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(71) Applicant: **Harmonic Drive Systems Inc.**
Shinagawa-ku
Tokyo
140-0013 (JP)

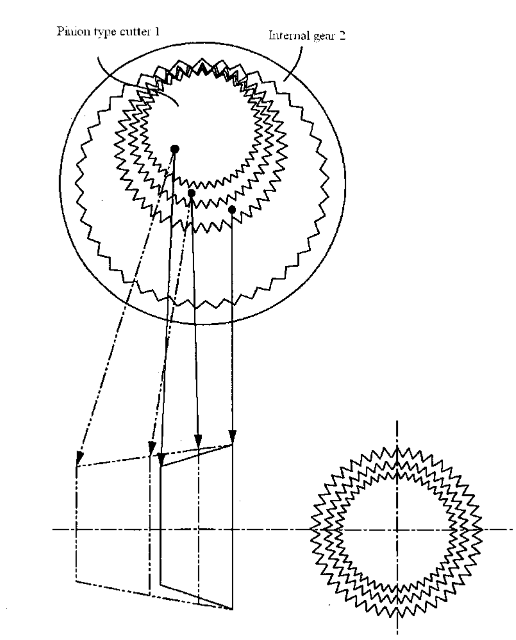
(72) Inventors:
- **Yamazaki, Hiroshi**
  Harmonic Drive Systems Inc.
  Azumino-shi
  Nagano-ken
  399-8305 (JP)
- **Yoshida, Yoshitaro**
  Harmonic Drive Systems Inc.
  Azumino-shi
  Nagano-ken
  399-8305 (JP)
- **Kiyosawa, Yoshihide**
  Harmonic Drive Systems Inc.
  Azumino-shi
  Nagano-ken
  399-8305 (JP)
- **Kishi, Satoshi**
  Nagano-ken
  381-0083 (JP)

(74) Representative: **Schmitt-Nilson, Gerhard**
Klunker Schmitt-Nilson Hirsch
Winzererstrasse 106
80797 München (DE)

(54) **Grinding wheel for relief machining for resharpenable pinion-type cutter**

(57) An axially perpendicular tooth shape profile contour for an internal gear is given as a series of dispersive points, the given series of axially perpendicular cross-sectional tooth shape profile points for the internal gear is interpolated by Akima method, the axially perpendicular cross-sectional tooth shape profile for the internal gear is defined, the axially perpendicular cross-sectional tooth shape profile is defined by a formula whereby the coordinate system has been transformed to a fixed coordinate system that rotates integrally with the pinion type cutter, the envelope of a group of curves represented by the formula is determined, the cutting edge shape profile of the pinion type cutter is determined by projecting the envelope onto the cone of the rake surface of the pinion type cutter, and the cutting edge shape profile of the pinion type cutter is defined by superposing, in the axial direction of the pinion type cutter, the cutting edge shape profile obtained by varying the center distance between the pinion type cutter and the internal gear This profile is expressed in the fixed coordinate system on the grinding wheel side in relief motion, and the axial cross-sectional tooth shape profile of the grinding wheel for relief machining is obtained. A grinding wheel for relief machining that can prevent generating tooth shape errors in an obtained gear by using a resharpened pinion type cutter, can be realized.

[FIG. 2]



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Description

[Technological Field]

[0001] The present invention relates to a grinding wheel for relief machining for a resharpenable pinion-type cutter having an arbitrary tooth profile for cutting the internal gear or the like of a wave gear device, and more particularly relates to method for designing the tooth shape profile of a grinding wheel for relief machining for a pinion-type cutter having a relief surface capable of reproducing a tooth shape profile required for the resultant gear even when pinion-type cutter is resharpened.

[Prior Art]

[0002] As a gearing mechanism, there is a wave gear mechanism known by the trade name "Harmonic Drive" owned by the present applicant, and the wave gear mechanism is comprised of three components: a rigid internal gear, a flexible external gear, and a wave generator, enabling a simple reduction gear mechanism with high reduction gear ratio to be realized. Conventionally, involute gearings have been used in wave gear mechanisms, but currently non-involute, specially shaped gears are adopted in order to improve performance characteristics.

[0003] Here, the pinion type cutter is generally used for the internal gear; however, when the pinion-type cutter is resharpened, a problem arises that a tooth shape profile required for a resultant gear cannot be reproduced.

[Disclosure of the Invention]

[Problems the Invention Is Intended to Solve]

[0004] An object of the present invention is to provide a grinding wheel for relief machining for a pinion-type cutter that can prevent generating tooth shape errors in an obtained gear by using the resharpened pinion type cutter.

[Means Used to Solve the Above-Mentioned Problems]

[0005] The tooth shape of the pinion type cutter machined by the grinding wheel for relief machining designed in accordance with the present invention is a continuum of cutting edge shapes with different radii, capable of cutting a gear that has the required tooth shape profile. The external peripheral relief surface can be a conical surface or a rotational surface. Also, the lateral relief surface can be a tapered helical surface.

[0006] Tooth shape profile of the pinion type cutter is defined as follows. Namely, in a coordinate system in which a pinion type cutter having a number of teeth zp is employed to cut and obtain an internal gear with a number of teeth z, an axially perpendicular tooth shape profile contour for the internal gear is given as a series of dispersive points, the given series of axially perpendicular cross-sectional tooth shape profile points for the internal gear is interpolated by the Akima method, and the axially perpendicular cross-sectional tooth shape profile for the internal gear is defined by the following formula, where t is a variable for expressing the profile,

[0007]

$$\left.\begin{aligned} x &= P(t) = P \\ y &= Q(t) = Q \end{aligned}\right\} \qquad (1)$$

[0008] The axially perpendicular cross-sectional tooth shape profile is defined by the following formula, in which the coordinate system has been transformed to a fixed coordinate system that rotates integrally with the pinion type cutter

[0009]

$$\left.\begin{aligned} u &= P\cos\left(\frac{1-i}{i}\theta\right)+Q\sin\left(\frac{1-i}{i}\theta\right)-a\cos\left(\frac{\theta}{i}\right) \\ v &= -P\sin\left(\frac{1-i}{i}\theta\right)+Q\cos\left(\frac{1-i}{i}\theta\right)+a\sin\left(\frac{\theta}{i}\right) \end{aligned}\right\} \quad (2)$$

where

$a = r - r_p$ (center distance between the internal gear and the pinion type cutter),
r: radius of the tooth cutting pitch circle of the internal gear,
r_p: radius of the tooth cutting pitch circle of the pinion type cutter.

[0010] The envelope of a group of curves defined by the above formula is obtained by using the following formula

$$\left.\begin{aligned} &\theta = \sin^{-1}\frac{-AC \pm B\sqrt{A^2+B^2-C^2}}{A^2+B^2} \\ &\text{where } A = -\frac{a}{i}\dot{Q},\ B = \frac{a}{i}\dot{P},\ C = -\frac{1-i}{i}(P\dot{P}+Q\dot{Q}) \\ &\dot{P} = \frac{dP}{dt}, \dot{Q} = \frac{dQ}{dt} \end{aligned}\right\} \quad (4)$$

[0011] The cutting edge shape profile of the pinion type cutter is determined by projecting the envelope onto the cone of the rake surface of the pinion type cutter.

[0012] The grinding wheel for relief machining for a pinion type cutter provided with such a profile in accordance with the present invention has a cutting edge shape profile defined as follows.

[0013] Specifically, considered here are a coordinate system op-uvw of a pinion type cutter rotating around an axis w, a stationary coordinate system o_0-$\xi_0\eta_0\zeta_0$ on the relief grinding wheel side, and a coordinate system o_G-$\xi\eta\zeta$ that is fixed to the relief grinding wheel in which the axis ζ_0 and grinding wheel axis ζ form a setting angle Γ_G.

[0014] In relief grinding, the grinding wheel moves diagonally by an amount equal to stan γ in the positive direction of the axis ξ_0 while moving by an amount of an "s" in the positive direction of the axis η_0 along the outside radial relief angle γ of the pinion type cutter as the pinion type cutter rotates by an angle of θ_p. The right-side relief surface of the cutting edge peak shape thus obtained is shaped as a tapered helical surface having a right-hand helix, and the left-side relief surface is a tapered helical surface having a left-hand helix.

[0015] Assuming that the external shape of the cutting edge tip of the pinion type cutter is a portion of a cone, the generating line that connects the cutting edge tip points in the axially perpendicular cross-sections of the pinion type cutter forms a straight line along the peaks of the cone, and the generating line that connects the pitch points of the pinion type cutter also forms a straight line along the peaks of the cone. The helix angle β of the tapered helical surface at the radius of the pitch circle of the pinion type cutter is approximated by the following formula from the geometric relationship whereby the generating lines are projected on the axis-containing horizontal plane of the pinion type cutter, where r_{Pc} is the radius of the pitch circle of the pinion type cutter, v_c is the coordinate value of the cutting edge in the pitch circle, and γ_c is the relief angle γ, reduced with r_{Pc}, of the outside diameter.

[0016]

$$\tan\beta_c = \frac{v_c \tan\gamma_c}{r_{Pc}} \qquad (7 \cdot 1)$$

[0017] The helix angle β of the tapered helical surface is determined in the following range.

[0018]

$$0 \leq \beta \leq 2\beta_c \qquad (7 \cdot 2)$$

[0019] The movement amount s is determined by the following expression, where r_{Pk} is the outside radius of the pinion type cutter.

[0020]

$$s = \frac{r_{Pk}\theta_P}{\tan\beta} \qquad (7 \cdot 3)$$

[0021] The cutting edge shape profile of the pinion type cutter obtained in Eqs. (2) and (4) is given as u = p(*t*) and v = q(*t*), where t is also a variable, and the result is interpolated by the Akima method and used. When projected onto a conical surface with a rake angle ε, this cutting edge shape profile is defined by the following formula.

[0022]

$$\left.\begin{aligned} u &= p \\ v &= q \\ w &= \left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon \end{aligned}\right\} \qquad (8)$$

[0023] This profile is expressed by the following formula in the fixed coordinate system o_G- ξ η ζ on the grinding wheel side in relief motion.

[0024]

$$\left.\begin{aligned} \xi &= b - q\sin\theta_p - p\cos\theta_p - s\tan\gamma \\ \eta &= \left(q\cos\theta_p - p\sin\theta_p\right)\sin\Gamma_G \\ &\quad + \left\{\left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon - s\right\}\cos\Gamma_G \\ \zeta &= \left(q\cos\theta_p - p\sin\theta_p\right)\cos\Gamma_G \\ &\quad - \left\{\left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon - s\right\}\sin\Gamma_G \end{aligned}\right\} \qquad (9)$$

[0025] An arbitrary radius of the relief grinding wheel is designated as *p*, and the cutting edge shape profile of the grinding wheel in axial cross-section is expressed by the following formula.

[0026]

$$\left.\begin{aligned}&\rho=\sqrt{\xi^2+\eta^2}\\&\zeta=\left(q\cos\theta_P-p\sin\theta_P\right)\cos\Gamma_G\\&\quad-\left\{\left(r_{Pk}-\sqrt{p^2+q^2}\right)\tan\varepsilon-s\right\}\sin\Gamma_G\end{aligned}\right\}\qquad(10)$$

[0027] The envelope of the group of curves that is expressed by the above formula and has t and θ_P as variables is assumed to be the cutting edge shape profile of the relief grinding wheel in axial cross section

[Effects of the Invention]

[0028] A relief surface can be machined with good precision after resharpening the pinion type cutter if a grinding wheel for relief machining designed in accordance with the present invention is used.

[Best Mode for Carrying Out the Invention]

[0029] A pinion type cutter according to the present invention will be described below with reference to the drawings.

[0030] In the present invention, the cutting edge shape of a pinion type cutter is defined by a continuum of pinion type cutter cutting edge shapes with different radii that can correctly cut a cylindrical internal spur gear with a required tooth shape in order to provide the pinion type cutter with an optimum relief surface. FIG. 1 is a perspective view showing the pinion type cutter, and FIG. 2 is a schematic diagram showing the internal gear, which is the resultant gear after cutting by the pinion type cutter, and the cutting edge shape in three different axially perpendicular cross-sections of the pinion type cutter. In the pinion type cutter 1 of the present invention, each of the cutting edge shapes in the respective axially perpendicular cross-sections is one that can correctly cut an internal gear 2 with the required tooth shape, and such cutting edge profiles appear as relief surfaces after resharpening.

(Method of designing and manufacturing the cutting edge shape profile of a pinion type cutter)

[0031] Described below is a method for designing and manufacturing the cutting edge shape profile of a pinion type cutter for cutting an arbitrary tooth shape. First, the tooth shape of an internal gear, which is a resultant gear after cutting by the pinion type cutter, is obtained from a rack tooth shape. Designating the profile-expressing mediating variable as *t,* the rack tooth shape profile can be given by the following formula (tertiary equation of the Akima method).

[0032]

$$\begin{aligned}X&=G(t)=G\\Y&=H(t)=H\end{aligned}\qquad(1\cdot1)$$

[0033] IfEq. (1•1) is expressed in the coordinate system O-XY fixed to a linearly moving rack, the result is the following formula, in which ϕ is the rotational angle of the gear, and r_c is the PCD radius of the internal gear.

[0034]

$$\begin{aligned}X_0&=X\\Y_0&=Y+r_c\phi\end{aligned}\qquad(1\cdot2)$$

[0035] If Eq. (1•2) is expressed in the stationary coordinate system o-x_0y_0 of an internal gear, the result is the following formula.

[0036]

$$x_0 = X_0 + r_c$$
$$y_0 = Y_0 \qquad (1 \cdot 3)$$

[0037] If Eq. (1•1) is expressed in a coordinate system o-xy that is fixed to a rotating internal gear, the result is the following formula.

[0038]

$$x = x_0 \cos\phi + y_0 \sin\phi$$
$$y = -x_0 \sin\phi + y_0 \cos\phi \qquad (1 \cdot 4)$$

[0039] IfEqs. (1•1), (1•2), and (1•3) are substituted into (1•4), the result is the following formula.

[0040]

$$x = (G + r_c)\cos\phi + (H + r_c\phi)\sin\phi$$
$$y = -(G + r_c)\sin\phi + (H + r_c\phi)\cos\phi \qquad (1 \cdot 4-1)$$

[0041] Eq. (1•4-1) expresses a group of curves related to *t* and ϕ, so the envelope of this group is the tooth shape profile of the intended internal gear. The condition formula of the envelope is the following Jacobian matrix.

[0042]

$$F_G(t,\phi) = \begin{vmatrix} \dfrac{\partial x}{\partial t} & \dfrac{\partial y}{\partial t} \\ \dfrac{\partial x}{\partial \phi} & \dfrac{\partial y}{\partial \phi} \end{vmatrix} = \frac{\partial x}{\partial t}\frac{\partial y}{\partial \phi} - \frac{\partial x}{\partial \phi}\frac{\partial y}{\partial t} = 0 \qquad (1 \cdot 5)$$

[0043] Calculating the Jacobian matrix for Eq. (1•4-1) gives the following formulae.

[0044]

$$\frac{\partial x}{\partial t} = \dot{G}\cos\phi + \dot{H}\sin\phi$$
$$\frac{\partial y}{\partial t} = -\dot{G}\sin\phi + \dot{H}\cos\phi$$
$$\frac{\partial x}{\partial \phi} = -(G + r_c)\sin\phi + r_c\sin\phi + (H + r_c\phi)\cos\phi \qquad (1 \cdot 5-1)$$
$$\frac{\partial y}{\partial \phi} = -(G + r_c)\cos\phi + r_c\cos\phi - (H + r_c\phi)\sin\phi$$

[0045]

$$F_G(t,\phi) = G\dot{G} + H\dot{H} + r_c\dot{H}\phi = 0 \qquad (1 \cdot 5-2)$$

[0046] Furthermore, transforming Eq. (1•5-2) gives the following formula.

[0047]

$$\dot{\phi} = -\frac{G\dot{G} + H\dot{H}}{r_c H} \qquad (1 \cdot 5-3)$$

[0048] Therefore, the computational formula for the intended tooth shape profile of a cylindrical internal spur gear is as follows.

[0049]

$$\begin{aligned} x &= (G + r_c)\cos\phi + (H + r_c\phi)\sin\phi \\ y &= -(G + r_c)\sin\phi + (H + r_c\phi)\cos\phi \\ \phi &= -\frac{G\dot{G} + H\dot{H}}{r_c \dot{H}} \\ \dot{G} &= \frac{\partial G}{\partial t} \\ \dot{H} &= \frac{\partial H}{\partial t} \end{aligned} \qquad (1 \cdot 4-2)$$

(Validity range limit of cylindrical internal spur gear)

[0050] There may be cases in which the tooth shape profile of a cylindrical internal spur gear is not valid. In such cases, a cusp is generated on the tooth shape profile. In view of the above, a method for searching out the cusp on the tooth shape profile of a cylindrical internal spur gear is considered. A cusp is a type of singular point of a function at which a slope of a tangent is undefined on the curve, so the validity limits of the tooth shape profile of a cylindrical internal spur gear can be known by identifying the undefined position. From this result, a cylindrical internal spur gear in which interference does not occur can be designed.

[0051] In view of the above, Eq. (1•4-1) that expresses the tooth shape profile of a cylindrical internal spur gear leads to a formula for determining the validity range. Letting Eq. (1•4-1) be x = x(t, ϕ) = x(t), y = y(t, ϕ) = y(t), the formula for the tangent to the gear tooth shape profile of the cylindrical internal spur gear can be written in the following manner from Eqs. (1•4-1) and (1•5-2).

[0052]

$$\frac{dy}{dx} = \frac{\frac{dy}{dt}}{\frac{dx}{dt}} = \frac{U_G}{V_G} \qquad (1 \cdot 6)$$

[0053] In the formula,

[0054]

$$\begin{aligned} U_G &= \frac{\partial y}{\partial t} + \frac{\partial y}{\partial \phi}\frac{d\phi}{dt} \\ V_G &= \frac{\partial x}{\partial t} + \frac{\partial x}{\partial \phi}\frac{d\phi}{dt} \end{aligned} \qquad (1 \cdot 7)$$

[0055] Now, the following formula is derived from the conditional formula $F_G(t,\theta) = 0$ of the envelope.

[0056]

$$\frac{d\phi}{dt} = -\frac{\dfrac{\partial F_G}{\partial t}}{\dfrac{\partial F_G}{\partial \phi}} \quad (1 \cdot 8)$$

[0057] The following formula can be obtained from Eq. (1•5-2).

[0058]

$$\begin{aligned} \frac{\partial F_G}{\partial t} &= \dot{G}^2 + \dot{H}^2 + G\ddot{G} + H\ddot{H} + r_c\ddot{H}\phi \\ \frac{\partial F_G}{\partial \phi} &= r_c\dot{H} \end{aligned} \quad (1 \cdot 9)$$

[0059] In view of the above, the position at which $U_G = 0$ and $V_G = 0$ at the same time may be read if the computational result of Eqs. (1•8) and (1•9) for each of the obtained coordinates are substituted into Eq. (1•7), and U_G and V_G are obtained and arranged in accordance with the coordinate numbers of these points. The point at which the two are zero at the same time is an undefined point, and its presence shows that there is a point in which the tooth shape profile of the cylindrical internal spur gear is invalid. In other words, Eq. (1•**7**) for deriving U_G and V_G is the formula for determining the validity limits of the tooth shape profile of the cylindrical internal spur gear.

[0060] Next, the cutting edge shape of the pinion type cutter is derived based on the internal gear tooth profile. Here, the profile contour of the internal gear tooth profile is given with a series of dispersive points. Shown in FIG. 3 is a coordinate system for a theoretical analysis to determine the cutting edge shape of a pinion type cutter. This diagram shows a coordinate system in which an internal gear with a number of teeth z is cut with a pinion type cutter that has a number of teeth zp. The coordinate system o-xy is fixed to the internal gear and rotates at an angle θ. The coordinate system o_P-u_0v_0 is a stationary coordinate system on the pinion type cutter side, and the coordinate system Op-uv is fixed to the pinion type cutter that rotates at the angle θ/*i*. The variable *i* is the gear ratio ($i = z_P/z < 1.0$). The series of tooth shape profile points in the axially perpendicular cross-section of a given internal gear is interpolated by the Akima method and is given by the following formula. In the formula, *t* is a profile-expressing variable.

[0061]

$$\left.\begin{aligned} x &= P(t) = P \\ y &= Q(t) = Q \end{aligned}\right\} \quad (1)$$

[0062] The following formula is obtained when this tooth shape profile is expressed in the coordinate system o-x_0y_0, then expressed in the coordinate system op-u_0v_0, and further expressed in the coordinate system op-uv that rotates integrally with the pinion type cutter.

[0063]

$$\left.\begin{aligned} u &= P\cos\left(\frac{1-i}{i}\theta\right) + Q\sin\left(\frac{1-i}{i}\theta\right) - a\cos\left(\frac{\theta}{i}\right) \\ v &= -P\sin\left(\frac{1-i}{i}\theta\right) + Q\cos\left(\frac{1-i}{i}\theta\right) + a\sin\left(\frac{\theta}{i}\right) \end{aligned}\right\} \quad (2)$$

[0064] Here, $a = r - r_P$ is the center distance between the internal gear and the pinion type cutter, *r* is the radius of the tooth cutting pitch circle of the internal gear, and r_P is the radius of the tooth cutting pitch circle of the pinion type cutter. Eq. (2) expresses a group of curves for which *t* and θ are variables, and the envelope of this group of curves is the required cutting edge shape profile of the pinion type cutter. A conditional formula for the envelope can be derived by computing the following Jacobian matrix for Eq. (2).

[0065]

$$F_p(t,\theta)=\begin{vmatrix}\dfrac{\partial u}{\partial t} & \dfrac{\partial v}{\partial t}\\ \dfrac{\partial u}{\partial \theta} & \dfrac{\partial v}{\partial \theta}\end{vmatrix}=\frac{\partial u}{\partial t}\frac{\partial v}{\partial \theta}-\frac{\partial u}{\partial \theta}\frac{\partial v}{\partial t}=0 \qquad (3)$$

[0066] The following formula is derived from the above equation.

[0067]

$$\left.\begin{aligned}&\theta=\sin^{-1}\frac{-AC\pm B\sqrt{A^2+B^2-C^2}}{A^2+B^2}\\ &\text{where}\quad A=-\frac{a}{i}\dot{Q},\ B=\frac{a}{i}\dot{P},\ C=-\frac{1-i}{i}(P\dot{P}+Q\dot{Q})\\ &\dot{P}=\frac{dP}{dt},\dot{Q}=\frac{dQ}{dt}\end{aligned}\right\} \quad (4)$$

(Method of preventing interference)

[0068] Similar to the description given above regarding the validity limits of the tooth shape profile of the internal gear described above, the cutting edge shape profile of a pinion type cutter calculated using the aforementioned theoretical formulae may have a cusp (singular point in which the tangent slope is undefined), and interference phenomenon may occur. In this case, the cutting edge shape profile of the pinion type cutter in not valid. In view of this, the following formulae can be derived from Eqs. (2) and (4) in order to verify the presence of a cusp.

[0069]

$$\frac{dv}{du}=\frac{\dfrac{dv}{dt}}{\dfrac{du}{dt}}=\frac{V_p}{U_p} \qquad (5)$$

,

[0070] where

$$\left.\begin{aligned}&U_p=\frac{\partial u}{\partial t}+\frac{\partial u}{\partial \theta}\frac{d\theta}{dt}\quad ,\quad V_p=\frac{\partial v}{\partial t}+\frac{\partial v}{\partial \theta}\frac{d\theta}{dt}\\ &\frac{d\theta}{dt}=\dot{\theta}=-\frac{\dot{A}\sin\theta+\dot{B}\cos\theta+\dot{C}}{A\cos\theta-B\sin\theta}\\ &\dot{A}=-\frac{a}{i}\ddot{Q},\ \dot{B}=\frac{a}{i}\ddot{P},\ \dot{C}=-\frac{1-i}{i}(P\ddot{P}+Q\ddot{Q}+\dot{P}^2+\dot{Q}^2)\end{aligned}\right\} \quad (6)$$

[0071] The slope of the tangent on the cutting edge shape profile is undefined when the denominator and numerator of Eq. (5) simultaneously satisfy the conditions $U_P = 0$ and $V_P = 0$, respectively.

(Method for designing and manufacturing a grinding wheel profile for relief machining)

[0072] Next, the method for designing the profile of a grinding wheel for the relief machining of a pinion type cutter defined in the above manner is described. The method is fundamentally the same as the method for designing the profile of a pinion type cutter.

[0073] First considered are a coordinate system O_P-uvw of a pinion type cutter rotating around an axis w, a stationary coordinate system O_0-$\xi_0\eta_0\zeta_0$ on the relief grinding wheel side, and a coordinate system O_G-$\xi\eta\zeta$ that is fixed to the relief grinding wheel in which the axis ζ_0 and grinding wheel axis (form a setting angle Γ_G, as shown in FIG. 4. In relief grinding, the grinding wheel moves diagonally by an amount equal to stan γ in the positive direction of the axis ξ_0 while moving in the form of an "s" in the positive direction of the axis η_0 along the outside radial relief angle γ of the pinion type cutter as the pinion type cutter rotates by an angle of θ_P. The right-side relief surface of the cutting edge peak shape thus obtained is shaped as a tapered helical surface having a right-hand helix, and the left-side relief surface is a tapered helical surface having a left-hand helix.

[0074] Assuming that the external shape of the cutting edge tip of the pinion type cutter is a portion of a cone, the generating line that connects the cutting edge tip points in the axially perpendicular cross-sections of the pinion type cutter forms a straight line along the peaks of the cone. In a similar manner, the generating line that connects the pitch points of the pinion type cutter also forms a straight line along the peaks of the cone. In view of the above, the helix angle β of the tapered helical surface at the radius of the pitch circle of the pinion type cutter is approximated by the following formula from the geometric relationship whereby the generating lines are projected on the axis-containing horizontal plane of the pinion type cutter, as shown in FIG. 5, where r_{Pc} is the radius of the pitch circle of the pinion type cutter, v_c is the coordinate value of the cutting edge in the pitch circle, and γ_c is the relief angle γ, reduced with r_{Pc}, of the outside diameter.

[0075]

$$\tan\beta_c = \frac{v_c \tan\gamma_c}{r_{Pc}} \qquad (7 \cdot 1)$$

[0076] The helix angle β of the tapered helical surface is determined in the following range with consideration given to the helix angle β_c thus obtained and the characteristics of the tooth shape.

[0077]

$$0 \le \beta \le 2\beta_c \qquad (7 \cdot 2)$$

[0078] The following relationship holds true when r_{Pk} is the outside radius of the pinion type cutter.

[0079]

$$s = \frac{r_{Pk}\theta_P}{\tan\beta} \qquad (7 \cdot 3)$$

[0080] The cutting edge shape profile of the pinion type cutter obtained in Eqs. (2) and (4) is given as u = p(*t*) and v = q(*t*), where t is also a variable, and the result is interpolated by the Akima method and used. When projected onto a conical surface with a rake angle ε, this cutting edge shape profile is expressed by the following formula.

[0081]

$$\left.\begin{aligned} u &= p \\ v &= q \\ w &= (r_{Pk} - \sqrt{p^2 + q^2}) \tan \varepsilon \end{aligned}\right\} \quad (8)$$

[0082] This profile is expressed by the following formula in the fixed coordinate system o_G-$\xi\ \eta\ \zeta$ on the grinding wheel side in relief motion.

[0083]

$$\left.\begin{aligned} \xi &= b - q \sin\theta_p - p\cos\theta_p - s\tan\gamma \\ \eta &= (q\cos\theta_p - p\sin\theta_p)\sin\Gamma_G \\ &\quad + \left\{\left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon - s\right\}\cos\Gamma_G \\ \zeta &= (q\cos\theta_p - p\sin\theta_p)\cos\Gamma_G \\ &\quad - \left\{\left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon - s\right\}\sin\Gamma_G \end{aligned}\right\} \quad (9)$$

[0084] Therefore, an arbitrary radius of the relief grinding wheel is designated as *p*, and the cutting edge shape profile of the grinding wheel in axial cross-section is expressed by the following formula.

[0085]

$$\left.\begin{aligned} \rho &= \sqrt{\xi^2 + \eta^2} \\ \zeta &= (q\cos\theta_p - p\sin\theta_p)\cos\Gamma_G \\ &\quad - \left\{\left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon - s\right\}\sin\Gamma_G \end{aligned}\right\} \quad (10)$$

[0086] Eq. (10) expresses a group of curves in which *t* and θ_P are variables, and the cutting edge shape profile of the relief grinding wheel in axial cross-section can be obtained as the envelope of this group of curves. The condition formula of the envelope is obtained by calculating the following Jacobian matrix with respect to Eq. (10).

[0087]

$$F_G(t, \theta_p) = \begin{vmatrix} \dfrac{\partial\rho}{\partial t} & \dfrac{\partial\zeta}{\partial t} \\ \dfrac{\partial\rho}{\partial\theta_p} & \dfrac{\partial\zeta}{\partial\theta_p} \end{vmatrix} = \frac{\partial\rho}{\partial t}\frac{\partial\zeta}{\partial\theta_p} - \frac{\partial\rho}{\partial\theta_p}\frac{\partial\zeta}{\partial t} = 0 \quad (11)$$

(Example)

[0088] A design and trial manufacture experiment was conducted in accordance with the specifications for the internal gear, pinion type cutter, and relief grinding wheel shown in Table.1. In this case, the radii of the tooth cutting pitch circles of the internal gear and pinion type cutter were set to values that were less than r = 63.842mm and r_P = 42.562mm, or to values that were greater than r = 65.039mm and r_P = 43.360mm, and when the cutting edge shape profile of the pinion type cutter was computed with Eqs. (2) and (4), folding interference occurred due to a cusp among the profile points *j* = 55 to 61, and it was impossible to design a cutting edge shape for the pinion type cutter. Occurrence of this interference phenomenon was also confirmed by Eqs. (5) and (6). In view of this, a trial manufacture was attempted so that the values of the radii of the tooth cutting pitch circles of the internal gear and the pinion type cutter were adopted as the intermediate values of the upper and lower limits described above, the radii were set to r = 64.458mm and r_P = 42.972mm, and the cutting edge shape profile for the pinion type cutter was established.

[0089] Next, this cutting edge shape profile of the pinion type cutter was adopted and interpolated using the Akima method to determine the profile of the relief grinding wheel by using Eqs. (9), (10), and (11). Some of the results are shown in FIG. 5. A relief cutting experiment was conducted for the pinion type cutter, a grinding wheel with this profile was manufactured on a trial basis, and it was confirmed that a high-precision pinion type cutter could be obtained.

[0090]

[TABLE 1]

Items		Data
Diametral pitch	*DP* l/inch	32,000
Internal gear:		
Number of profile points	j	1~140
Number of teeth	z	162
Pitch circle diameter	d_o mm	128,916
Addendum circle diameter	d_k mm	127,278
Dedendum circle diameter	d_b mm	129.852
Pinion cutter:		
Number of teeth	z_p	108
Pitch circle diameter	d_{pc} mm	83.944
Major diameter	d_{pk} mm	86.880
Radial rake angle	s deg	5
Radial relief angle	y deg	5
Relief grinding wheel:		
Major diameter	2_{px} mm	150
Setting angle	Γ_G deg	0.14583

[0091] The pinion type cutter of the present invention, in addition to being applicable to internal gears, may also be applied to the cutting of cylindrical gears, internal and external bevel gears, face gears, circular and non-circular gears of worm gears, and other gears.

[0092] The grinding wheel can be fed linearly, or the shafts of the grinding wheel and pinion type cutter can be fed in threadable fashion, when a relief surface is formed on the pinion type cutter.

[Brief Description of the Drawings]

[0093]

[Figure 1]

[0094] A perspective view showing a pinion type cutter

[Figure 2]

[0095] A schematic diagram for describing the cutting edge shape profile contour of the pinion type cutter

[Figure 3]

[0096] A diagram showing a coordinate system for a theoretical analysis to determine the cutting edge shape profile contour of the pinion type cutter

[Figure 4]

[0097] A diagram showing a coordinate system for determining the cutting edge shape profile contour of a relief grinding wheel

[Figure 5]

[0098] A diagram showing a conical surface and helix angle of a tapered helical surface in the pitch circle radius of a pinion type cutter

[Figure 6]

[0099] A graph showing a computational example of the cutting edge shape profile of the relief grinding wheel

[Symbols]

[0100]

1: Pinion type cutter
2: Internal gear

Claims

1. A grinding wheel for relief machining used for resharpening a pinion-type cutter in which the cutting edge shape profile is defined as shown in (A) so that a gear that has the required tooth shape profile can be cut, wherein said grinding wheel for relief machining is **characterized in** having an axial cross-section cutting edge shape profile defined as shown in (B).

(A) In a coordinate system in which a pinion type cutter having a number of teeth zp is employed to cut and obtain an internal gear with a number of teeth z, an axially perpendicular tooth shape profile contour for the internal gear is given as a series of dispersive points, the given series of axially perpendicular cross-sectional tooth shape profile points for the internal gear is interpolated by the Akima method, and the axially perpendicular cross-sectional tooth shape profile for the internal gear is defined by the following formula, where t is a variable representing the profile

$$\left.\begin{array}{l} x = P(t) = P \\ y = Q(t) = Q \end{array}\right\} ;$$

the axially perpendicular cross-sectional tooth shape profile is defined by the following formula, in which the coordinate system has been transformed to a fixed coordinate system that rotates integrally with the pinion type cutter

$$
\left.\begin{aligned}
u &= P\cos\left(\frac{1-i}{i}\theta\right)+Q\sin\left(\frac{1-i}{i}\theta\right)-a\cos\left(\frac{\theta}{i}\right)\\
v &= -P\sin\left(\frac{1-i}{i}\theta\right)+Q\cos\left(\frac{1-i}{i}\theta\right)+a\sin\left(\frac{\theta}{i}\right)
\end{aligned}\right\} \quad (\mathrm{I})
$$

where $\alpha = r - r_P$ (center distance between the internal gear and the pinion type cutter),

r: radius of the tooth cutting pitch circle of the internal gear,
r_p: radius of the tooth cutting pitch circle of the pinion type cutter;
the envelope of a group of curves defined by the above formula is obtained by using the following formula.

$$
\left.\begin{aligned}
&\theta = \sin^{-1}\frac{-AC \pm B\sqrt{A^2+B^2-C^2}}{A^2+B^2}\\
&\text{where} \quad A = -\frac{a}{i}\dot{Q},\ B = \frac{a}{i}\dot{P},\ C = -\frac{1-i}{i}(P\dot{P}+Q\dot{Q})\\
&\dot{P} = \frac{dP}{dt}, \dot{Q} = \frac{dQ}{dt}
\end{aligned}\right\} \quad (\mathrm{II})
$$

;

and
the cutting edge shape profile of the pinion type cutter is determined by projecting the envelope onto the cone of the rake surface of the pinion type cutter.

(B) Considered here are a coordinate system op-uvw of a pinion type cutter rotating around an axis w, a stationary coordinate system o_0-$\xi_0\eta_0\zeta_0$ on the relief grinding wheel side, and a coordinate system o_G-$\xi\eta\zeta$ that is fixed to the relief grinding wheel in which the axis ζ_0 and grinding wheel axis ζ form a setting angle Γ_G;
in relief grinding, the grinding wheel moves diagonally by an amount equal to stan γ in the positive direction of the axis ξ_0 while moving by an amount of an "s" in the positive direction of the axis η_0 along the outside radial relief angle γ of the pinion type cutter as the pinion type cutter rotates by an angle of θ_P, wherein the right-side relief surface of the cutting edge peak shape thus obtained is shaped as a tapered helical surface having a right-hand helix, and the left-side relief surface is a tapered helical surface having a left-hand helix; and
assuming that the external shape of the cutting edge tip of the pinion type cutter is a portion of a cone, the generating line that connects the cutting edge tip points in the axial perpendicular cross-sections of said pinion type cutter forms a straight line along the peaks of the cone, the generating line that connects the pitch points of said pinion type cutter also forms a straight line along the peaks of the cone, and the helix angle β of the tapered helical surface at the radius of the pitch circle of said pinion type cutter is approximated by the following formula from the geometric relationship whereby the generating lines are projected on the axis-containing horizontal plane of said pinion type cutter, where r_{Pc} is the radius of the pitch circle of the pinion type cutter, V_c is the coordinate value of the cutting edge in the pitch circle, and γ_c is the relief angle γ, reduced with r_{Pc}, of the outside diameter.

$$\tan\beta_c = \frac{v_c \tan\gamma_c}{r_{Pc}}$$

The helix angle β of the tapered helical surface is determined in the following range.

$$0 \le \beta \le 2\beta_c$$

The movement amount s is determined by the following expression, where r_{Pk} is the outside radius of the pinion type cutter.

$$s = \frac{r_{Pk}\theta_P}{\tan\beta}$$

The cutting edge shape profile of the pinion type cutter obtained in Eqs. (I) and (II) is given as u = p(*t*) and v = q(*t*), where t is also a variable, and the result is interpolated by the Akima method and used. When projected onto a conical surface with a rake angle ε, this cutting edge shape profile is defined by the following formula.

$$\left.\begin{aligned} u &= p \\ v &= q \\ w &= \left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon \end{aligned}\right\}$$

This profile is expressed by the following formula in the fixed coordinate system o_G- ξ η ξ on the grinding wheel side in relief motion.

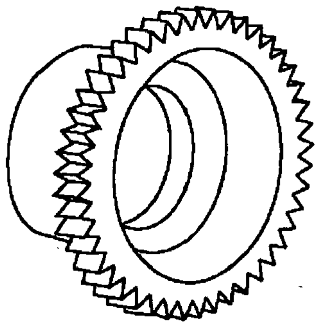
$$\left.\begin{aligned}
&\xi = b - q\sin\theta_P - p\cos\theta_P - s\tan\gamma\\
&\eta = \left(q\cos\theta_P - p\sin\theta_P\right)\sin\Gamma_G\\
&\quad + \left\{\left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon - s\right\}\cos\Gamma_G\\
&\zeta = \left(q\cos\theta_P - p\sin\theta_P\right)\cos\Gamma_G\\
&\quad - \left\{\left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon - s\right\}\sin\Gamma_G
\end{aligned}\right\}$$

An arbitrary radius of the relief grinding wheel is designated as *p*, and the cutting edge shape profile of said grinding wheel in axial cross section is expressed by the following formula.

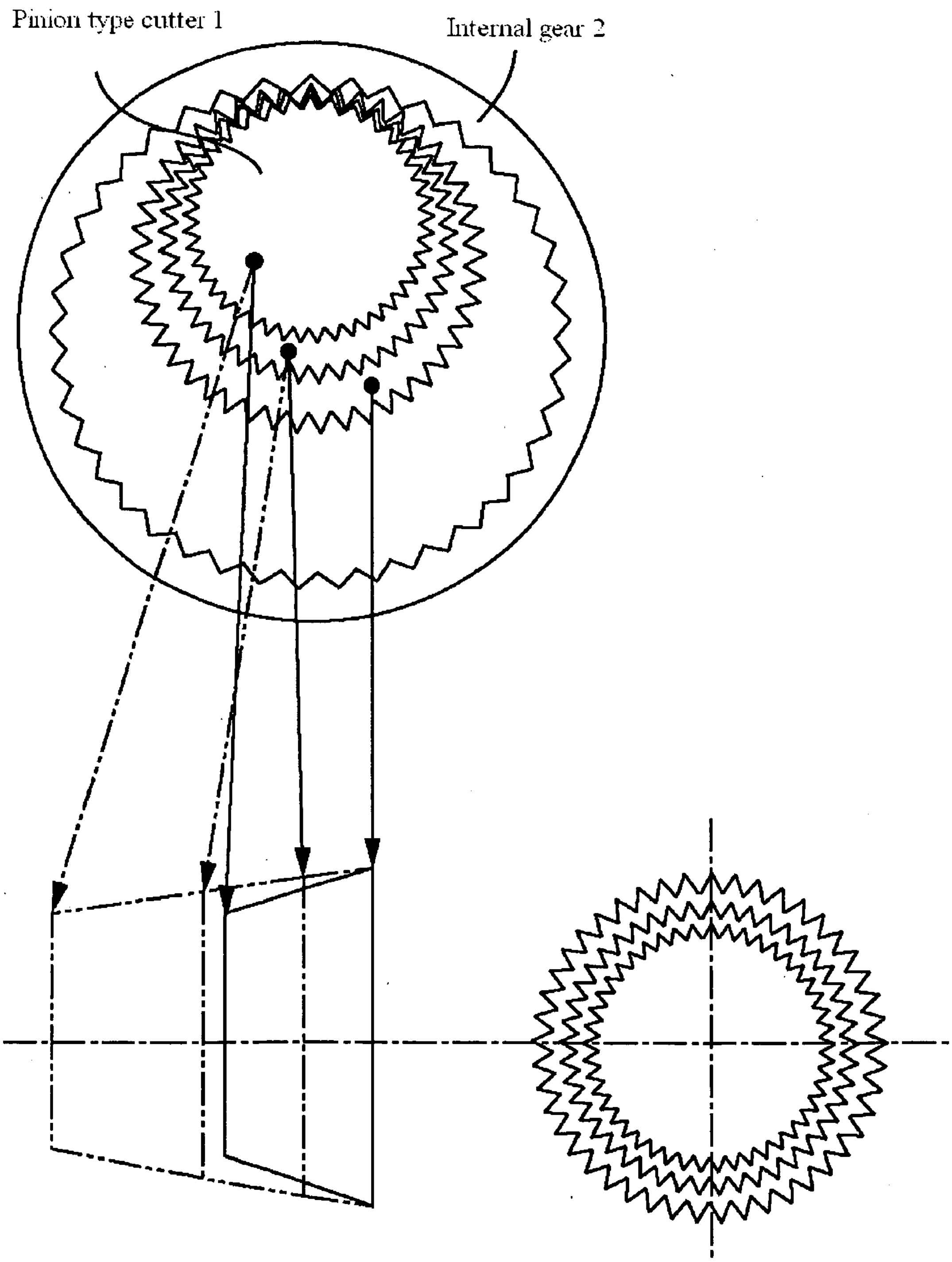
$$\left.\begin{aligned}
&\rho = \sqrt{\xi^2 + \eta^2}\\
&\zeta = \left(q\cos\theta_P - p\sin\theta_P\right)\cos\Gamma_G\\
&\quad - \left\{\left(r_{Pk} - \sqrt{p^2 + q^2}\right)\tan\varepsilon - s\right\}\sin\Gamma_G
\end{aligned}\right\}$$

The envelope of the group of curves that are expressed by the above formula and has *t* and θ_P as variables is assumed to be the cutting edge shape profile of the relief grinding wheel in axial cross section.

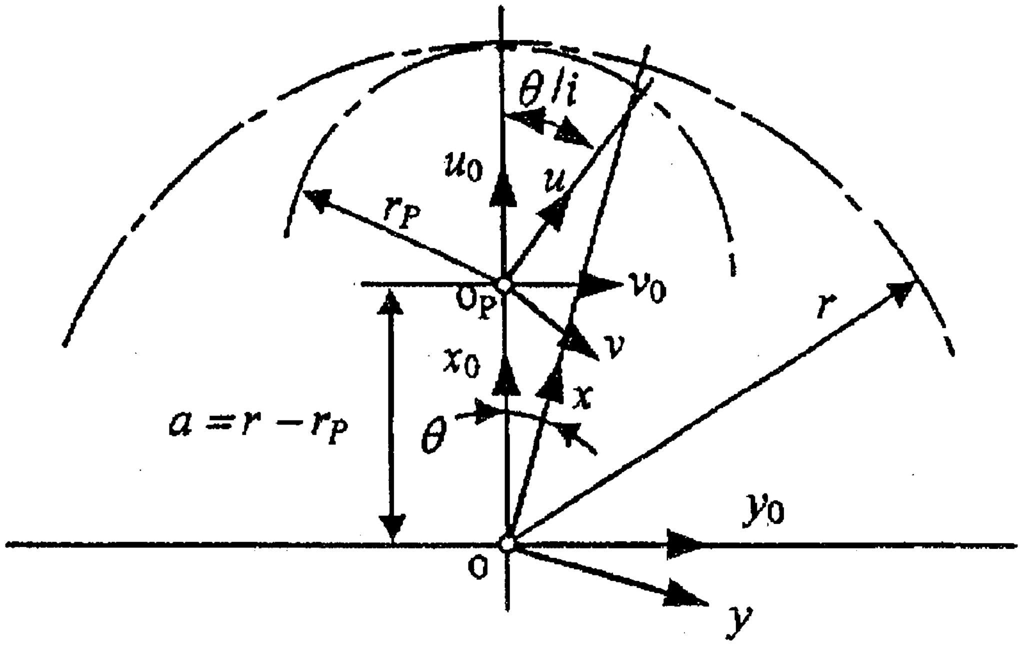
[FIG. 1]



[FIG. 2]

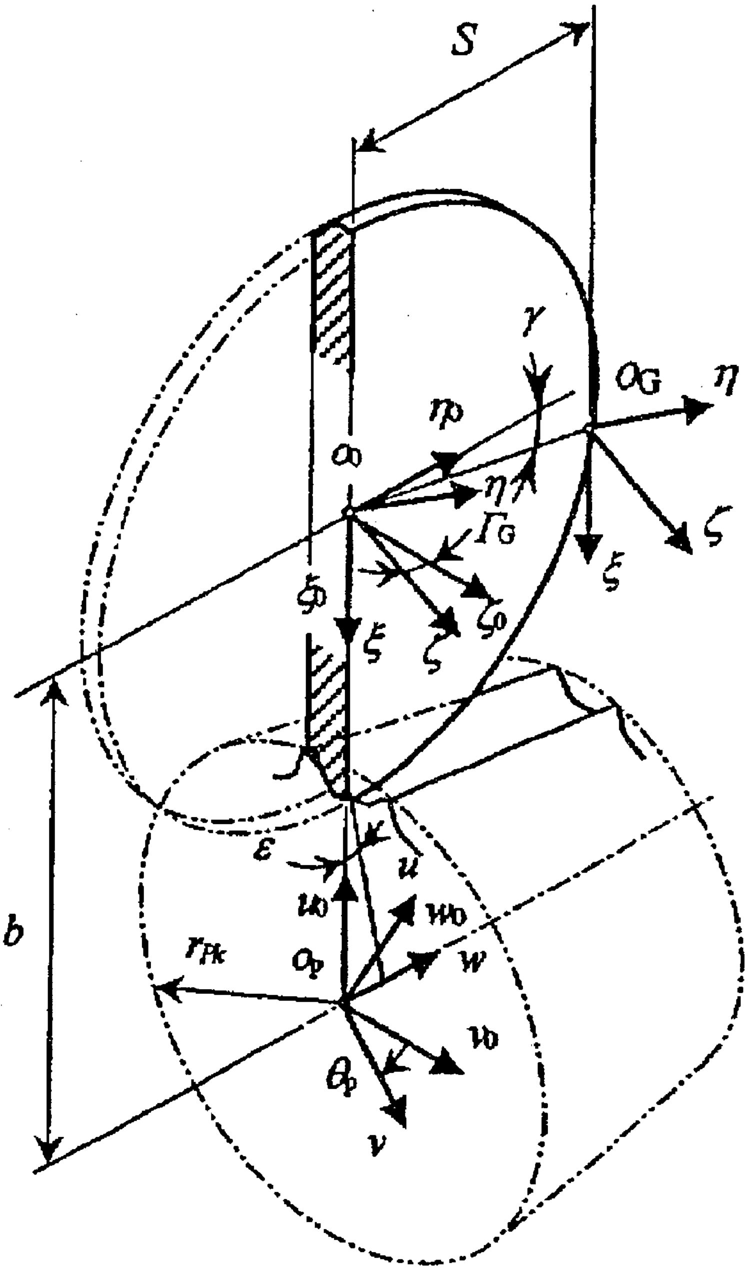


[FIG. 3]



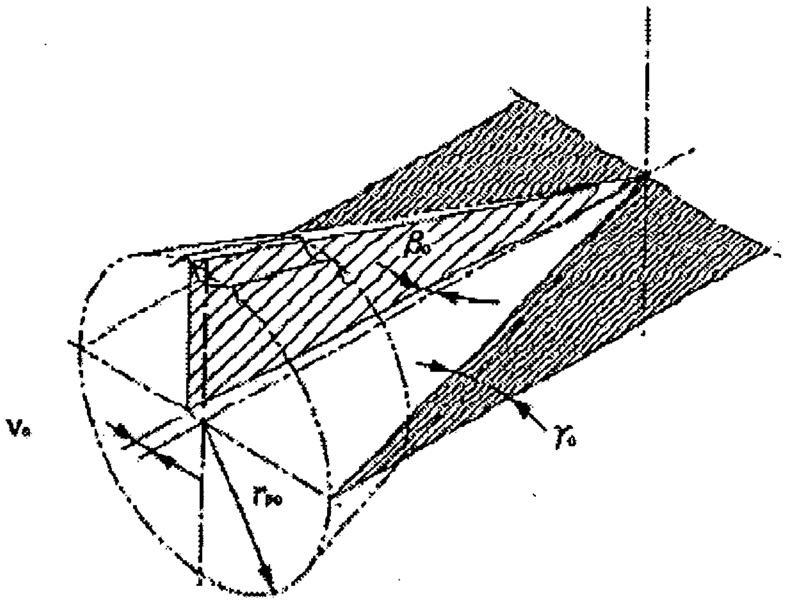
(Relationship of the coordinate systems for pinion type cutter and internal gear)

[FIG. 4]

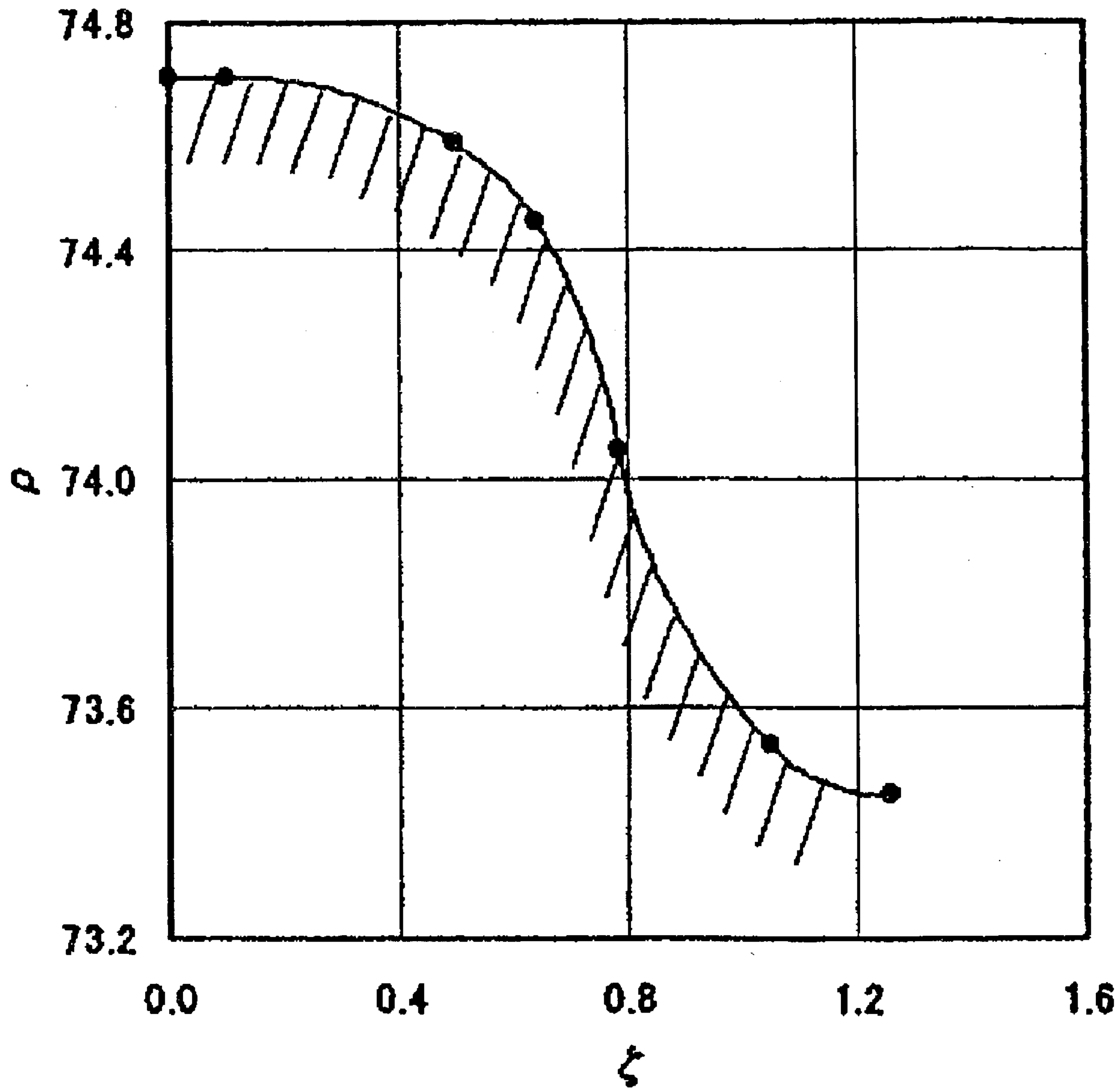


(Relationship of the coordinate systems for pinion type cutter and relief grinding wheel)

[FIG. 5]



[FIG. 6]



(Contour of the relief grinding wheel)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 06 00 2184

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	20 March 2006	Eder, R

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