearer to the projected gear axis. The location of the lines 67 and 70 can be determined as described below.

The basic crown gears contain tooth sides which preferably are surfaces of revolution in the case of longitudinally curved tooth gears or planes where the teeth of the crown gears are straight. In Figure 3, 72 indicates...
the tooth direction of the teeth of the crown gears from which the gears 10 and 11 are derived. The tooth direction of the crown gears from which the gears 20 and 21 are derived is indicated at 73 in Figure 6. The lines 72 and 73 are pitch lines of the crown gears, that is, the lines formed by the intersection of the tooth surfaces of the crown gears with their pitch planes.

The principles on which are based the determination of the crown gear centers for a hypoid pair constructed according to this invention, are the same whether the crown gears have circular arcuate teeth or straight inclined teeth. Mathematically considered, the longitudinally curved tooth gears represent the broader or more general case and in what follows the method of determining the crown gear centers for such gears will be specifically considered, it being understood that the same method may be applied to the determination of the crown gear centers for the crown gears which have straight teeth.

The center of tooth curvature of the crown gear tooth 72 is at 75, Figure 3. The tooth surfaces of gear and pinion and of their respective crown gears will contact in the mean point of contact 62. To avoid bias bearing, that is a tooth surface contact which extends diagonally of the tooth surfaces of the mating gears, the mating gears should be so constructed that the points of contact between mating tooth surfaces will move straight up the tooth profiles from the bottom to the top of the same during the mesh of the gears.

Reference is now made particularly to Figure 7 which is an enlarged diagrammatic view of the parts about the mean contact point 62 of Figure 3, and to Figure 8 which is a diagrammatic side elevation looking in the direction of the arrow 100 shown in Figure 7. Let us now consider a point 76 on the side of the crown gear tooth, shown in full at 77 in Figure 8, which point 76 lies directly above or below the mean point of contact 62. The point 76, in other words, lies in a plane which passes through the mean point of contact 62 and is perpendicular to the pitch line 72. Depending on the side of the crown gear tooth considered, the point 76 is situated above or below the pitch plane of the crown gear by a distance s.

After the crown gear and blank, say, the gear blank, have rolled together a certain distance the point 76 will become a point of contact between the cutting edge of the tool, which represents the tooth surface of the crown gear and the tooth surface of the blank being generated. So, the point 76 becomes a point of contact between the crown gear tooth surface and the gear blank tooth surface in some point 79. Line 76–79 is actually a circular arc about the crown gear center, but in the relatively infinite enlargement of Figures 7 and 8 this line appears as a straight line.

In uniform motion gears, in general, a force extending in the direction of the tooth normal at any point of tooth contact produces moments on either gear of a pair which are in the proportion of their respective numbers of teeth. We will now consider a force extending in the direction of the tooth normal at the mean point of contact 62 and a force extending in the direction of the tooth normal at points 76 and 79. The latter two points are on the same point of the tooth surface in different positions of the roll, of crown gear and blank. The forces acting at 62 and 76 are assumed equal. Hence the moment produced on the crown gear by the forces acting at 62 and 76 are equal, or, in other words, the increment in moment between the points 62 and 76 is zero. The increment in moment exerted upon the crown gear at 62 and 79 is, therefore, also zero.

Hence, the increment in moment exerted upon the gear being cut by forces extending in the direction of the tooth normal at 62 and 79 must be zero, in order that gear and crown gear roll together with uniform motion. This fact makes it possible to readily determine the distance Z between the points 76 and 79, that is, the distance which the crown gear must roll before the point 76 becomes a point of contact at 79 with the blank being cut.

For convenience, the following symbols are employed:

$s$ = the distance of the considered point 76 above or below the pitch plane of the crown gear. This point is above said plane if the tooth side of the crown gear is considered which faces the pinion apex. For convenience, the distance $s$ is supposed to be infinitely small.

$A_1$, $A_2$ = the cone distances of gear and pinion, respectively, the distances 15–62 and 15–63, respectively, in Figure 3.

$A_1$, $A_2$ = the cone distances of the crown gears underlying the generation of the gear and pinion respectively, the distances 63–62 and 63–62, respectively, in Figure 3.

$h$, $H$ = the spiral angles of pinion and gear respectively.

$k$, $p$ = the spiral angle of the basic crown gears.

$s$ = the normal pressure angle.

From the consideration of uniform motion gearing outlined above, and applying the known rules of mathematics, the following equation can be derived:

$$ Z = \frac{A_1 \cos H}{s \tan P(A_2 \sin h_2 - A_1 \sin H)} + A_1 \tan a \cos (h_2 - H) $$

(1)

In this equation, the upper sign refers to the tooth side of the gear which faces the pinion.
5

apex during the mesh and to the mating tooth side of the pinion. The lower sign refers to the other tooth side.

Generally, the point 79, which is a point of contact between the crown gear and gear blank, is not also a point of contact between the gear and pinion. Point 79 of the gear tooth surface will make contact with the mating tooth surface of the pinion in some other position 80, located by turning the point 79 about the axis of the gear.

As explained above, the moments, exerted upon the gear by a force normal to its tooth surface at points 62 and 79 are equal and therefore, at 80 are also equal. Hence the moments exerted upon the pinion at the points 62 and 80 are equal.

It is understood that the forces here considered are always in a direction perpendicular to the tooth surface and considering the points 62 and 76 are of such magnitude that their projection to the pitch plane are alike. If the profile of the crown gear tooth is straight, this results in the normal forces being equal also.

From what has been said, it follows that the point 79 of the gear tooth surface is turned about the gear axis to the position 80 where the moment produced on the pinion by a force extending along the tooth normal equals the moments produced on the pinion at the point 62. Now, the tooth normal when swung about the gear axis from 79 to 80 changes its inclination to the pitch plane.

At 79, the inclination of the tooth normal equals the pressure angle of the tool, that is, the pressure angle of the crown gear tooth surface. At point 80, however, the inclination of the tooth normal to the pitch plane is different. The point 80, therefore, cannot be a point of contact between the pinion and its basic crown gear. If it were, then the pressure angle of the pinion at the point 80 would be the pressure angle of the tool which represents the basic crown gear from which the pinion is generated, whereas, as stated above, the pressure angle or inclination of the tooth normal at the point 80 should be different from the pressure angle of the tool. Point 80 of the pinion cannot, therefore, be a point of contact between the pinion and its basic crown gear, represented by the tool. Point 80 becomes a point of contact between the pinion and its basic crown gear at some position 81, obtained by turning the point 80 about the axis of the pinion until the tooth normal has an inclination angle with respect to the plane of the crown gear equal to the pressure angle of the tool or tooth of the crown gear.

The crown gear to which the pinion is conjugate is so determined, therefore, that the tooth normal at point 81 when swung about the crown gear axis to the point 76 will have the known inclination of the tooth normal at the last named point.

From Figure 7, it will be seen that the point 81 is situated on the line 79—76 prolonged. The spiral angle $h_2$ of the crown gear is preferably selected, therefore, slightly larger than the spiral angle $H$ of the gear, and is such as results from the geometric addition of the distances 79—80 and 80—81. In other words, the distance 79—81 which results from said geometric addition, is situated in the direction of the peripheral motion of the crown gear. The crown gear axes lie on a line passing through the point 79 which is perpendicular to line 79—81.

The spiral angle $h_2$ of the two crown gears from which the gear and pinion are derived, therefore, are alike. However, ordinarily, the cone distance $A_4$ of the crown gear from which the gear is generated is different from the cone distance $A_4$ of the crown gear from which the pinion is derived.

Based on the above considerations, the following equation, from which the spiral angle $h_2$ of the crown gears may be determined, may be derived:

$$\tan h_2 = \frac{\tan H}{\frac{1 + A_4 \tan p \tan h}{A_4 \tan p}}$$

If we let the distance 79—80 equal $a$, the distance $x$ can be determined as follows:

$$x = \frac{\tan p}{A_4} (A_4 \sin h - A_4 \sin H) + \tan a \cos (h - H) \left(1 + \frac{A_4 \tan p}{A_4 \tan p}\right) =$$

$$\frac{\cos h - \cos H \tan p (A_4 \sin h - A_4 \sin h_2) + A_4 \tan a \cos (h - h_2)}{\cos a \cos \tan p (A_4 \sin h_2 - A_4 \sin H) + A_4 \tan a \cos (h_2 - H)}$$

$x$ will be positive if plotted in the direction shown in Figure 7 and negative if plotted in the opposite direction.

Inasmuch as the axis of the crown gear to which the pinion is generated conjugate must be so located as to permit swinging of the 105 tooth normal at point 81 into its known position at the point 76, that is, in such as the crown gear axis from which the pinion is derived must be so located that the points 81...
and 76 are at the same distance from this axis and that the tooth normals at 81 and 76 have the same inclination to this axis, the following formula can be derived:

\[
\frac{Z}{s}A_1 \sin h_3 (A_4 - 1) = \frac{Z}{s} \left[ (A_1 \sin H - A_4 \tan h_3) + \frac{\tan p \cos H}{\tan P \cos h} \right. \\
\left. (A_2 \sin h - A_4 \sin h_3) + A_4 \sin h_3 \tan \frac{a}{A_4} \tan \frac{p}{P} \cos H (\tan h - \tan H) \right]
\]

In this formula, \( h_3 \) may be determined from equation (2) and the values of \( Z/s \) and \( Z/s \) may be introduced from equations (1) and (3), respectively.

The two equations are thus obtained, one for the upper sign or one tooth side of the crown gear; and the other for the lower sign or the other tooth side of the crown gear. The cone distances \( A_3 \) and \( A_4 \) of the two crown gears may be determined from these equations by the known means of mathematics.

Gears generated according to the present invention will transmit true uniform motion and will be free from bias bearing.

The relation of the pitch cone angles of the mate gears to the respective numbers of teeth and to the lengthwise curvature of the teeth may be assumed or determined in any suitable way, for instance, in the manner described in my copending application, Serial No. 171,099 filed February 28, 1927.

In cutting longitudinally curved tooth gears with this invention, a spherical cutter, that is, a cutter having cutting edges of circular arc profile, such as shown in Figure 9, may be employed to obtain gears of theoretical accuracy and no bias, or a straight-sided or conical cutter may be used. In the latter case, to avoid bias, the gears will be cut, preferably, parallel depth, that is, with teeth of uniform or constant depth along their lengths. The cutter will preferably cut two side faces of the blank simultaneously and will be so positioned, as described, as to represent two adjacent tooth sides of a crown gear tooth. If the cutter is spherical, then for theoretically correct gears, its axis should pass through the sphere centers of the tooth sides of the crown gear represented by the cutting edges.

Preferably the crown gears will have teeth which taper in depth in such fashion that the points or tips of the crown gear teeth are in line with their apexes or centers. The mean radius \( r \) of the cutter, the average cone distance

\[ A_5 = \left( A_3 + A_4 \right) / 2 \]

and the spiral angle \( h_3 \) of the crown gears are then in a certain inter-relation, which may be determined by scaling the drawing or with the following formula:

\[
\left( 1 - \frac{A_5}{r} \sin h_3 \right) \sin \frac{a}{A_4} = \frac{A_4}{A_3} \cos^2 h_3 D,
\]

where \( D \) is the dedendum of the blank at a diametral pitch of one measured normal or perpendicular to the teeth. The actual dedendum at the center of the face equals:

\[
\frac{2A_4}{N_5} \cos h_3 D,
\]

where \( N_5 \) is the average tooth number of the crown gear.

While I prefer to generate longitudinally curved tooth gears with this invention, by using rotary annular face mills, it will be understood that, if desired, planing tools may be used instead which are reciprocated across the face of the blank in separate paths curved about the center of curvature of the crown gear teeth as a center. The principles of the present invention are applicable, also, to the production of longitudinally curved tooth gears in a hobbing or continuous indexing process whether a face mill or a worm hob be employed or a pair of planing tools reciprocating in straight paths across the face of a continuously rotating gear blank.

The present invention is not limited to the production of gears by planing or milling tools, but may be employed also in grinding or lapping.

In general, it may be said, that while this invention has been described with reference to particular embodiments, it will be understood that the invention is not limited to the embodiments discussed, but is capable of further modification, and that this application is intended to cover any variations, uses, or adaptations of the invention, following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice in the gear art and may be applied to the essential features hereinafter set forth and as fall within the scope of the invention and the limits of the appended claims.

Having thus described my invention, what I claim is:

1. The method of producing a pair of hypoid gears which consists in cutting the side tooth surfaces of each member of the pair by moving a tool across the face of a
tapered gear blank in a path inclined to a straight generatrix of the pitch surface of the blank, while rotating the blank on its axis and simultaneously producing an additional relative movement between the tool and blank about an axis offset from the blank axis.

2. The method of producing a pair of hypoid gears which consists in cutting the side tooth surfaces of each member of the pair by moving a tool across the face of a tapered gear blank in a path inclined to a straight generatrix of the pitch surface of the blank while simultaneously producing a relative motion between the tool and blank corresponding to that of a gear meshing with a crown gear whose axis is offset from the axis of the blank.

3. The method of producing a pair of hypoid gears which consists in cutting the side tooth faces of each member of the pair by moving a tool in a circular arcuate path across the face of a tapered gear blank while rotating the blank on its axis and simultaneously moving the tool and blank relatively to each other about an axis offset from the blank axis.

4. The method of producing a pair of hypoid gears which consists in cutting the side tooth surfaces of each member of the pair by producing a relative movement between the tool employed and a tapered gear blank corresponding to that of a gear meshing with a crown gear whose axis is offset from the axis of the blank, while moving the tool across the face of the blank in a path inclined to a straight generatrix of the pitch surface of the crown gear to describe thereby a tooth surface of the crown gear.

5. The method of producing a pair of hypoid gears which consists in cutting the side tooth surfaces of each member of the pair by producing a relative movement between the tool employed and a tapered gear blank corresponding to that of a gear meshing with a crown gear whose axis is offset from the axis of the blank while rotating the tool in a curved path across the face of the blank to describe thereby a tooth surface of the crown gear.

6. The method whereby the tooth surfaces of each member of a pair of hypoid gears may be cut two sides simultaneously, which consists in moving a pair of cutting edges across the face of a tapered gear blank in paths inclined to straight generatrices of the pitch surface of the blank, while rotating the blank on its axis and simultaneously producing an additional relative movement between the cutting edges and blank about an axis offset from the blank axis.

7. The method whereby the tooth surfaces of each member of a pair of hypoid gears may be cut two sides simultaneously, which consists in moving a pair of cutting edges across the face of a tapered gear blank in paths inclined to straight generatrices of the pitch surface of the blank, while simultaneously producing an additional relative movement between the cutting edges and blank corresponding to that of a gear meshing with a crown gear whose axis is offset from the axis of the blank.

8. The method whereby the tooth surfaces of each member of a pair of hypoid gears may be cut two sides simultaneously, which consists in moving a pair of cutting edges across the face of a tapered gear blank while simultaneously producing a relative movement between the cutting edges and blank about an axis offset from the blank axis.

9. The method whereby the tooth surfaces of each member of a pair of hypoid gears may be cut two sides simultaneously, which consists in moving a pair of cutting edges in separate concentrically curved paths across the face of a tapered gear blank while simultaneously producing a relative movement between the cutting edges and blank corresponding to that of a gear meshing with a crown gear whose axis is offset from the axis of the blank.

10. The method whereby the tooth surfaces of each member of a pair of hypoid gears may be cut two sides simultaneously, which consists in moving a pair of cutting edges in separate concentrically curved paths across the face of a tapered gear blank while simultaneously producing a relative movement between the cutting edges and blank corresponding to that of a gear meshing with a crown gear whose axis is offset from the axis of the blank.

11. The method whereby the tooth surfaces of each member of a pair of hypoid gears may be cut two sides simultaneously, which consists in employing, in each case, a rotary annular face mill, having a plurality of cutting edges adapted to finish cut adjacent side tooth faces of a gear blank, and rotating said tool in engagement with a tapered gear blank while rotating the blank on its axis and simultaneously producing an additional relative movement between the tool and blank about an axis offset from the blank axis.

12. The method whereby the tooth surfaces of each member of a pair of hypoid gears may be cut two sides simultaneously, which consists in employing, in each case, a rotary annular face mill, provided with a plurality of cutting edges adapted to finish cut adjacent side tooth faces of a gear blank, and rotating said tool in engagement with a tapered gear blank while simultaneously producing a relative movement between the tool and blank corresponding to that of a gear meshing with a crown gear whose axis is offset from the axis of the blank.

13. The method of producing a pair of hypoid gears which consists in cutting the side tooth faces of one member of the pair
conjugate to an offset basic gear having teeth inclined to the straight generatrices of its pitch surface, by moving a tool, representing a relative movement between the tool and blank in the manner of a gear meshing with said basic gear, while maintaining the axis of the blank offset from the axis of said basic gear, and in cutting the side faces of the other member of the pair conjugate to another offset basic gear whose teeth have the same inclination angle as the teeth of the first basic gear by moving a tool, representing a relative movement between the tool and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of the basic gear.

14. The method of producing a pair of hypoid gears which consists in cutting the tooth surfaces of each member of the pair conjugate to an offset basic gear, having teeth inclined to the straight generatrices of its pitch surface, by moving a tool, representing a relative movement between the tool and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of said basic gear, the basic gears to which the two members are generated conjugate having the same tooth inclination angles but having axes offset different amounts from the axes of the respective blanks during the generation of the two gears.

15. The method of producing a pair of hypoid gears which consists in cutting the tooth surfaces of each member of the pair conjugate to an offset basic gear having longitudinally curved teeth, by moving a tool, representing a tooth surface of said basic gear, in a curved path across the face of a tapered gear blank while imparting a relative movement between the tool and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of said basic gear, the basic gears to which the two members of the pair are generated conjugate, having the same tooth inclination angles, but having axes offset different amounts from the axes of the respective blanks during the generation of the two gears.

16. The method of producing a pair of hypoid gears which consists in cutting the tooth surfaces of each member of the pair conjugate to an offset basic gear having longitudinally curved teeth by rotating an angular face mill in engagement with a tapered gear blank while imparting a relative movement between said tool and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of said basic gear, the basic gears to which the two members are generated conjugate having the same tooth inclination angles but having axes offset different amounts from the axes of the respective blanks during the generation of the two gears.

17. The method of producing a pair of hypoid gears which consists in cutting the side tooth faces of each member of the pair two sides simultaneously, conjugate to an offset basic gear, having teeth inclined to the straight generatrices of its pitch surface, by moving a pair of cutting edges, representing tooth surfaces of said basic gear, across the face of a tapered gear blank while imparting a relative movement between the cutting edges and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of said basic gear, the basic gears to which the two members of the pair are generated conjugate having the same tooth inclination angles but having axes offset different amounts from the axes of the respective blanks during the generation of the two gears.

18. The method of producing a pair of hypoid gears which consists in cutting each member of the pair two side faces simultaneously conjugate to offset basic gears having longitudinally curved teeth by moving a pair of cutting edges in separate curved paths across the face of a tapered gear blank while imparting a relative movement between the cutting edges and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of said basic gear, the basic gears to which the two members are generated conjugate having the same tooth inclination angles but having axes offset different amounts from the axes of the respective blanks during the generation of the two gears.

19. The method of producing a pair of hypoid gears which consists in cutting the side tooth surfaces of each member of the pair conjugate to offset basic gears having longitudinally curved teeth by rotating an angular face mill, provided with a plurality of cutting edges adapted to finish cut adjacent side tooth faces of a gear blank, in engagement with a tapered gear blank while imparting a relative movement between the tool and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of said basic gear, the basic gears to which the two members are generated conjugate having the same tooth inclination angles but having axes offset different amounts from the axes of the respective blanks during the generation of the two gears.

20. The method of producing a pair of hypoid gears which consists in cutting the tooth surfaces of each member of the pair conjugate to an offset basic gear, having teeth inclined to the straight generatrices of
its pitch surface, by moving a tool, representing a tooth surface of the basic gear, across the face of a tapered gear blank while imparting a relative movement between the tool and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of said basic gear, the basic gears to which the two members of the pair are respectively generated conjugate, having the same tooth inclination angles, but different cone distances.

21. The method of producing a pair of hypoid gears which consists in cutting each tooth surface of each member of the pair conjugate to an offset basic gear having longitudinally curved teeth, by moving a tool, representing a tooth surface of said basic gear, in a curved path across the face of a tapered gear blank while imparting a relative movement between the tool and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of said basic gear, the basic gears to which the two members of the pair are generated conjugate, having the same tooth inclination angles but different cone distances.

22. The method of producing a pair of hypoid gears which consists in cutting the side tooth surfaces of each member of the pair conjugate to an offset basic gear having longitudinal teeth, by moving a pair of cutting edges, representing the tooth surfaces of said basic gear, across the face of a tapered gear blank while imparting a relative movement between the cutting edges and blank in the manner of a gear meshing with said basic gear with its axis offset from the axis of said basic gear, the basic gears to which the two members of the pair are respectively generated conjugate having the same tooth inclination angles but different cone distances.

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