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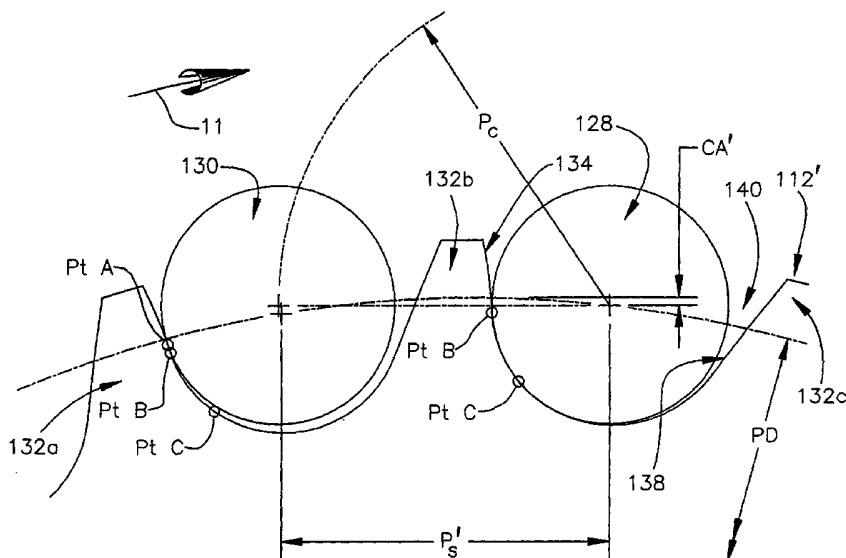
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(54) Title: **ROLLER CHAIN SPROCKET WITH ADDED CHORDAL PITCH REDUCTION**



(57) **Abstract:** A sprocket (112) is defined to include added chordal pitch reduction when in a new or "as-manufactured" condition. The sprocket chordal pitch P_s is purposefully reduced as compared to the as-built chain pitch P_c (or a theoretical maximum sprocket chordal pitch) a select amount referred to herein as "added chordal pitch reduction." This added chordal pitch reduction is in addition to the inherent chordal pitch reduction that exists owing to manufacturing tolerances. A sprocket (112) incorporating added chordal pitch reduction is highly desired in that it facilitates extension of the meshing time interval for an associated chain roller. The sprocket (112) is formed to have a chordal pitch that is reduced relative to a maximum theoretical sprocket chordal pitch (or the chain link pitch) by an amount between about 0.2 % and about 1 % of the maximum theoretical sprocket chordal pitch.



WO 03/048604 A2

ROLLER CHAIN SPROCKET WITH ADDED CHORDAL PITCH REDUCTION

Background of the Invention

5 The present invention relates to the automotive timing chain art. It finds particular application in conjunction with a unidirectional roller chain sprocket for use in automotive camshaft drive applications and will be described with particular reference thereto. However, the
10 present invention may also find application in conjunction with other types of chain drive systems and applications where reducing the noise levels associated with chain drives is desired.

 Roller chain sprockets for use in camshaft drives
15 of automotive engines are typically manufactured according to ISO (International Organization for Standardization) standard 606:1994(E). The ISO-606 standard specifies requirements for short-pitch precision roller chains and associated chain wheels or sprockets.

20 Figure 1 illustrates a symmetrical tooth space form for an ISO-606 compliant sprocket. The tooth space has a continuous fillet or root radius R_i extending from one tooth flank (i.e., side) to the adjacent tooth flank as defined by the roller seating angle α . The flank radius R_f
25 is tangent to the roller seating radius R_i at the tangency point TP. A chain with a link pitch P has rollers of diameter D_1 in contact with the tooth spaces. The ISO sprocket has a chordal pitch also of length P , a root diameter D_2 , and Z number of teeth. The pitch circle
30 diameter PD , tip or outside diameter OD , and tooth angle A (equal to $360^\circ/Z$) further define the ISO-606 compliant sprocket. The maximum and minimum roller seating angle α is defined as:

$$\alpha_{\max} = 140^{\circ} - (90^{\circ}/Z) \quad \text{and} \quad \alpha_{\min} = 120^{\circ} - (90^{\circ}/Z)$$

With reference to Figure 2, an exemplary ISO-606 compliant roller chain drive system 10 rotates in a clockwise direction as shown by arrow 11. The chain drive system 10 includes a drive sprocket 12, a driven sprocket 14 and a roller chain 16 having a number of rollers 18. The sprockets 12, 14, and chain 16 each generally comply with the ISO-606 standard.

The roller chain 16 engages and wraps about sprockets 12 and 14 and has two spans extending between the sprockets, slack strand 20 and taut strand 22. The roller chain 16 is under tension as shown by arrows 24. The taut strand 22 may be guided from the driven sprocket 14 to the drive sprocket 12 with a chain guide 26. A first roller 28 is shown at the onset of meshing at a 12 o'clock position on the drive sprocket 12. A second roller 30 is adjacent to the first roller 28 and is the next roller to mesh with the drive sprocket 12.

Chain drive systems have several components of undesirable noise. A major source of roller chain drive noise is the sound generated as a roller leaves the span and collides with the sprocket during meshing. The resultant impact noise is repeated with a frequency generally equal to that of the frequency of the chain meshing with the sprocket. The loudness of the impact noise is a function of the impact energy (E_A) that must be absorbed during the meshing process. The impact energy absorbed is related to engine speed, chain mass, and the impact velocity between the chain and the sprocket at the onset of meshing. The impact velocity is affected by the

chain-sprocket engagement geometry, of which an engaging flank pressure angle γ (Fig. 3) is a factor, where:

$$E_A = \frac{wP}{2000} V_A^2 ;$$

$$V_A = \frac{\pi n P}{30000} \sin \left(\frac{360}{Z} + \gamma \right) ;$$

$$\gamma = \frac{180 - A - \alpha}{2} ; \text{ and}$$

	E_A	=	Impact Energy [N·m]
	V_A	=	Roller Impact Velocity [m/s]
5	γ	=	Engaging Flank Pressure Angle
	n	=	Engine Speed [RPM]
	w	=	Chain Mass [Kg/m]
	Z	=	Number of Sprocket Teeth
	A	=	Tooth Angle ($360^\circ/Z$)
10	α	=	Roller Seating Angle
	P	=	Chain Pitch (Chordal Pitch)

The impact energy (E_A) equation presumes the chain drive kinematics will conform generally to a quasi-static analytical model and that the roller-sprocket driving contact will occur at a tangent point TP (Fig. 3) of the flank and root radii as the sprocket collects a roller from the span.

As shown in Figure 3, the pressure angle γ is defined as the angle between a line A extending from the center of the engaging roller 28, when it is contacting the engaging tooth flank at the tangency point TP, through the center of the flank radius R_f , and a line B connecting the centers of the fully seated roller 28, when it is seated on the root diameter D_2 , and the center of the next meshing roller 30, as if it were also seated on the root diameter D_2 in its engaging tooth space. The roller seating angles

α and pressure angles γ listed in Figure 27 are calculated from the equations defined above. It should be appreciated that γ is a minimum when α is a maximum. The exemplary 18-tooth, ISO-606 compliant, sprocket 12 of Figure 3 will have
5 a pressure angle γ in the range of 12.5° to 22.5° as listed in the table of Figure 27.

Figure 3 also shows the engagement path (phantom rollers) and the driving contact position of roller 28 (solid) as the drive sprocket 12 rotates in the direction
10 of arrow 11. Figure 3 depicts the theoretical case with chain roller 27 seated on root diameter D_2 of a maximum material sprocket with both chain pitch and sprocket chordal pitch equal to theoretical pitch P . For this theoretical case, the noise occurring at the onset of
15 roller engagement has a radial component F_{IR} as a result of roller 28 colliding with the root surface R_i and a tangential component F_{IT} generated as the same roller 28 collides with the engaging tooth flank at point TP as the roller moves into driving contact. It is believed that the
20 radial impact occurs first, with the tangential impact following nearly simultaneously. Roller impact velocity V_A is shown to act through, and is substantially normal to, engaging flank tangent point TP with roller 28 in driving contact at point TP.

25 The impact energy (E_A) equation accounts only for a tangential roller impact during meshing. The actual roller engagement, presumed to have a tangential and radial impact (occurring in any order), would therefore seem to be at variance with the impact energy (E_A) equation. The
30 application of this quasi-static model, which is beneficially used as a directional tool, permits an analysis of those features that may be modified to reduce

the impact energy that must be absorbed during the tangential roller-sprocket collision at the onset of meshing. The radial collision during meshing, and its effect on noise levels, can be evaluated apart from the
5 impact energy (E_A) equation.

Under actual conditions as a result of feature dimensional tolerances, there will normally be a pitch mismatch between the chain and sprocket, with increased mismatch as the components wear in use. This pitch
10 mismatch serves to move the point of meshing impact, with the radial collision still occurring at the root surface R_i but not necessarily at D_2 . The tangential collision will normally be in the proximity of point TP, but this contact could take place high up on the engaging side of root
15 radius R_i or even radially outward from point TP on the engaging flank radius R_f as a function of the actual chain-sprocket pitch mismatch.

Reducing the engaging flank pressure angle γ reduces the meshing noise levels associated with roller
20 chain drives, as predicted by the impact energy (E_A) equation set forth above. It is feasible but not recommended to reduce the pressure angle γ while maintaining a symmetrical tooth profile, which could be accomplished by simply increasing the roller seating angle
25 α , effectively decreasing the pressure angle for both flanks. This profile as described requires that a worn chain would, as the roller travels around a sprocket wrap (discussed below), interface with a much steeper incline and the rollers would necessarily ride higher up on the
30 coast flank prior to leaving the wrap.

Another source of chain drive noise is the broadband mechanical noise generated in part by shaft torsional vibrations and slight dimensional inaccuracies

between the chain and the sprockets. Contributing to a greater extent to the broadband mechanical noise level is the intermittent or vibrating contact that occurs between the unloaded rollers and the sprocket teeth as the rollers travel around the sprocket wrap. In particular, ordinary chain drive system wear comprises sprocket tooth face wear and chain wear. The chain wear is caused by bearing wear in the chain joints and can be characterized as pitch elongation. It is believed that a worn chain meshing with an ISO standard sprocket will have only one roller in driving contact and loaded at a maximum loading condition.

With reference again to Figure 2, driving contact at maximum loading occurs as a roller enters a drive sprocket wrap 32 at engagement. Engaging roller 28 is shown in driving contact and loaded at a maximum loading condition. The loading on roller 28 is primarily meshing impact loading and the chain tension loading. The next several rollers in the wrap 32 forward of roller 28 share in the chain tension loading, but at a progressively decreasing rate. The loading of roller 28 (and to a lesser extent for the next several rollers in the wrap) serves to maintain the roller in solid or hard contact with the sprocket root surface 34.

A roller 36 is the last roller in the drive sprocket wrap 32 prior to entering the slack strand 20. Roller 36 is also in hard contact with drive sprocket 12, but at some point higher up (e.g., radially outwardly) on the root surface 34. With the exception of rollers 28 and 36, and the several rollers forward of roller 28 that share the chain tension loading, the remaining rollers in the drive sprocket wrap 32 are not in hard contact with the sprocket root surface 34, and are therefore free to vibrate

against the sprocket root surfaces as they travel around the wrap, thereby contributing to the generation of unwanted broadband mechanical noise.

A roller 38 is the last roller in a sprocket wrap
5 40 of the driven sprocket 14 before entering the taut strand 22. The roller 38 is in driving contact with the sprocket 14. As with the roller 36 in the drive sprocket wrap 32, a roller 42 in the sprocket wrap 40 is in hard contact with a root radius 44 of driven sprocket 14, but
10 generally not at the root diameter.

It is known that providing pitch line clearance (PLC) between sprocket teeth promotes hard contact between the chain rollers and sprocket in the sprocket wrap, even as the roller chain wears. The amount of pitch line
15 clearance added to the tooth space defines a length of a short arc that is centered in the tooth space and forms a segment of the root diameter D_2 . The root fillet radius R_i is tangent to the flank radius R_f and the root diameter arc segment. The tooth profile is still symmetrical, but R_i is
20 no longer a continuous fillet radius from one flank radius to the adjacent flank radius. This has the effect of reducing the broadband mechanical noise component of a chain drive system. However, adding pitch line clearance between sprocket teeth does not reduce chain drive noise
25 caused by the roller-sprocket collision at impact.

Chordal action, or chordal rise and fall, is another important factor affecting the operating smoothness and noise levels of a chain drive, particularly at high speeds. Chordal action occurs as the chain enters the
30 sprocket from the free span during meshing and it can cause a movement of the free chain in a direction perpendicular to the chain travel but in the same plane as the chain and

sprockets. This chain motion resulting from chordal action will contribute an objectionable noise level component to the meshing noise levels, so it is therefore beneficial to reduce chordal action inherent in a roller chain drive.

5 Figures 4a and 4b illustrate the chordal action for an 18-tooth, ISO-606 compliant, sprocket having a chordal pitch of 9.525 mm. Chordal rise 45 may conventionally be defined as the displacement of the chain centerline as the sprocket rotates through an angle $A/2$,
10 where:

$$\text{Chordal rise} = r_p - r_c = r_p [1 - \cos(180^\circ/Z)]$$

where r_c is the chordal radius, or the distance from the sprocket center to a pitch chord of length P ; r_p is the actual theoretical pitch radius; and Z is the number of
15 sprocket teeth.

It is known that a short pitch chain provides reduced chordal action compared to a longer pitch chain having a similar pitch radius. Figures 4a and 4b show only the drive sprocket and assume a driven sprocket (not shown)
20 also having 18-teeth and in phase with the drive sprocket shown. In other words, at $T = 0$ (Fig. 4a), both sprockets will have a tooth center at the 12 o'clock position. Accordingly, this chain drive arrangement under quasi-static conditions will have a top or taut strand that will
25 move up and down in a uniform manner a distance equal to that of the chordal rise. At $T = 0$, a roller 46 is at the onset of meshing, with chordal pitch P horizontal and in line with taut strand 22. At $T = 0 + (A/2)$, (Fig. 4b), roller 46 has moved to the 12 o'clock position.

30 For many chain drives, the drive and driven sprockets will be of different sizes and will not

necessarily be in phase. The chain guide 26 (Fig. 2) has the primary purpose to control chain strand vibration in the taut span. The geometry of the guide-chain interface also defines the length of free span chain over which chordal rise and fall is allowed to operate. Figure 5 is an enlarged view of Figure 2 showing the first roller 28 at the onset of engagement and the second roller 30 as the next roller about to mesh with sprocket 12. In this example, the chain guide 26 controls and guides the engaging portion of the taut strand 22 except for five (5) unsupported or "free" link pitches extending between the chain guide 26 and the engaging roller 28. This length of unsupported link pitches for the engaging portion of taut strand 22 in this example is horizontal when roller 28 is at the 12 o'clock position.

With reference to Figures 6 and 7, the drive sprocket 12 is rotated in a clockwise direction to advance roller 28 to a new angular position $(A/2) + \omega$, where ω is the added rotation angle as determined by a quasi-static engagement geometry with roller 28 being fully seated and roller 30 is at the instant of sprocket engagement. As shown in Figure 6, roller 28 is considered to be seated and in hard contact with the root surface at D_2 at the onset of meshing of roller 30, and a straight line is assumed for the chain span from roller 28 to a chain pin center 48, about which the unsupported or "free" span from pin 48 to engaging roller 30 is considered to rotate.

As a result of the chordal action, the engaging free span is no longer horizontal to satisfy the roller engaging geometry. This is in contrast to the chain drive as described in Figure 4a in which chordal action causes the taut strand to move uniformly, but in a horizontal path

because the drive and driven sprockets have the same number of teeth and the sprocket teeth are in phase. It should be appreciated that the straight line assumption is valid only in a quasi-static model. The amount of movement or deviation from the straight line assumption will be a function of the drive dynamics, the chain control devices, and the chain drive and sprocket geometry. The location and chain-interfacing contour of the chain guide 26 will determine the number of free span pitches for which chain motion will take place as a result of the chordal rise and fall during the roller meshing process.

As best seen in Figure 7, assuming that rollers 28 and 30 are in hard contact with the sprocket root surfaces at D_2 , the chordal rise is the perpendicular displacement of the center of roller 30 (located on the pitch diameter PD) from the taut span 22 path as it moves from its initial meshing position shown through the 12 o'clock position.

Accordingly, it is desirable to develop a new and improved roller chain drive system which meets the above-stated needs and overcomes the foregoing disadvantages and others while providing better and more advantageous results.

Summary of the Invention

In accordance with a first aspect of the present invention, a unidirectional roller chain drive system includes an as-manufactured drive sprocket including a plurality of teeth, an as-manufactured driven sprocket including a plurality of teeth, and an as-built roller chain engaged with said drive sprocket and said driven sprocket. The roller chain defines a chain link pitch (P_c). The drive sprocket and/or the driven sprocket define(s) a sprocket chordal pitch (P_s') that is less than the chain

link pitch (P_c) by more than about 0.2% of the chain link pitch (P_c).

In accordance with a more limited aspect of the present invention, the drive sprocket and/or the driven sprocket define(s) a sprocket chordal pitch (P_s') that is
5 less than the chain link pitch (P_c) by more than about 0.2% of the chain link pitch (P_c) but no more than about 1% of the chain link pitch (P_c).

In accordance with another aspect of the present invention, an as-manufactured sprocket is provided that is
10 adapted for use in conjunction with an associated as-built roller chain including a plurality of rollers and defining a chain pitch P_c . The sprocket includes a plurality of sprocket teeth projecting outwardly therefrom and defining
15 a plurality of tooth spaces located respectively between successive teeth. Each of the tooth spaces is adapted to receive a roller of the associated roller chain. The sprocket defines a sprocket chordal pitch (P_s') that is reduced relative to the chain pitch P_c of the associated
20 roller chain by more than about 0.2% of the chain pitch P_c .

In accordance with a more limited aspect of the present invention, the sprocket chordal pitch (P_s') is reduced relative to the chain link pitch (P_c) by about 0.2% to about 1% of the chain link pitch.

In accordance with another aspect of the present invention, a method of extending the meshing interval for an as-built roller chain and an as-manufactured sprocket is provided. The method includes defining the sprocket to
25 have a sprocket chordal pitch (P_s') that is reduced relative to a chain link pitch (P_c) of the roller chain by more than about 0.2% of the chain link pitch (P_c).
30

In accordance with a more limited aspect of the present invention, the sprocket chordal pitch (P_s') is

reduced relative to the chain link pitch (P_c), by more than about 0.2% of the chain link pitch (P_c), and less than or equal about 1% of the chain link pitch (P_c).

5 A main advantage of the present invention resides in the provision of a sprocket exhibiting improved noise characteristics when in use with an associated roller chain of a roller chain drive system.

Another advantage of the present invention is found in the provision of a sprocket wherein the meshing
10 interval for the rollers of an associated roller chain is lengthened to reduce noise during use.

A still further advantage of the present invention resides in the provision of a sprocket and a roller chain drive system incorporating the sprocket
15 wherein added chordal pitch reduction lengthens the meshing time interval and, thus, serves to provide a more gradual load transfer from a seated roller to the engaging roller at the onset of meshing, thereby spreading the meshing impact over a longer time period which helps to minimize
20 the noise associated with roller impact.

Further advantages of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description of the preferred embodiments.

25 **Brief Description of the Drawings**

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating a preferred embodiment and are not to be
30 construed as limiting the invention.

Figure 1 illustrates a symmetrical tooth space form for a ISO-606 compliant roller chain sprocket;

Figure 2 is an exemplary roller chain drive system having a ISO-606 compliant drive sprocket, driven sprocket, and roller chain;

Figure 3 shows an engagement path (phantom) and
5 a roller (solid) in a driving position as an ISO-606 compliant drive sprocket rotates in a clockwise direction;

Figure 4a shows a roller at the onset of meshing with an exemplary 18-tooth sprocket;

Figure 4b shows the drive sprocket of Figure 4a
10 rotated in a clockwise direction until the roller is at a 12 o'clock position;

Figure 5 is an enlarged view of the drive sprocket of Figure 2 with a roller fully seated in a tooth space and a second roller about to mesh with the drive
15 sprocket;

Figure 6 shows the drive sprocket of Figure 5 rotated in a clockwise direction until the second roller initially contacts the drive sprocket;

Figure 7 is an enlarged view of Figure 6 showing
20 that the second roller initially contacts a root surface (i.e., radial impact) of the drive sprocket, under theoretical conditions;

Figure 8 illustrates a roller chain drive system having a roller chain drive sprocket and driven sprocket
25 which incorporate the features of the present invention therein;

Figure 9 illustrates the roller chain drive sprocket of Figure 8 with an asymmetrical tooth space form in accordance with one embodiment of the present invention;

30 Figure 10 is an enlarged view of the asymmetrical tooth space form of Figure 9 showing a roller in two-point contact with the sprocket;

Figure 11 shows an engagement path (phantom) and the instant of full mesh (solid) of a roller as the drive sprocket of Figure 8 rotates in a clockwise direction;

Figure 12 is an enlarged view of the drive sprocket of Figure 8 with a first roller fully seated in a tooth space and a second roller as the next roller to be collected from the taut span of the roller chain;

Figure 13 shows the drive sprocket of Figure 12 rotated in a clockwise direction until the second roller initially contacts the drive sprocket;

Figure 14 is an enlarged view of Figure 13 showing the first roller in two-point contact and second roller at initial tangential contact with the drive sprocket;

Figure 14a illustrates the progression of the first and second rollers as the drive sprocket of Figure 14 is rotated in a clockwise direction;

Figure 14b is an enlarged view of the drive sprocket of Figure 14 rotated in a clockwise direction to advance the second roller to the instant of full mesh at a 12 o'clock position;

Figure 15 illustrates a roller chain drive sprocket with an asymmetrical tooth space form in accordance with another embodiment of the present invention;

Figure 16 is an enlarged partial view of Figure 8, showing the contact progression as the rollers travel around the drive sprocket wrap;

Figure 17 is an enlarged view of a roller exiting a sprocket wrap of the sprocket of Figure 16;

Figure 18 illustrates a roller chain sprocket with an asymmetrical tooth space form in accordance with another embodiment of the present invention;

Figure 19 illustrates a roller chain sprocket with an asymmetrical tooth space form in accordance with a further embodiment of the present invention;

Figure 20 is a front view of an exemplary random-
5 engagement roller chain sprocket which incorporates the features of the present invention therein;

Figure 21 is an enlarged view of the sprocket of Figure 20 showing an asymmetrical tooth space form which incorporates engaging flank relief and tooth space
10 clearance in accordance with the present invention;

Figure 21a is an enlarged view of the sprocket of Figure 21 showing an inclined root surface thereof which provides flank relief and tooth space clearance;

Figure 22 is another embodiment of the inclined
15 root surface of Figure 21a which only provides flank relief;

Figure 23 illustrates the asymmetrical tooth space form of Figure 9 overlaid with the asymmetrical tooth space form of Figure 21;

Figure 24 illustrates the meshing progression of
20 a first roller and the meshing of a second adjacent roller with the sprocket of Figure 20 as the sprocket is rotated in a clockwise direction;

Figure 25 illustrates the sprocket of Figure 20
25 with a first roller in two-point contact, a second roller at initial tangential contact, and a third roller as the next roller to engage with the drive sprocket;

Figure 26 illustrates the sprocket of Figure 25
rotated in a clockwise direction until the instant of
30 initial engagement of the third roller at a root surface of the sprocket;

Figure 27 is a table listing roller seating angles α and pressure angles γ for a number of different ISO-606 compliant sprocket sizes;

Figure 28 is a table listing the maximum Beta (β) angles and the corresponding minimum pressure angles (γ) for three different asymmetrical tooth space profiles (1-3) of varying sprocket sizes; and,

Figures 29 - 31 are included to illustrate a sprocket incorporating added chordal pitch reduction (CPR) in accordance with the present invention.

Detailed Description of the Preferred Embodiments

With reference now to Figure 8, a roller chain drive system 110 includes a drive sprocket 112 and a driven sprocket 114 which incorporate the features of the present invention therein. The roller chain drive system 110 further includes a roller chain 116 having a number of rollers 118 which engage and wrap about sprockets 112, 114. The roller chain moves around the sprockets 112, 114, both of which rotate in a clockwise direction as shown by arrow 11.

The roller chain 116 has two spans extending between the sprockets, slack strand 120 and taut strand 122. The roller chain 116 is under tension as shown by arrows 124. A central portion of the taut strand 122 may be guided from the driven sprocket 114 to the drive sprocket 112 with a chain guide 126. A first roller 128 is shown fully seated at a 12 o'clock position on the drive sprocket 112. A second roller 130 is adjacent to the first roller 128 and is about to mesh with the drive sprocket 112.

To facilitate a description of the asymmetrical tooth profiles of the present invention, reference will be

made only to the drive sprocket 112. However, the asymmetrical tooth profiles of the present invention can be equally applied to the driven sprocket 114, as well as to other types of sprockets such as idler sprockets and sprockets associated with counter rotating balance shafts.

Referring now to Figures 9 and 10, the sprocket 112 includes a first tooth 132 having an engaging flank 134, and a second tooth 136 having a coast or disengaging flank 138. The engaging flank 134 and coast flank 138 cooperate to define a tooth space 140 having a root surface 141. The tooth space 140 receives the engaging roller 128 (shown in phantom). The engaging roller 128 has a diameter D_1 , and is shown fully seated in two-point contact within the tooth space 140 as described further below. More particularly, the engaging roller 128, when fully seated in the tooth space, contacts two lines B and C that extend axially along each sprocket tooth surface or face (i.e., in a direction orthogonal to the plane of the drawings). However, to facilitate a description thereof, the lines A, B, and C are hereafter shown and referred to as contact points within the tooth space.

The engaging flank 134 has a radius R_f which is tangent to a radially outer end of a flank flat 144. The asymmetrical engaging flank radius R_f is smaller than the R_{fISO} radius specified by the ISO-606 standard. However, the magnitude of the asymmetrical engaging flank radius R_f should be as large as possible while still satisfying the roller meshing (engaging) and disengaging geometry. The location of the flank flat 144 is defined by an angle β , with the flat orientation being normal or perpendicular to a line that passes through Point B and the center of roller 128 when the roller is contacting the sprocket at Points B

and C. The length of the flank flat, which extends radially outward from Point B, affects a time delay between an initial tangential impact between sprocket 112 and roller 128 at a first contact Point A along the flank flat 144, and a subsequent radial impact at Point C. It is believed that the roller stays substantially in contact with the flank flat from its initial tangential contact at Point A until the roller moves to a fully engaged two-point contact position at Points B and C. The pressure angle γ , the amount of pitch mismatch between the chain and the sprocket, and the length of the flank flat can be varied to achieve a desired initial roller contact Point A at the onset of roller-sprocket meshing.

It should be appreciated that flank (tangential) contact always occurs first, with radial contact then occurring always at Point C regardless of chain pitch length. In contrast, with known tooth space forms (e.g., ISO-606 compliant and asymmetrical) incorporating single-point contact (e.g. single line contact), an engaging roller must move to a driving position after making radial contact. The pressure angles γ therefore assume that the engaging roller will contact at the flank radius/root radius tangent point. Thus, the meshing contact location of the known single point/line tooth space forms is pitch "sensitive" to determine where the radial impact as well as driving (tangential) impact will occur.

The engaging flank roller seating angle β (Fig. 9) and a disengaging flank roller seating angle β' replace the ISO-606 roller seating angle α (ISO profile shown in phantom). As illustrated in Figure 9, β is the angle defined by the line 152 passing through the center of the roller 128 and the sprocket center to a second line which

also passes through the center of roller 128 and Point B. Also shown in Figure 9, β' is the angle defined by a line passing through the arc center of R_i' and the sprocket center to a second line which also passes through the arc center of R_i' and the arc center of R_f' . The pressure angle γ is a function of the engaging flank roller seating angle β . That is, as β increases, γ decreases. A minimum asymmetrical pressure angle can be determined from the following equation, where:

$$\gamma_{\min} = \beta_{\max} - (\alpha_{\max} / 2 + \gamma_{\text{ISO min}})$$

Therefore, an asymmetrical pressure angle $\gamma_{\min} = 0$ when $\beta_{\max} = (\alpha_{\max} / 2 + \gamma_{\text{ISO min}})$ as illustrated in the table of Figure 28. Figure 28 lists the maximum Beta (β) angles and the corresponding minimum pressure angles (γ) for several sprocket sizes of three different asymmetrical tooth space profiles (1-3). It should be appreciated that reducing the engaging flank pressure angle γ reduces the tangential impact force component F_{TA} (Fig. 14) and thus the tangential impact noise contribution to the overall noise level at the onset of engagement.

That is, the impact force F_{TA} is a function of the impact velocity which in turn is related to pressure angle γ . As pressure angle γ is reduced, it provides a corresponding reduction in the impact velocity between the chain and the sprocket at the onset of meshing. A minimum pressure angle γ also facilitates a greater separation or distance between tangential contact points A and B to further increase or maximize the meshing interval. In the preferred embodiment, the engaging flank pressure angle γ is in the range of about -2.0° to about $+5^\circ$ to optimize the staged impact between the roller and the sprocket.

In the embodiment being described, roller seating angle β is greater than ISO $\alpha_{\max}/2$ at a maximum material condition and β can be adjusted until a desired engaging flank pressure angle γ is achieved. For instance, the roller seating angle β of Figure 9 provides a pressure angle γ that is less than zero, or a negative value. The negative pressure angle γ is best seen in Figure 11, as contrasted with the ISO-606 compliant tooth profile of Figure 3 with a positive pressure angle γ . As shown in FIGURE 11, the asymmetrical profile pressure angle γ is defined as the angle between a line A extending from the center of the fully engaged roller 128, when it is contacting the engaging tooth flank at points B and C, through point B, and a line B connecting the centers of the fully seated roller 128, and the center of the next meshing roller 130 as if it were also two-point seated at full mesh in its engaging tooth space. It is believed that a small negative pressure angle for the theoretical chain/sprocket interface beneficially provides a pressure angle γ closer to zero (0) for a "nominal" system or for a system with wear. However, the engaging flank roller seating angle β may be beneficially adjusted so as to provide any engaging flank pressure angle γ having a value less than the minimum ISO-606 pressure angle.

Referring again to Figures 9 and 10, a first root radius R_i is tangent to a radially inner end of the flank flat 144, and tangent to a radially outer end of an inclined root surface 146. As best seen in Figure 10, a maximum root radius R_i must be equal to, or less than, a minimum roller radius $0.5D_1$ to facilitate the fully engaged two-point/line contact at Points B and C. Accordingly, this will define a small clearance 148 (Fig. 10) between

the engaging flank **134** at root radius R_i and the roller **128** at full mesh (i.e. two-point/line contact). The flank flat **144** and the inclined root surface **146** necessarily extend inside Points B and C respectively to facilitate the two-point/line roller contact at full engagement for all dimensional tolerance conditions of the roller **128** diameter D_1 and the root radius R_i . A second root radius R_i' is tangent to a radially inner end of the inclined root surface **146** at line **150**. The disengaging flank radius R_f' is tangent to R_i' at a point defined by disengaging flank roller seating angle β' . The radius R_f' can have a value in the ISO-606 range.

The inclined root surface **146** is a flat surface having a finite length which defines a tooth space clearance (TSC). The tooth space clearance compensates for chain pitch elongation or chain wear by accommodating a specified degree of chain pitch elongation ΔP . In other words, the tooth space clearance TSC enables rollers of a worn chain to be maintained in hard contact with the inclined root surface of the sprocket teeth. In addition, the inclined root surface **146** facilitates reducing the radial reaction force thereby reducing the roller radial impact noise contribution to the overall noise level.

The inclined root surface **146** may be inclined at any angle ϕ necessary to satisfy a specific chain drive geometry and chain pitch elongation. As shown in Figure 9, the inclined root surface angle ϕ is measured from a line **152** passing through the center of roller **128** and the sprocket center to a second line **154** which also passes through the center of roller **128** and Point C. The inclined root surface **146** is normal to the line **154**, and the inclined root surface extends radially inward to line **150**

where it is tangent to R_i' . In the embodiment being described, the inclined root surface angle ϕ is preferably in the range of about 20° to about 35° .

Figure 12 is an enlarged view of Figure 8 showing the first roller 128 at full engagement in two-point/line contact across the thickness or width of the sprocket tooth profile, and the second roller 130 as the next roller about to mesh with sprocket 112. As with the ISO-606 compliant drive system 10, the chain guide 126 controls and guides a central portion of the taut strand 122 except for five unsupported link pitches extending between the chain guide 126 and the engaging roller 128 (and except for the unsupported link pitches extending between the driven sprocket and the chain guide). The taut strand 122 is horizontal when roller 128 is at the 12 o'clock position.

Figure 13 shows the drive sprocket 112 rotated in a clockwise direction $(A/2) + \omega$, as determined by the instant of sprocket engagement by roller 130. A straight line is assumed for the chain span from roller 128 to a chain pin center 156, about which the unsupported span from pin center 156 to engaging roller 130 is considered to rotate. It should be appreciated that the straight line assumption is valid only in a quasi-static model. The amount of movement (or deviation from the straight line assumption) previously mentioned will be a function of the drive dynamics as well as the drive and sprocket geometry.

The sprocket contact at the onset of mesh for roller 130 occurs earlier than for the ISO-606 counterpart, thereby reducing the amount of chordal rise and, just as importantly, allows the initial contact to beneficially occur at a desired pressure angle γ on the engaging flank at Point A. Furthermore, the radial sprocket contact for

roller 130, with its contribution to the overall noise level, does not occur until the sprocket rotation places roller 130 at the 12 o'clock position. This is referred to as lengthening the meshing interval.

5 Figure 14, an enlarged view of Figure 13, more clearly shows the onset of meshing for roller 130. Just prior to the onset of mesh, roller 128 is assumed to carry the entire taut strand load $F_{TB} + F_{\phi}$, which load is shown as force vector arrows. Actually, the arrows represent
10 reaction forces to the taut strand chain force. At the instant of mesh for roller 130, a tangential impact occurs as shown by impact force vector F_{IA} . The tangential impact is not the same as the taut strand chain loading. In particular, impact loading or impact force is related to
15 the impact velocity V_A . It is known that impact occurs during a collision between two bodies, resulting in relatively large forces over a comparatively short interval of time. A radial impact force vector F_{IC} is shown only as an outline in that the radial impact does not occur until
20 the sprocket has rotated sufficiently to place roller 130 at a 12 o'clock position.

 Figure 14a shows the same roller positions (solid) for rollers 128 and 130 as shown in Figure 14, but in addition, shows the roller positions (in phantom)
25 relative to the sprocket profile once roller 130 reaches its two-point/line mesh at the 12 o'clock position. As a result of the pitch mismatch between the chain and sprocket, roller 128 must move to a new position. In particular, as roller 130 moves from initial contact to
30 full mesh, roller 128 progresses forward in its tooth space. Small clearances in the chain joints, however, reduce the amount of forward progression required for

roller 128. Also occurring at the onset of meshing is the beginning of the taut strand load transfer from roller 128 to roller 130.

The asymmetrical profile provides for the previously described "staged" meshing that exhibits a lengthened meshing interval. In particular, referring again to Figure 14, the Point A tangential contact occurs at the onset of mesh, with its related impact force F_{IA} . The roller 130 is believed to stay substantially in hard contact with the engaging flank 134 as the sprocket rotation moves the roller into full mesh with its resulting radial contact at Point C.

Figure 14b is an enlarged view of Figure 14, except that sprocket 112 has been rotated to advance roller 130 to the instant of full mesh at the 12 o'clock position. At this instant of full mesh, the radial impact force F_{IC} occurs and the taut strand load transfer is considered to be complete. At the instant of the radial collision by roller 130 at Point C, with its resultant radial impact force F_{IC} , the tangential impact force of F_{IA} has already occurred and is no longer a factor. The time delay ("staged" engagement) between the tangential and radial roller-sprocket collisions effectively spreads the impact energy over a greater time interval, thereby reducing its contribution to the generated noise level at mesh frequency. Additionally, it is believed that the present asymmetrical sprocket tooth profile beneficially permits a more gradual taut strand load transfer from a fully engaged roller 128 to a meshing roller 130 as the meshing roller 130 moves from its Point A initial mesh to its full two-point mesh position.

Referring again to Figure 14, the chordal rise (and fall) with the present asymmetrical profile is the perpendicular displacement of the center of roller 130 from the taut strand 122 path as it moves from its initial meshing contact Point A to the mesh position presently occupied by roller 128. It is believed that roller 130 will stay in hard contact with the engaging flank 134 as the roller moves from initial tangential contact to full mesh, and accordingly, the chordal rise is reduced as the distance between Points A and B is increased. As shown in Figure 14, chain pitch P_c is beneficially greater than sprocket 112 chordal pitch P_s .

Referring now to Figure 15, the length of the inclined root surface 146 (Fig. 10) may be reduced to zero (0), thereby eliminating the inclined root surface 146 and permitting root radius R_i' to be tangent to the root surface and the roller 128 at Point C. That is, R_i' is tangent to a short flat at Point C, and the flat is tangent to R_i . If the inclined root surface 146 is eliminated, the engaging flank pressure angle γ would generally be in the range of some positive value to zero, but normally not less than zero. The reason is that a negative γ requires chordal pitch reduction so that the roller can exit the sprocket wrap 60 (Fig. 16) without interfering with R_f .

Figure 16 shows the roller contact to the sprocket 112 profile for all the rollers in the wrap 60. Roller 128 is in full two-point mesh as shown. Line 160 shows the contact point for each of the rollers, as well as the contact progression as the rollers travel around the wrap. The inherent pitch mismatch between the sprocket and roller chain causes the rollers to climb up the coast side flank as the rollers progress around the sprocket wrap.

With the addition of appreciable chordal pitch reduction, the extent to which the rollers climb up the coast side flank is increased.

It is important to note that chordal pitch
5 reduction is required when the pressure angle γ has a negative value. Otherwise, as is evident from an examination of Figures 16 and 17, roller 162 would interfere with the engaging flank (with a maximum material sprocket and a theoretical pitch [shortest] chain) as it
10 exits the wrap 60 back into the span. That is, chordal pitch reduction permits the roller 162 to exit the wrap 60 with a clearance 163 at the engaging flank. Also, the reduced chordal pitch serves to increase the meshing interval (staged meshing) as previously mentioned. Figure
15 16, showing the roller contact progression in the wrap 60, serves also to show why the shallow β' angle and tooth space clearance TSC helps maintain "hard" roller-sprocket contact for the rollers in the wrap.

In addition, the disengaging flank roller seating
20 angle β' (Fig. 9) may be adjusted to have a maximum value which is equal to $\alpha_{\min}/2$ or even less. This reduced roller seating angle β' promotes faster separation when the roller leaves the sprocket and enters the span. This reduced angle β' also allows for the roller in a worn chain to ride
25 up the coast flank surface to a less severe angle as the roller moves around the sprocket in the wrap.

It is contemplated that the above-described asymmetrical tooth profile features can be altered without substantially deviating from the chain and sprocket meshing
30 kinematics that produce the noise reduction advantages of the present invention. For example, the engaging asymmetrical flank profile could be approximated by an involute form, and the disengaging asymmetrical flank

profile could be approximated by a different involute form. Slight changes to the asymmetrical tooth profiles may be made for manufacturing and/or quality control reasons, or simply to improve part dimensioning. These changes are
5 within the scope of the invention as disclosed herein.

In a further embodiment, the engaging flank inclined root surface **146** (Fig. 9) may be replaced with a coast flank inclined root surface **164** as shown in Figure 18. The coast flank inclined root surface **164** provides
10 tooth space clearance (TSC) in the same manner as described above with regard to the inclined root surface **146**. In addition, the disengaging flank inclined root surface **164** beneficially moves the roller to a preferred radially outward position as the chain wears.

Alternatively, the coast flank inclined root surface **164** may be included with the engaging flank inclined root surface **146** as shown in Figure 19. The engaging flank and coast flank inclined root surfaces **146**, **164** cooperate to provide tooth space clearance (TSC) in the
15 same manner as previously described.

Referring now to Figure 20, any one of the above-described asymmetrical tooth profile embodiments of Figures 9, 15, 18, and 19 may be incorporated into a random-engagement roller chain sprocket **300**. The sprocket **300** is
20 shown as an 18-tooth sprocket. However, the sprocket **300** may have more or less teeth, as desired. The sprocket **300** includes a first group of arbitrarily positioned sprocket teeth **302** each having a profile which incorporates the flank flat **144** shown in Figures 9, 15, 18 and 19. Further,
25 the sprocket teeth **302** can incorporate none, one or both inclined root surfaces **146**, **164** as shown in Figs. 9, 15, 18 and 19. The remaining sprocket teeth **304** (sprocket teeth 1,

3, 4, 9, 13, 14, and 16) are randomly positioned around the sprocket and incorporate a tooth profile different from that of the first group of sprocket teeth 302. As described further below, the first and second groups of sprocket teeth 302, 304 cooperate to reduce chain drive system noise levels below a noise level which either tooth profile used alone would produce.

Figure 21 illustrates an exemplary tooth profile for one of the sprocket teeth 304. An engaging flank 306 and a coast or disengaging flank 308 of an adjacent tooth cooperate to define a tooth space 310 having a root surface 311. The tooth space 310 receives an engaging roller 314 (shown in phantom). The engaging roller 314 has a roller diameter D_1 and is shown fully seated with single point (line) contact within the tooth space 310. As best seen in Figure 21a, the engaging roller 314 does not contact the engaging flank 306 at the onset of meshing, moving instead directly from the span to full-mesh root contact on an inclined root surface 316 at a contact point C' located radially outward of contact point C in a direction toward the engaging flank 306. Contact point C' is a roller/tooth contact line that extends axially along each sprocket tooth surface (i.e., in a direction orthogonal to the plane of the drawings). Thus, a clearance 321 is defined between the roller 314 and the engaging flank 306.

As shown in Figures 21 and 21a, the first or engaging root radius R_i is tangent to inclined root surface 316 at line 319, and also tangent to R_f as defined by angle β . Angle β has no functional requirements specific to the onset of roller meshing since roller/flank contact will not take place with tooth profile 304. It should be noted that

R_i can be equal to the ISO-606 root radius for tooth profile 304.

The length of the inclined root surface from point C to its radially outer end at line 319 is determined by the amount of flank offset required to ensure that the roller will not have engaging flank contact for any expected chain pitch elongation (wear) throughout its design life. In the preferred embodiment, the flank offset 323 is in the range of about 0.025 to about 0.13 mm. The flank offset 323 is an extension of inclined root surface 316 which provides tooth space clearance (TSC) in the same manner described above with regard to inclined root surface 146.

As previously mentioned, tooth space clearance compensates for chain pitch elongation or chain wear by accommodating a specified degree of chain pitch elongation. In other words, the tooth space clearance TSC enables rollers of a worn chain to be maintained in hard contact with the inclined root surface of the sprocket teeth. In addition, the inclined root surface 316 facilitates reducing the radial reaction force thereby reducing the roller radial impact noise contribution to the overall noise level.

The inclined root surface 316 may be inclined at any angle ϕ necessary to satisfy a specific chain drive geometry and chain pitch elongation. The inclined root surface angle ϕ is measured from a line 320 passing through the center of roller 314 and the sprocket center to a second line 322 which also passes through the center of roller 314 and through contact point C. The inclined root surface 316 is normal to the line 322, and the inclined root surface extends radially inward to line 318 where it

is tangent to R_i' . In the embodiment being described, the inclined root surface angle ϕ is preferably in the range of about 20° to about 35° .

Figure 22 shows another embodiment of the tooth profile 304 where no tooth space clearance TSC is provided. That is, the flat surface portion of the inclined root surface from line 318 to line 322 is not present. Thus, the profile of the tooth 304 from point C to the outside or tip diameter at the disengaging side of the tooth space is substantially identical to the tooth profile shown in Figure 15. The remaining flat surface portion 323 of the inclined root surface 316 from line 322 to line 319 functions only to provide the engaging flank offset as described above.

It should be appreciated that the portion of the engaging flank inclined root surface from line 318 to line 322 may be replaced with a coast flank inclined root surface 164 as in Figure 18. That is, the tooth profile 304 may be substantially identical to the tooth profile for sprocket 112 shown in Figure 18 from contact point C to the outer diameter of the coast flank 138. The coast flank inclined root surface 164 provides tooth space clearance (TSC) in the same manner as the inclined root surface 316. In addition, the coast flank inclined root surface beneficially moves the roller to a preferred radially outward position as the chain wears. Alternatively, the coast flank inclined root surface 164 may be included with the engaging flank inclined root surface 316 in the same manner as shown in Figure 19 (where the inclined surface 164 is included with the inclined surface 146). Thus, the tooth profile 304 may also be substantially identical to the tooth profile for sprocket 112 shown in Figure 19 from

contact point C to the outer diameter of the coast flank
138.

Pitch mismatch is inherent in a chain/sprocket interface except at one condition - the theoretical
5 condition which is defined as a chain at its shortest pitch (shortest being theoretical pitch) and a maximum material sprocket. This theoretical condition therefore defines one limit (zero, or no pitch mismatch) of the tolerance range of the pitch mismatch relationship of chain and sprocket.
10 The other limit is defined when a longest "as built" chain is used with a sprocket at minimum material conditions - or in other words, a sprocket having a minimum profile. This limit produces the greatest amount of pitch mismatch. The pitch mismatch range is therefore determined by the part
15 feature tolerances.

Additional pitch mismatch may be introduced to facilitate a greater time delay, or "staged" meshing, between the initial tangential contact at point A and the full seated contact at points B and C for tooth profile
20 302. It should be appreciated that staged contact for profile 302 is enhanced due to the flank flat 144 which causes initial contact to occur higher up on the engaging flank. This will result in reduced mesh frequency noise levels because the point and rhythm of the initial roller-
25 to-sprocket contacts are altered for each tooth profile 302, 304 since profile 304 does not have a tangential contact.

The sprocket chordal pitch is necessarily shorter than the chain pitch to facilitate the "staged" roller-
30 tooth contact. In addition, chordal pitch reduction also provides roller-to-flank clearance as the roller exits the sprocket wrap back into the span.

FIGURE 29 partially illustrates an asymmetric sprocket 112 including a plurality of teeth 132 of the same profile. For convenience and ease of understanding the feature of added chordal pitch reduction (CPR), successive
5 teeth 132 are identified using reference numerals including a suffix "a," "b," etc., i.e., 132a, 132b, 132c. The sprocket 112 is intended to rotate in a clockwise direction 11 and, accordingly, each tooth 132 includes an engaging flank 134 and a disengaging flank 138. A tooth space 140
10 is defined between the engaging flank 134 of each tooth and the disengaging flank of the next or successive tooth 132. A roller chain comprising rollers 128,130 and links (the links are not shown) is engaged with the sprocket 112, with the rollers 128,130 fully seated in their respective tooth
15 spaces 140.

As described above, the roller chain includes a chain pitch P_c when new or "as built" that is defined by the distance from center-to-center of successive rollers 128,130. Sprocket chordal pitch is defined herein as the
20 straight-line distance between the centers of successive rollers if both rollers are seated in full-mesh driving contact with the sprocket when the sprocket is in a new or "as-manufactured" condition. Thus, for the sprocket 112, illustrated in FIGURE 29, the sprocket chordal pitch P_s is
25 the straight-line distance between the centers of the rollers 128,130 when both rollers are engaged at points B and C on their respective engaging flanks 134. In the example illustrated in FIGURE 29, the sprocket 112 includes a chordal pitch P_s that is approximately 0.1% reduced
30 relative to the chain pitch P_c due to manufacturing tolerances. Thus, as illustrated in FIGURE 29, the roller 128 is seated in two-point driving contact with the

engaging flank **134** of the tooth **132b**, i.e., the roller is engaged with points B and C on the engaging flank **134** of the tooth **132b**. The next-meshing roller **130** has just engaged the engaging flank **134** of the tooth **132a** at an initial contact point A. However, as illustrated, point A is very nearly coincident with point B because the sprocket chordal pitch P_s is nominally equal to the chain link pitch P_c . Thus, the roller **130** essentially seats in two-point driving contact with points B and C of the engaging flank **134** of the tooth **132a**, even though the roller **130** has just engaged the sprocket **112**. Accordingly, those of ordinary skill in the art will recognize that staged-impact, i.e., an extension of the meshing time interval, is not present to any meaningful degree in FIGURE 29. In other words, the roller **130** undesirably seats in two-point driving contact at points B and C almost immediately upon engaging the sprocket **112**. In this case, the chordal action (chordal rise and fall) as indicated at **CA** and defined above is larger than desired.

FIGURE 30 partially illustrates a sprocket **112'** that is identical to the sprocket **112** except that it is defined to include added chordal pitch reduction (CPR) when in a new or "as-manufactured" condition, i.e., the sprocket chordal pitch P_s' is purposefully reduced as compared to the as-built chain pitch P_c a select amount referred to herein as "added chordal pitch reduction." As described below, this purposefully added chordal pitch reduction is in addition to the inherent chordal pitch reduction that exists owing to manufacturing tolerances. Added chordal pitch reduction in accordance with the present invention and as shown in FIGURE 30 is highly desired in that it extends the meshing time interval, i.e., it

enhances staged impact of a next-meshing roller 130 with the sprocket 112'. This is readily apparent by comparing FIGURES 29 and 30. In FIGURE 30, it can be seen that the roller 128 is fully engaged and seated in two-point driving
5 contact with the engaging flank 134 of the tooth 132b, i.e., the roller 128 is in contact with both points B and C. The next-meshing roller 130 has just engaged the sprocket 112' and is not yet fully seated in two-point driving contact. Instead, the next-meshing roller 130
10 makes initial contact with the engaging flank 134 at point A and, owing to the added chordal pitch reduction in accordance with the present invention, the point A is spaced radially outward from point B. Therefore, the roller 130 will seat in driving contact with points B and
15 C only upon further rotation 11 of the sprocket 112'. As described above, this delay between initial contact of the roller 130 at point A and subsequent engagement of the roller with points B and C is a highly desired staged impact or extension of the meshing time interval.

20 This movement of the initial contact point A radially outwardly for the sprocket 112' as compared to the sprocket 112 is readily apparent by comparing FIGURES 29 and 30. Also, further comparison of FIGURES 29 and 30 indicates that, use of the sprocket 112', including added
25 chordal pitch reduction, also reduces the chordal rise and fall action CA' as compared to the chordal action CA of the sprocket 112.

The preferred amount of added chordal pitch reduction is best understood with reference now to FIGURE
30 31. There, the sprocket 112 is illustrated together with the rollers 128 and 130, both of which are fully seated in two-point driving contact with their respective engaging

flanks 134 at points B and C. As noted above, the sprocket 112 has no added chordal pitch reduction. The line P_s1 indicates a maximum chordal pitch based upon a standard maximum "over-pin" tolerance. The line P_s2 indicates a minimum chordal pitch based upon a standard minimum over-pin tolerance. In particular, the line P_s2 indicates a chordal pitch reduction of approximately 0.2% as compared to the maximum chordal pitch P_s1 owing to manufacturing tolerances. Thus, those of ordinary skill in the art will recognize that the sprocket chordal pitches P_s1, P_s2 represent the maximum and minimum sprocket chordal pitch dimensions for a sprocket 112 with no added chordal pitch reduction. In other words, a sprocket with no added chordal pitch reduction will exhibit, at most, chordal pitch reduction of approximately 0.2% due to manufacturing tolerances as indicated by the line P_s2 .

With continuing reference to FIGURE 31, the line P_s3 indicates the maximum sprocket chordal pitch based upon a maximum over-pin tolerance for a sprocket having 1% added chordal pitch reduction. The line P_s4 indicates the minimum chordal pitch based upon a minimum over-pin tolerance for a sprocket with 1% added chordal pitch reduction. In other words, the reduced sprocket chordal pitch represented by the line P_s3 indicates a 1% reduction of the maximum possible sprocket chordal pitch P_s1 for a sprocket 112 with no added chordal pitch reduction. Likewise, the reduced sprocket chordal pitch represented by the line P_s4 indicates a 1% reduction of the minimum chordal pitch P_s2 for a sprocket 112 with no added chordal pitch reduction.

It is most preferred that a sprocket 112' formed in accordance with the present invention include no more than 1% added chordal pitch reduction relative to the

maximum chordal pitch P_{s1} for a sprocket with no added chordal pitch reduction (which is equal to the as-built chain link pitch P_c). The sprocket 112 illustrated in FIGURE 29 has no added chordal pitch reduction but, due to manufacturing tolerances, exhibits nominal chordal pitch reduction of about 0.1%, i.e., the chordal pitch of the sprocket 112 would fall midway between the chordal pitch P_{s1} and P_{s2} shown in FIGURE 31. The sprocket 112' illustrated in FIGURE 30 and formed in accordance with the present invention incorporates added chordal pitch reduction of 0.5% relative to the sprocket 112 illustrated in FIGURE 29.

The sprocket 112' incorporating added chordal pitch reduction in accordance with the present invention can be an asymmetric sprocket including nominally identical asymmetric tooth profiles. The teeth on a sprocket formed in accordance with the present invention can be formed with any of the asymmetric profiles described herein. Alternatively, the sprocket 112' can be a random asymmetric sprocket 300 as described herein that includes multiple different asymmetric tooth profiles on a single sprocket. Also, a sprocket featuring added chordal pitch reduction in accordance with the present invention can be a drive sprocket or a driven sprocket, and a roller chain drive system formed in accordance with the present invention can include a drive sprocket and/or a driven sprocket incorporating added chordal pitch reduction in accordance with the present invention.

Finally, it should be noted that, although the asymmetric tooth profiles illustrated herein are conformed to result in the rollers 128,130 seating in two-point driving contact therewith, other arrangements are contemplated. In particular, a sprocket incorporating one-

point seating asymmetric tooth profiles can also incorporate added chordal pitch reduction in accordance with the present invention. For example, commonly assigned U.S. Patent No. 5,876,295 discloses additional asymmetric
5 tooth profiles and sprockets that can include chordal pitch reduction in accordance with the present invention. Accordingly, the disclosure of U.S. Patent No. 5,876,295 is hereby expressly incorporated by reference herein. Other asymmetric tooth profiles that may be used on a sprocket
10 formed in accordance with the present invention are described in commonly assigned U.S. Patent Nos. 5,921,878 and 5,993,344, and the disclosures of both of these patents are hereby expressly incorporated by reference herein.

The staged roller contact for tooth profile 302
15 may be further assisted by providing a sprocket tooth pressure angle γ that is substantially less than the ISO-606 standard. Pressure angles γ equal to or very close to zero (0), or even negative pressure angles, are contemplated.

20 Figure 23 illustrates the tooth profile 304 overlaid with the tooth profile 302 (phantom). An engaging roller is shown at the onset of initial tangential contact at point A along the engaging flank of the tooth profile 302. The engaging roller will maintain contact with the
25 engaging flank until it is at full mesh and seated at points B and C as previously described with reference to Figure 9. The tooth profile 304 is overlaid on the tooth profile 302 to show that an engaging roller only has radial contact on the inclined root surface of the tooth profile
30 304 (see Figs. 21a and 22) and does not have tangential contact with the tooth profile 304.

The pressure angle γ for tooth profile 304 has no functional purpose during the onset of roller meshing since the roller does not contact the engaging flank. The pressure angle γ_{302} for the tooth profile 302 is shown as a negative value. Thus $\gamma_{\min}$ may be a small negative value, and $\gamma_{\max}$ may be a positive value equal to some value less than the ISO-606 minimum pressure angle γ . As a result, initial roller-to-sprocket contact for tooth profile 302 of sprocket 300 (Fig. 20) occurs at point A followed by full engagement contact at points B and C. The sprocket 300 may, or may not incorporate additional chordal pitch reduction, and may, or may not incorporate tooth space clearance (TSC), as described above.

Figure 24 shows the engagement path of a roller 342 from initial contact at point A (phantom) to fully-seated, two-point contact (solid) in a sprocket tooth 302, and an engagement path of the roller 314 engaging an adjacent sprocket tooth 304 of the random engagement sprocket 300. At the onset of meshing for roller 314, a small portion of the chain load transfer takes place with tooth 304 picking up a share of the loading. However, tooth 302 continues to carry a larger portion of the chain loading until an engaging roller meshes with another tooth 302 with its attendant flank contact. The reference l in Figure 24 indicates the amount of "staging" for the tooth 302 from the initial contact at point A to the full mesh contact at points B and C.

Figures 25 and 26 illustrate the meshing delay between the tooth profiles 302, 304. In particular, as shown in Figure 25, the sprocket 300 has a further roller 344 fully-seated in two-point contact with a sprocket tooth incorporating the tooth profile 302. The roller 342 is

shown at the instant of initial tangential contact at point A of a second sprocket tooth also incorporating the tooth profile 302. The roller 314 is the next roller in the span and will mesh with a sprocket tooth incorporating the tooth profile 304. The sprocket 300 must rotate through an angle τ for roller 342 to move from its initial contact position at point A to full mesh, seated in two-point contact with the tooth profile 302 at a 12 o'clock position.

With reference to Figure 26, the sprocket 300 of Figure 25 is shown rotated in a clockwise direction until roller 314 is at the onset of meshing with the tooth profile 304. The sprocket 300 must now rotate through a smaller angle κ to have roller 314 seated at the 12 o'clock position. Thus, the sprocket 300 must rotate through an additional angle $\tau - \kappa$ for an engaging roller to be fully seated in the tooth profile 302.

Referring again to Figure 20, the two sets of tooth profiles 302, 304 are arranged in a random pattern in order to modify the meshing impact frequency by altering the point and rhythm of initial roller-to-sprocket contact. However, the two sets of tooth profiles 302, 304 could be arranged in many different random patterns. Further, it is also contemplated that the two sets of tooth profiles 302, 304 could be arranged in many regular patterns that would work equally as well. In all cases, the arrangement of two sets of different tooth profiles on a sprocket provides a means for breaking up the mesh frequency impact noise normally associated with and induced by a full complement of substantially identically shaped sprocket teeth. The mesh frequency noise reduction is achieved by altering the point and rhythm of initial roller-to-sprocket contact.

The crankshaft sprocket, generally the smallest sprocket in the chain drive, is usually the major noise contributor. The typically larger driven camshaft sprocket, however, will also contribute to the generated noise levels, but generally to a lesser extent than the crankshaft sprocket. However, the driven sprocket, particularly if it is nearly the same size or smaller than the driving sprocket, may be the prime noise generator, as in the case with balance shaft sprockets and pump sprockets. Thus, the features of the present invention may also be used advantageously with camshaft or other driven sprockets as well.

It should be appreciated that the tooth profile features of Figures 20-26 can be altered slightly without substantially deviating from the chain and sprocket meshing kinematics that produce the noise reduction advantages of the present invention. For example, the engaging asymmetrical flank profile could be approximated by an involute form, and the disengaging asymmetrical flank profile could be approximated by a different involute form. Slight changes to the profile may be done for manufacturing and/or quality control reasons - or simply to improve part dimensioning.

The invention has been described with reference to the preferred embodiments. Obviously, modifications will occur to others upon a reading and understanding of this specification and this invention is intended to include same insofar as they come within the scope of the appended claims or the equivalents thereof.

Having thus described the preferred embodiments, the invention is now claimed to be:

1. A unidirectional roller chain drive system comprising:

an as-manufactured drive sprocket including a plurality of teeth;

an as-manufactured driven sprocket including a plurality of teeth; and,

an as-built roller chain engaged with said drive sprocket and said driven sprocket, said roller chain defining a chain link pitch (P_c), wherein at least one of said drive sprocket and said driven sprocket defines a sprocket chordal pitch (P_s') that is less than said chain link pitch (P_c) by more than 0.2% of said chain link pitch (P_c).

2. The unidirectional roller chain drive system as set forth in claim 1, wherein said at least one of said drive sprocket and said driven sprocket comprises a plurality of teeth each having an asymmetric profile.

3. The unidirectional roller chain drive system as set forth in claim 2, wherein said at least one of said drive sprocket and said driven sprocket comprises first and second different asymmetric tooth profiles.

4. The unidirectional roller chain drive system as set forth in claim 3, wherein said first and second different asymmetric tooth profiles are arranged arbitrarily on said at least one sprocket.

5. The unidirectional roller chain drive system as set forth in claim 2, wherein each of said plurality of teeth includes an engaging flank conformed to engage said rollers of said roller chain in one-point driving contact in a full mesh position.

6. The unidirectional roller chain drive system as set forth in claim 2, wherein each of said plurality of teeth includes an engaging flank conformed to engage said rollers of said roller chain in two-point driving contact in a full mesh position.

7. The unidirectional roller chain drive system as set forth in claim 1, wherein said sprocket chordal pitch P_s' is less than said chain link pitch P_c by more than 0.2% but less than or equal to 1%.

8. The unidirectional roller chain drive system as set forth in claim 2, wherein said teeth defines tooth spaces therebetween, said tooth spaces defining an engaging flank pressure angle in the range of about -2° to about $+5^\circ$.

9. An as-manufactured sprocket adapted for use in conjunction with an associated as-built roller chain comprising a plurality of rollers and that defines a chain pitch P_c , said sprocket comprising:

a plurality of sprocket teeth projecting outwardly therefrom and defining a plurality of tooth spaces located respectively between successive teeth, each of said tooth spaces adapted to receive a roller of said associated roller chain, said sprocket defining a sprocket chordal pitch P_s' that is reduced relative to said chain pitch P_c of

said associated roller chain by more than 0.2% of said chain pitch P_c .

10. The sprocket as set forth in claim 9, wherein said tooth spaces are asymmetric tooth spaces.

11. The sprocket as set forth in claim 10, wherein said tooth spaces are defined with an engaging flank pressure angle in the range of about -2° to about $+5^\circ$.

12. The sprocket as set forth in claim 9, wherein said plurality of sprocket teeth are asymmetric teeth and each include an engaging flank and a disengaging flank, said engaging flank of each of said plurality of sprocket teeth adapted to engage the associated rollers of said associated roller chain in one-point driving contact.

13. The sprocket as set forth in claim 9, wherein said plurality of sprocket teeth are asymmetric teeth each including an engaging flank and a disengaging flank, said engaging flank of each tooth dimensioned and conformed relative to the associated rollers of the associated roller chain so that said engaging flanks engages the associated rollers in two-point driving contact at roller seating points (B,C) when the associated roller is in full mesh in one of said tooth spaces.

14. The sprocket as set forth in claim 13 wherein said reduced sprocket chordal pitch P_s' causes the associated rollers of the associated roller chain make initial contact with respective engaging flanks of said teeth at a point (A) spaced radially outwardly from said points (B,C)

whereby the time between the associated roller contacting the point (A) and seating at points (B,C) is lengthened.

15. The sprocket as set forth in claim 9 wherein said plurality of sprocket teeth are asymmetric teeth of at least two different profiles arranged irregularly on said sprocket.

16. The sprocket as set forth in claim 15 wherein said sprocket chordal pitch P_s' is reduced relative to said chain pitch P_c of said associated roller chain by more than 0.2% of said chain pitch P_c and less than or equal to 1% of said chain pitch P_c .

17. A method of extending the meshing interval for an as-built roller chain and an as-manufactured sprocket, said method comprising:

defining said sprocket to have a sprocket chordal pitch P_s' that is reduced relative to a chain link pitch P_c of the roller chain by more than about 0.2% of the chain link pitch P_c .

18. The method as set forth in claim 17, wherein said sprocket chordal pitch P_s' is reduced relative to the chain link pitch P_c by more than about 0.2% of the chain link pitch P_c and less than or equal about 1% of the chain link pitch P_c .

19. The method as set forth in claim 18, further comprising:

defining said sprocket to have tooth spaces between consecutive teeth that are defined with an engaging flank pressure angle in the range of about -2° to about $+5^\circ$.

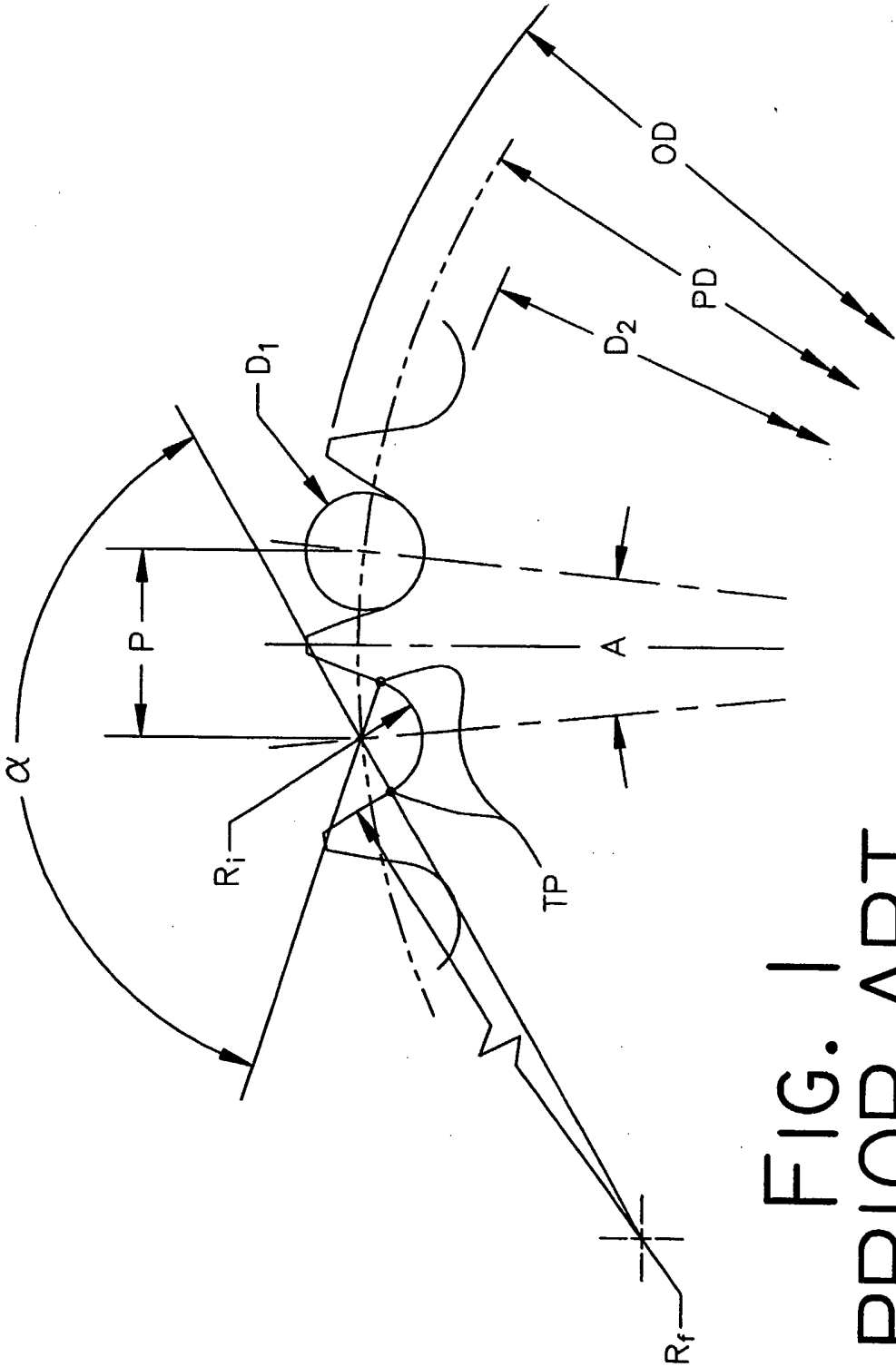


FIG. 1
PRIOR ART

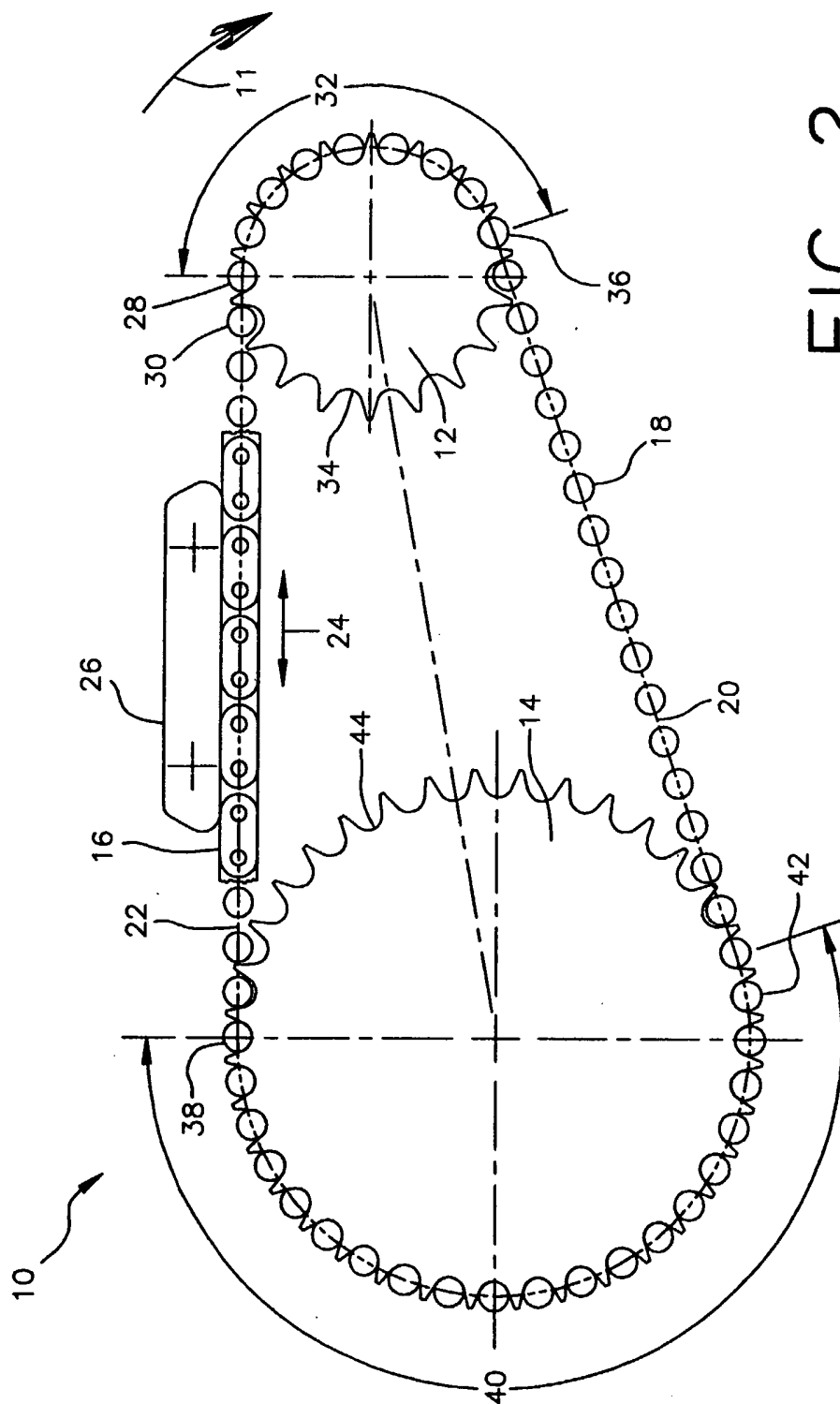


FIG. 2
PRIOR ART

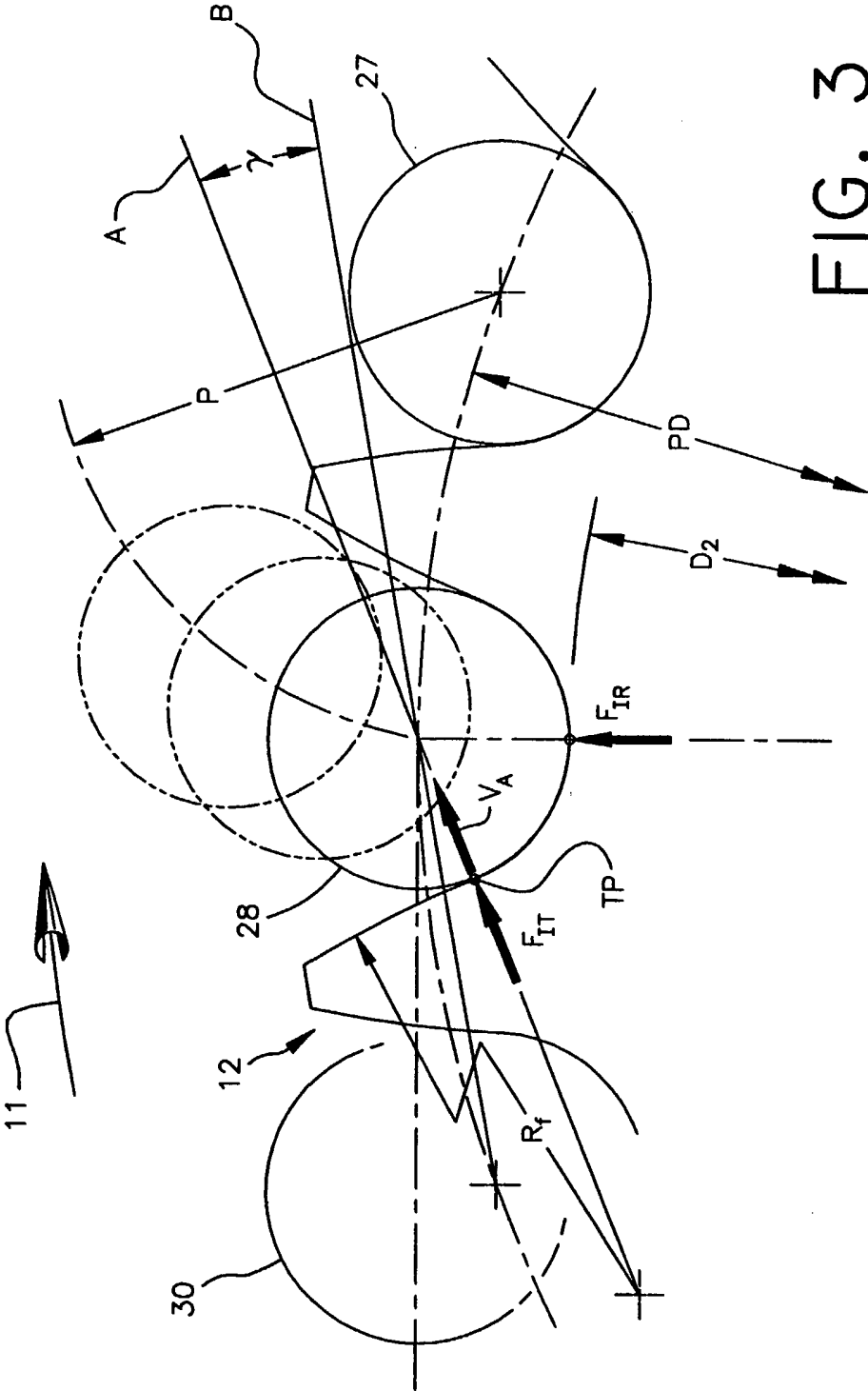


FIG. 3
PRIOR ART

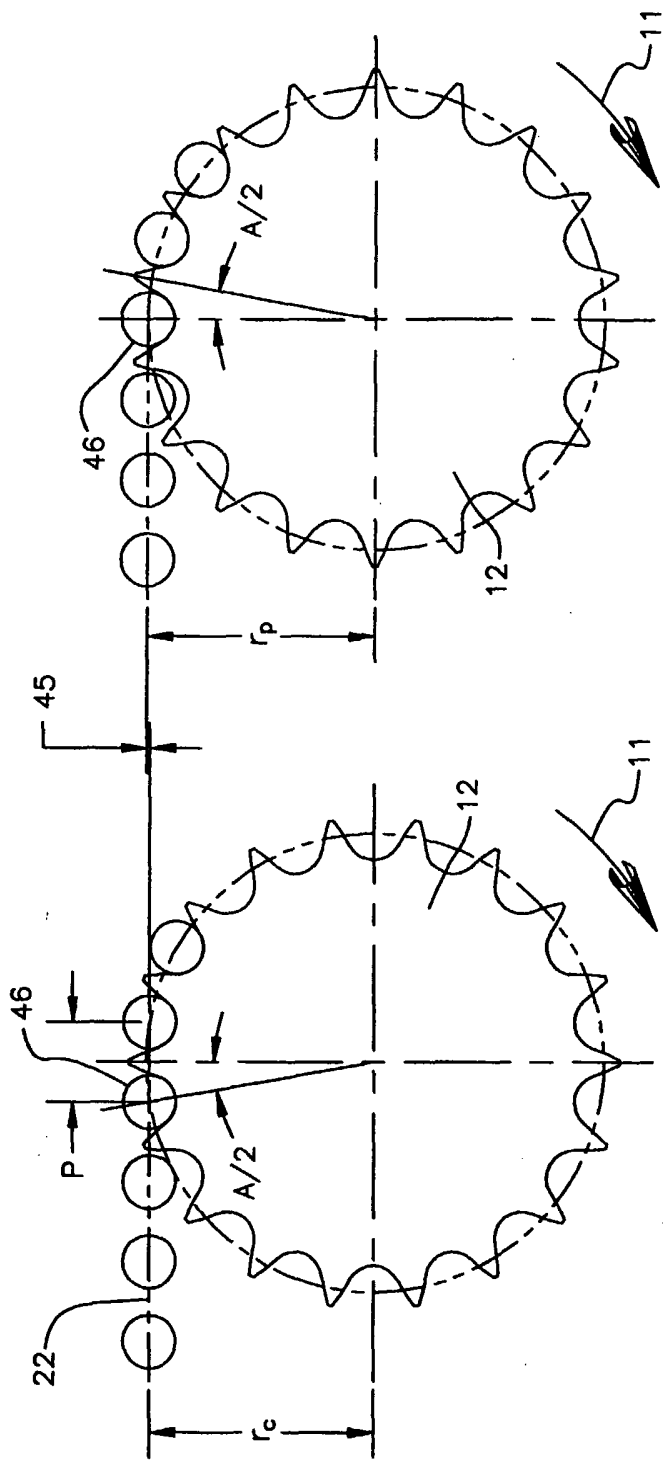


FIG. 4^a
PRIOR ART

FIG. 4^b
PRIOR ART

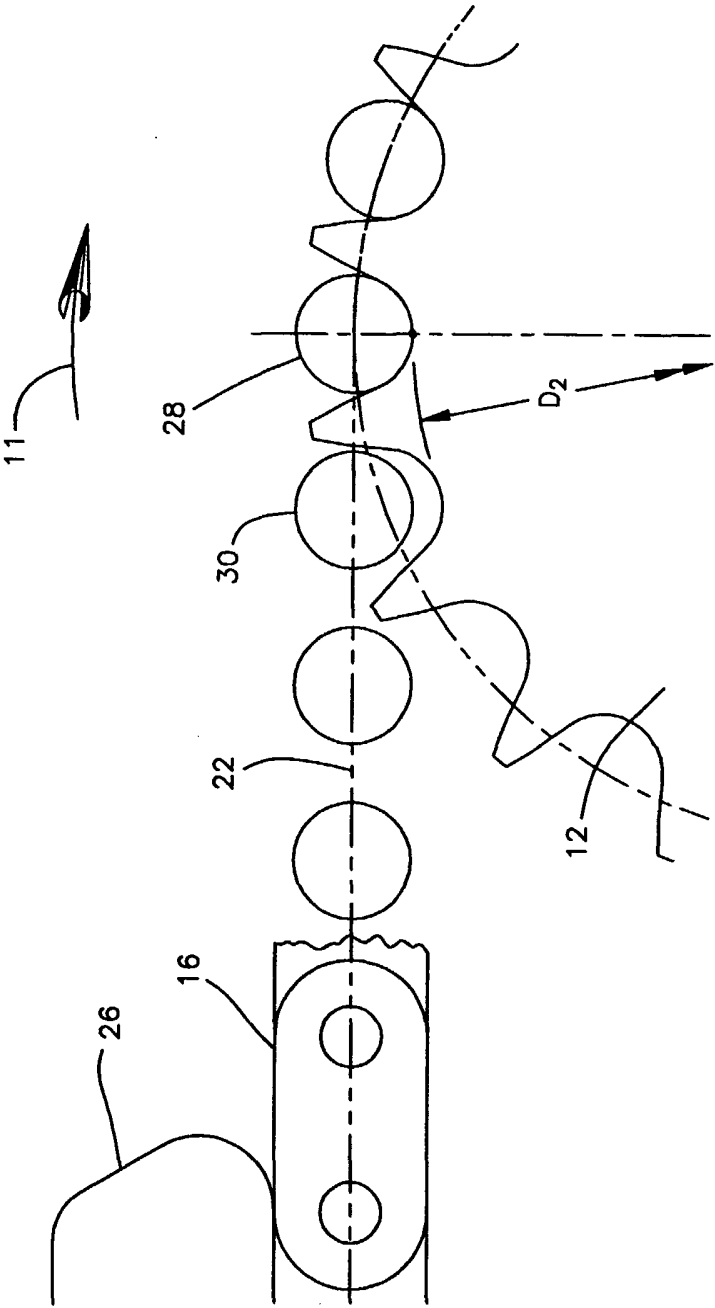


FIG. 5
PRIOR ART

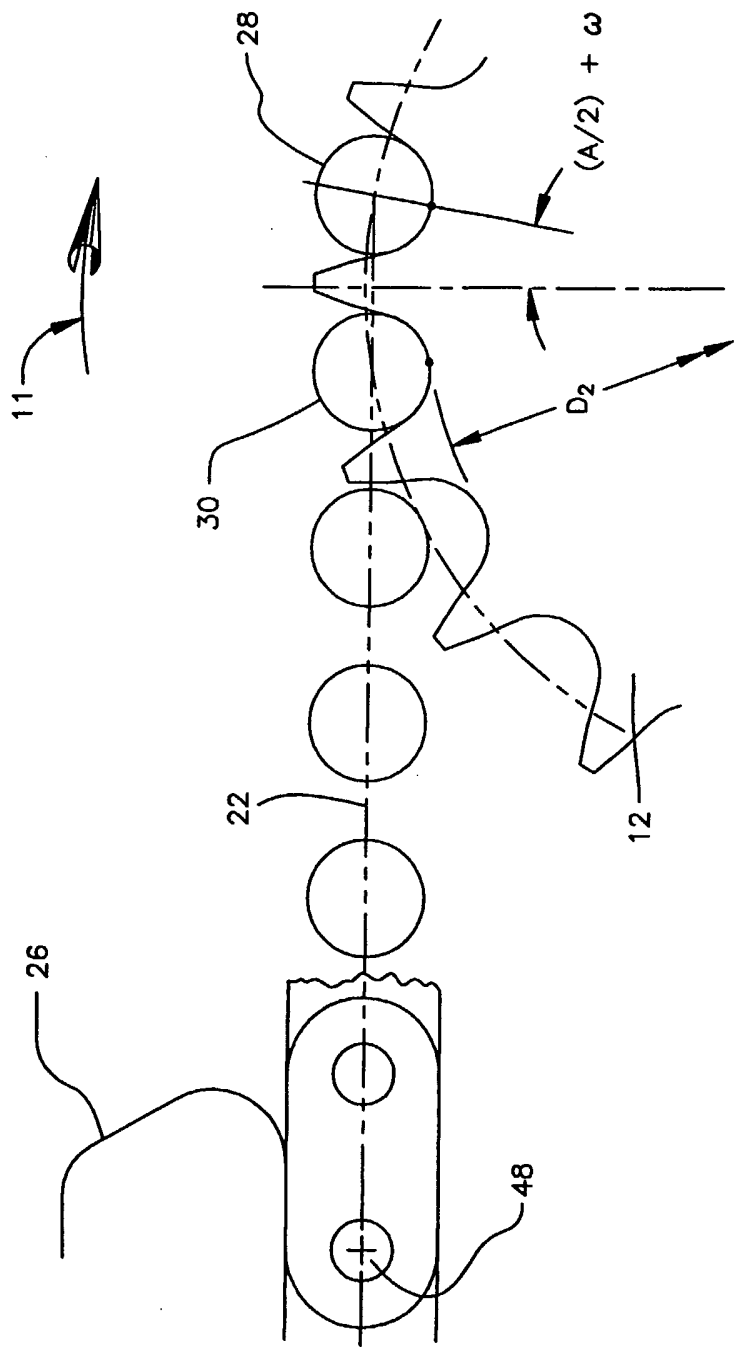


FIG. 6
PRIOR ART

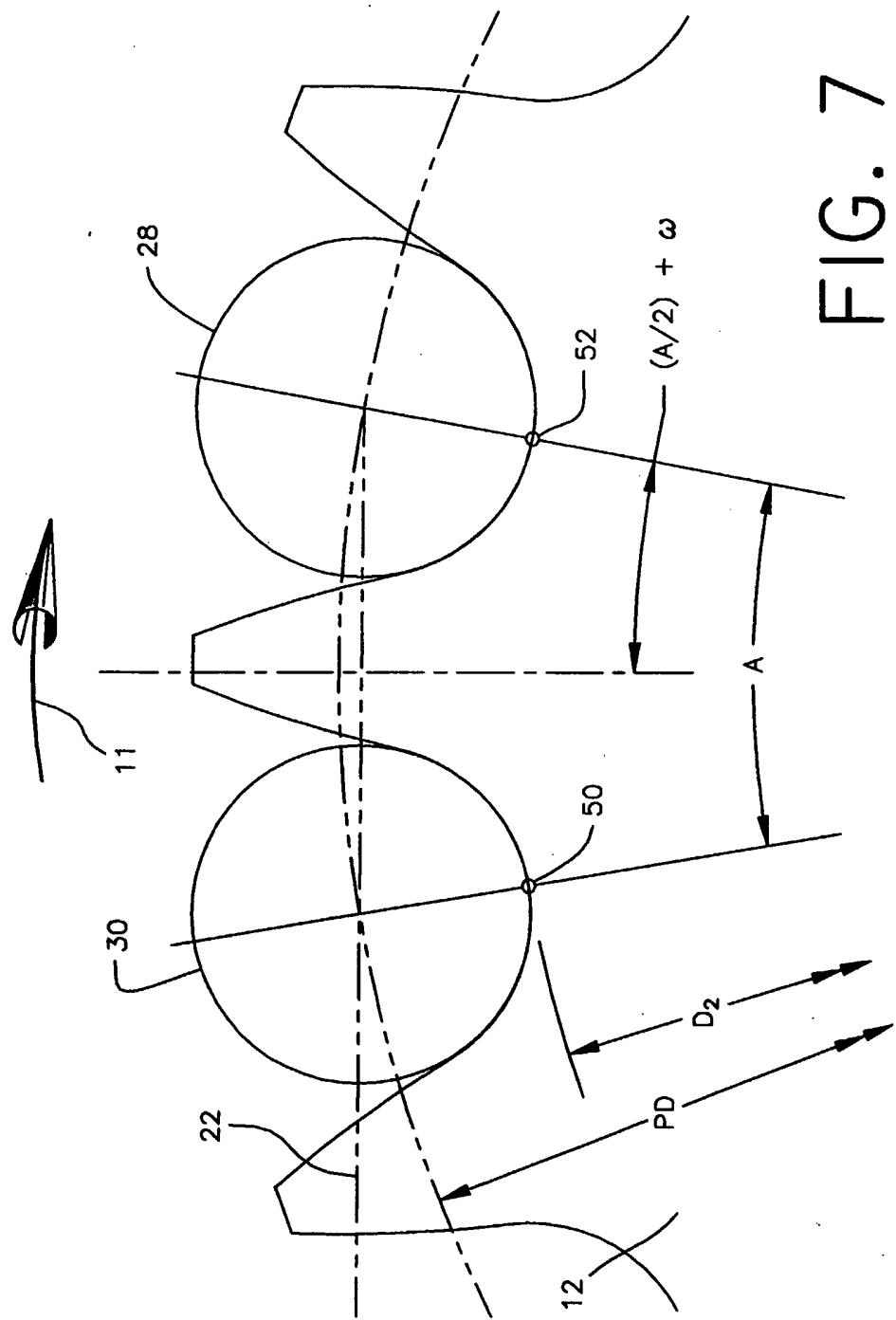


FIG. 7
PRIOR ART

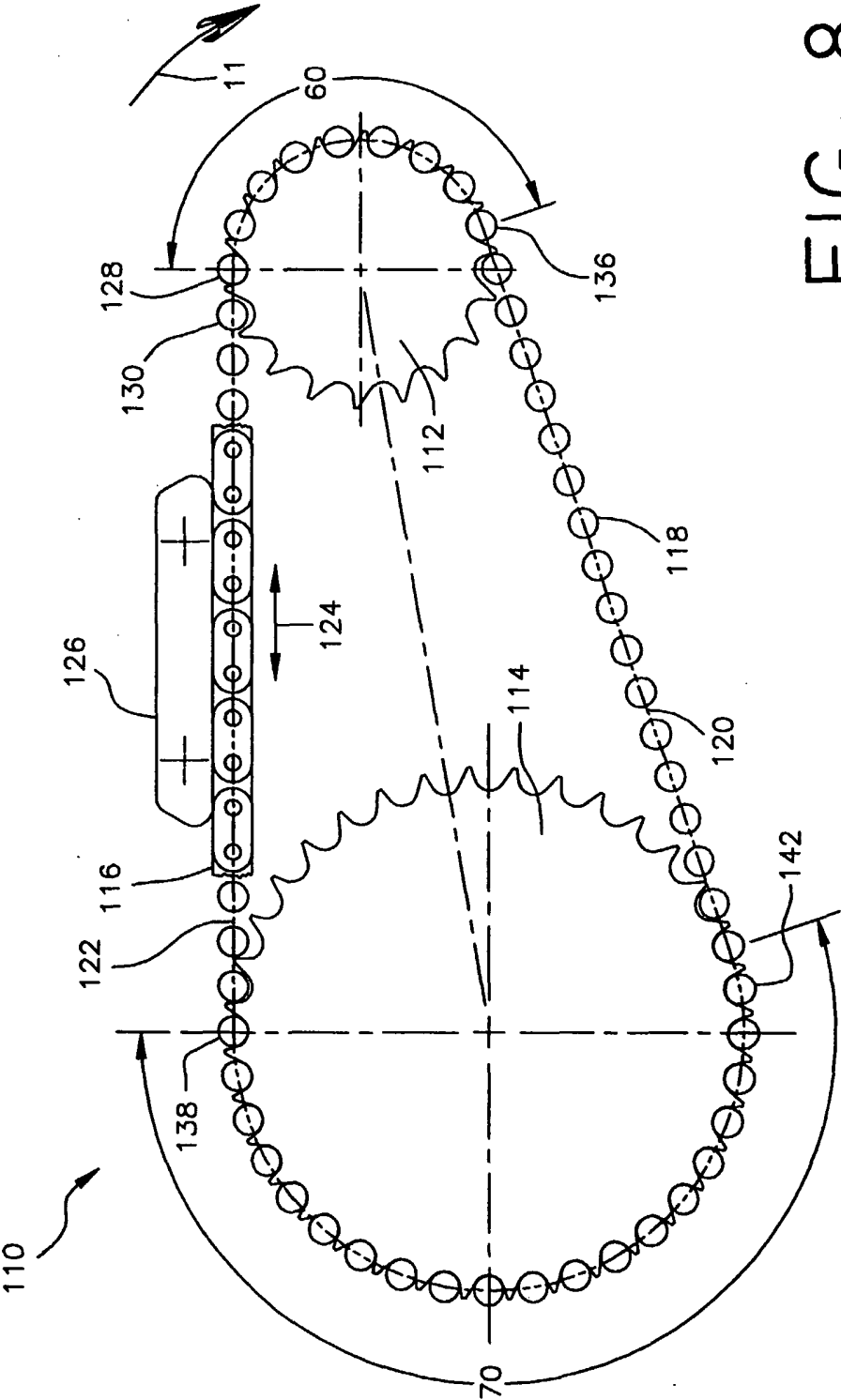


FIG. 8

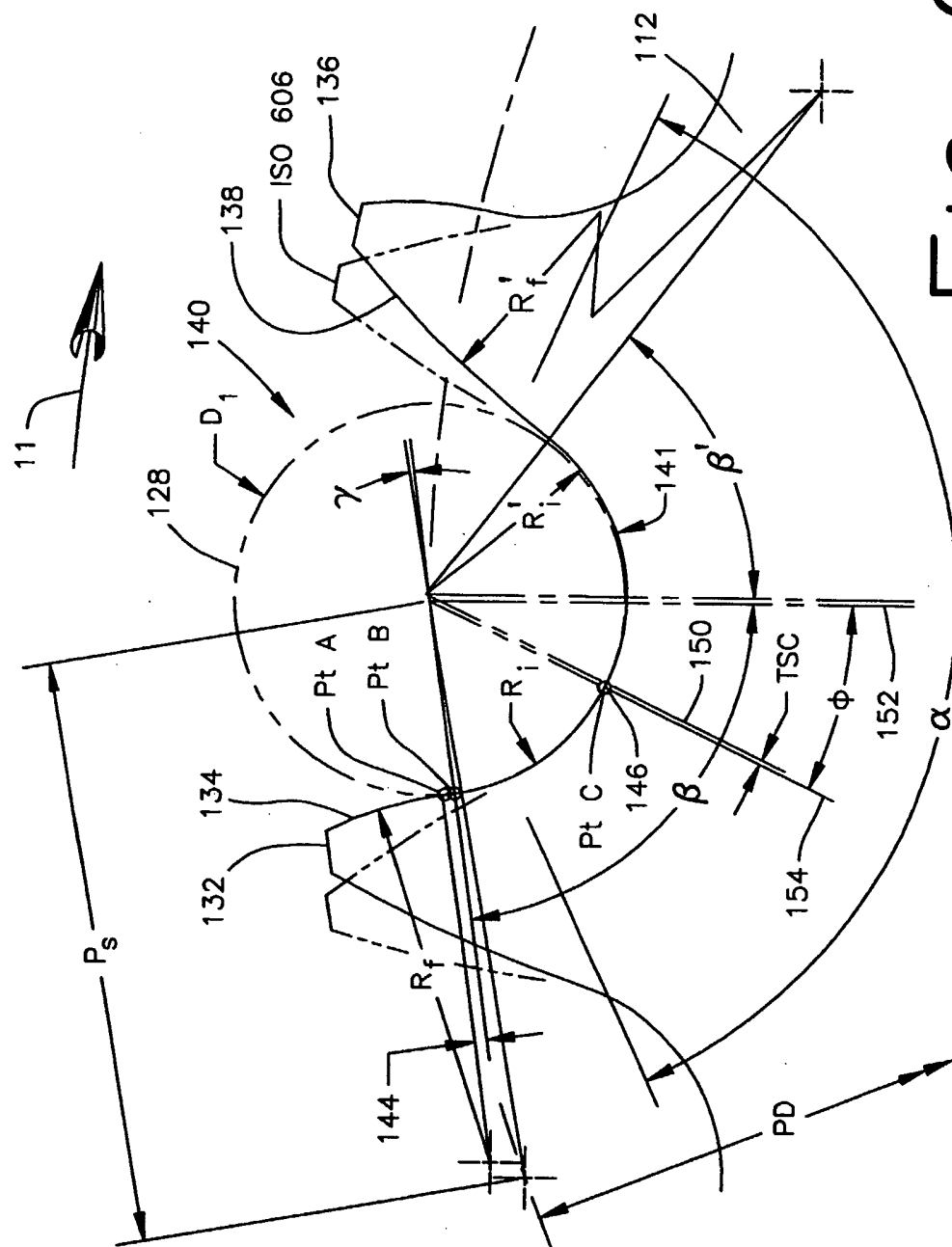


FIG. 9

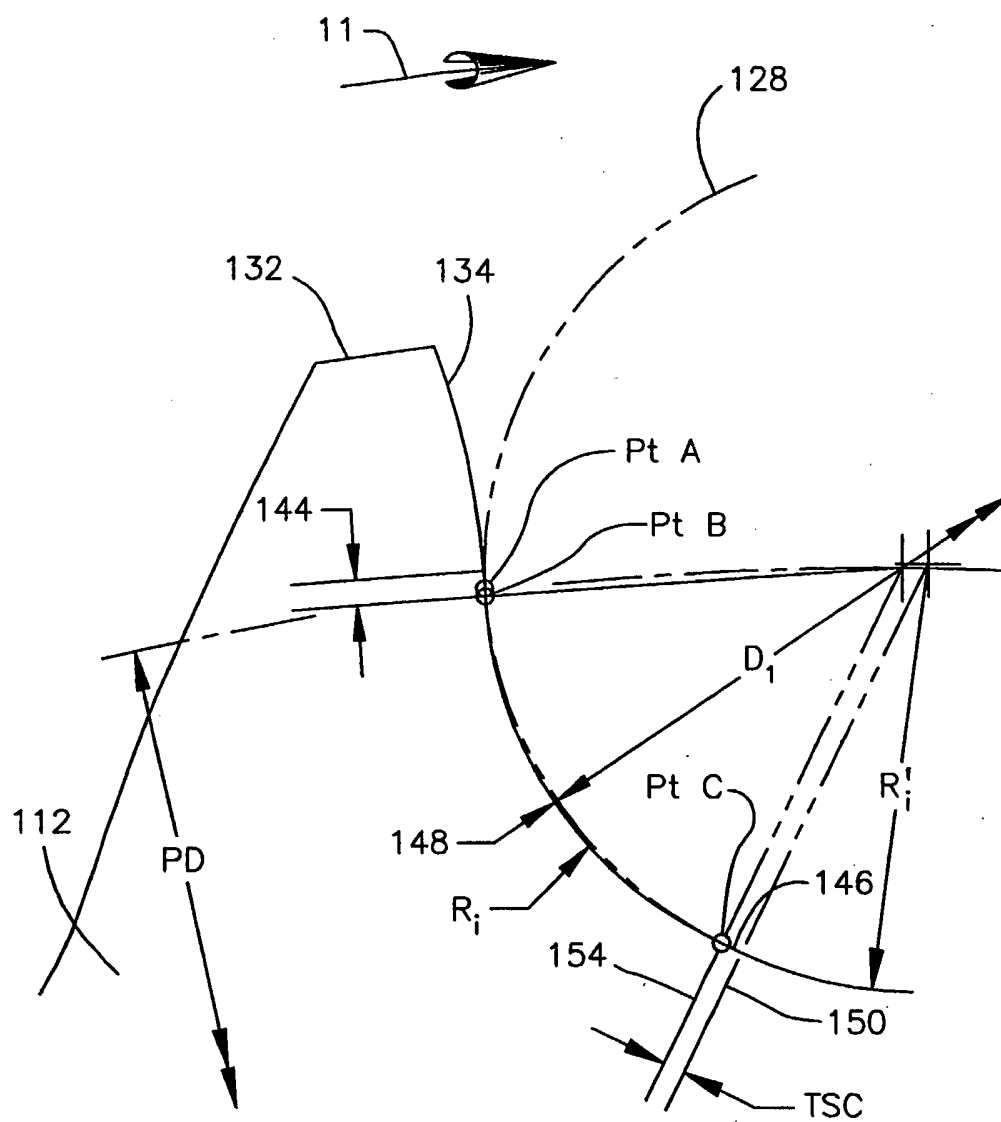


FIG. 10

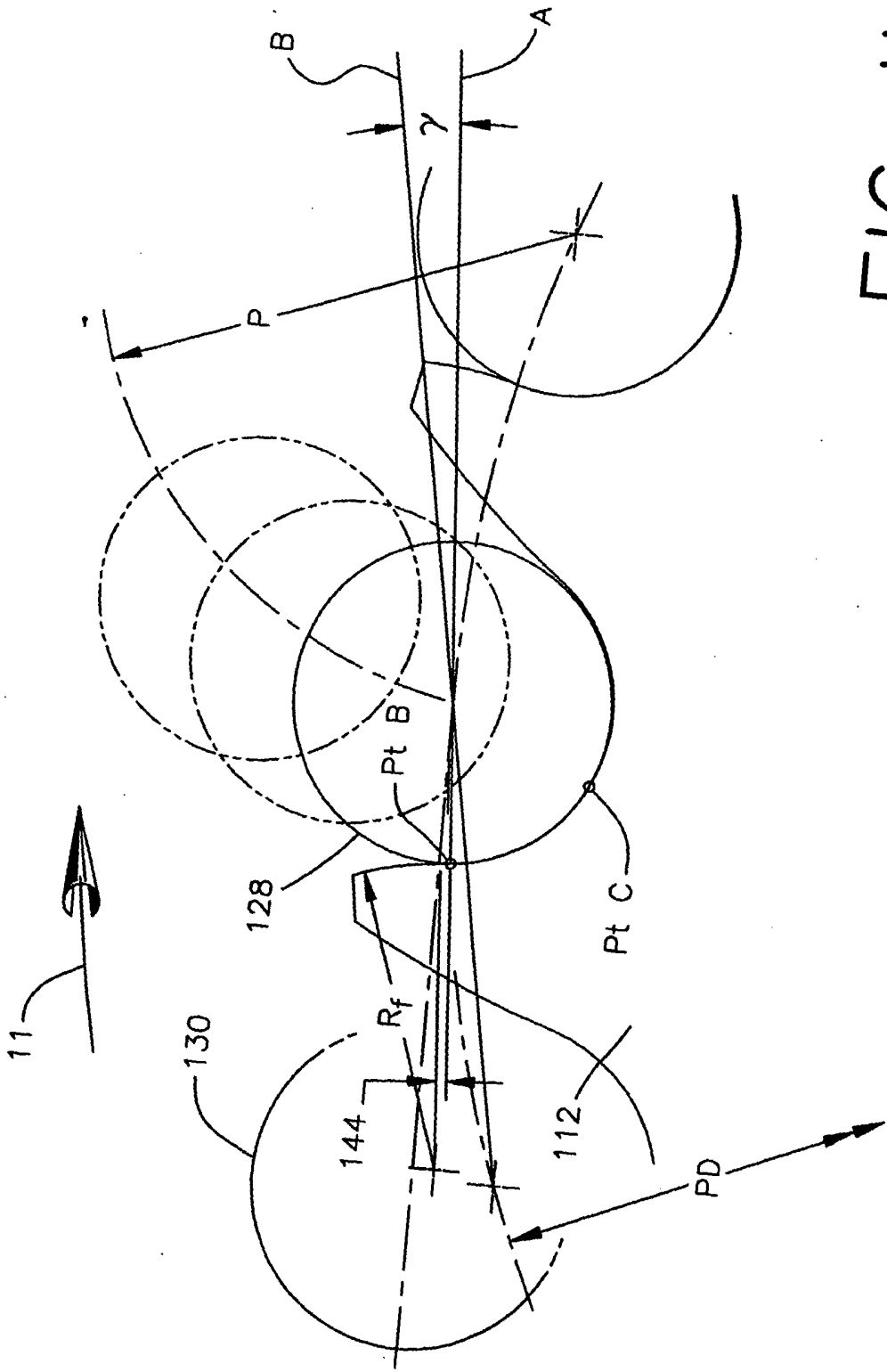


FIG. 11

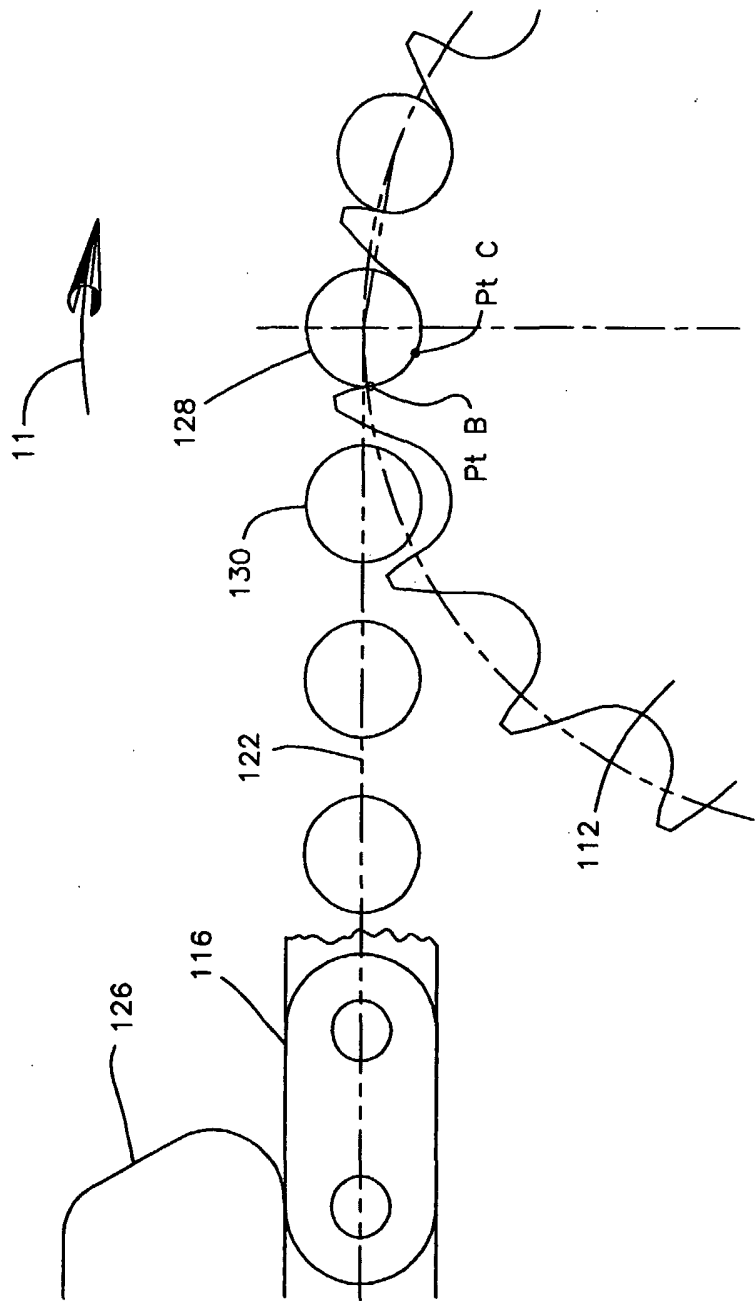


FIG. 12

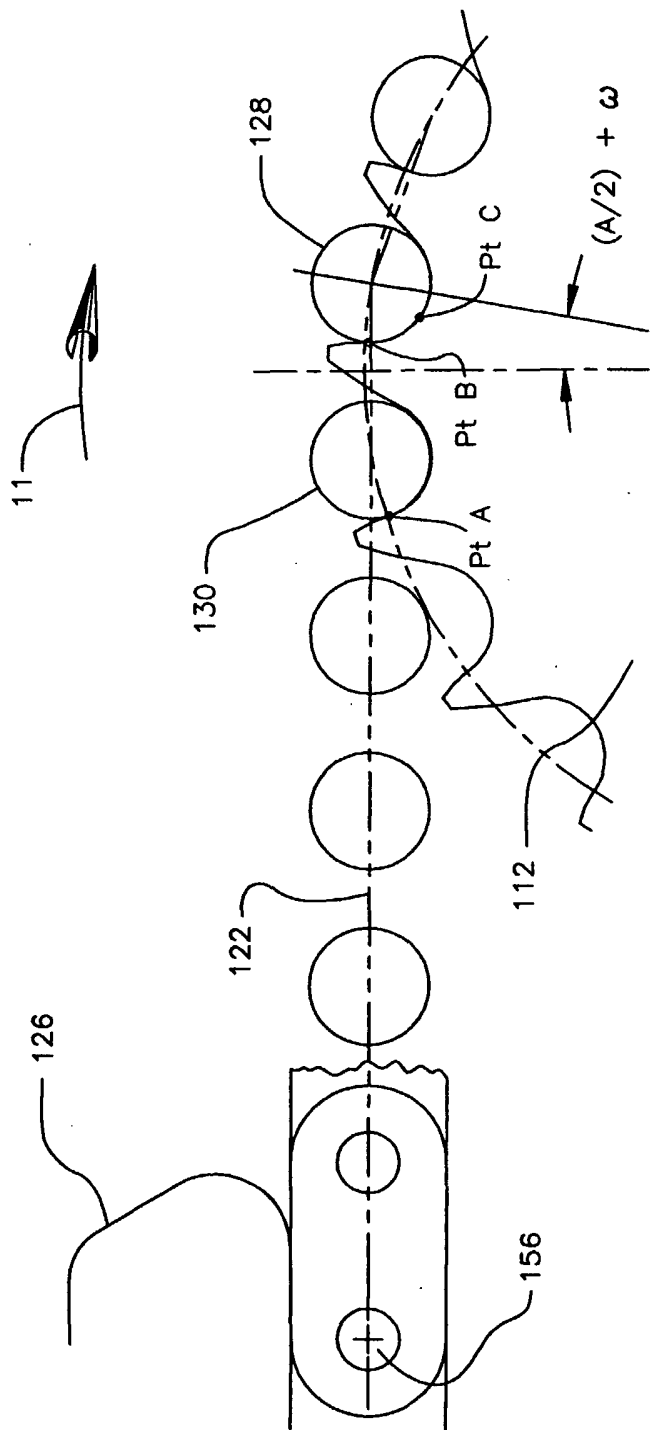


FIG. 13

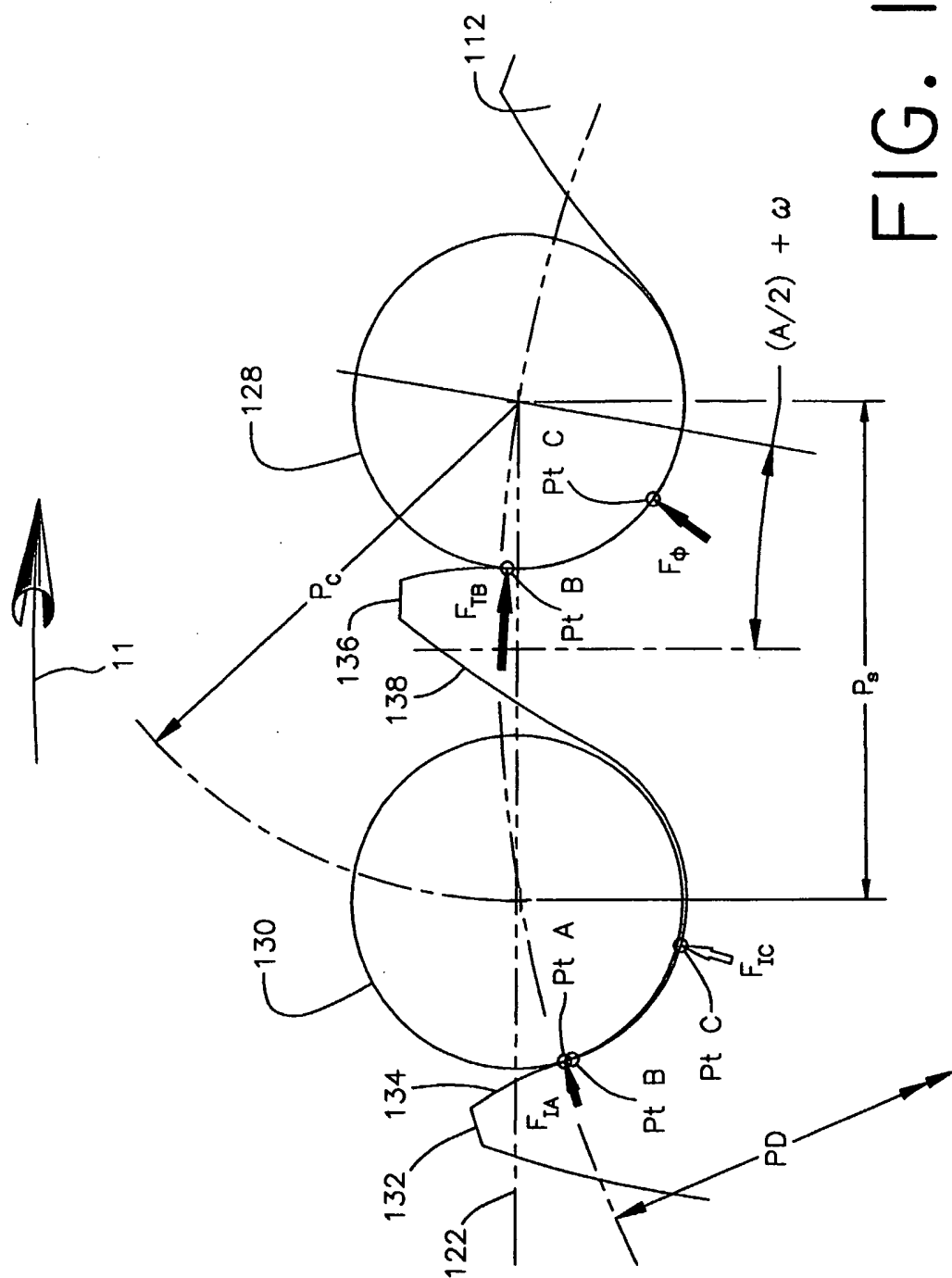


FIG. 14

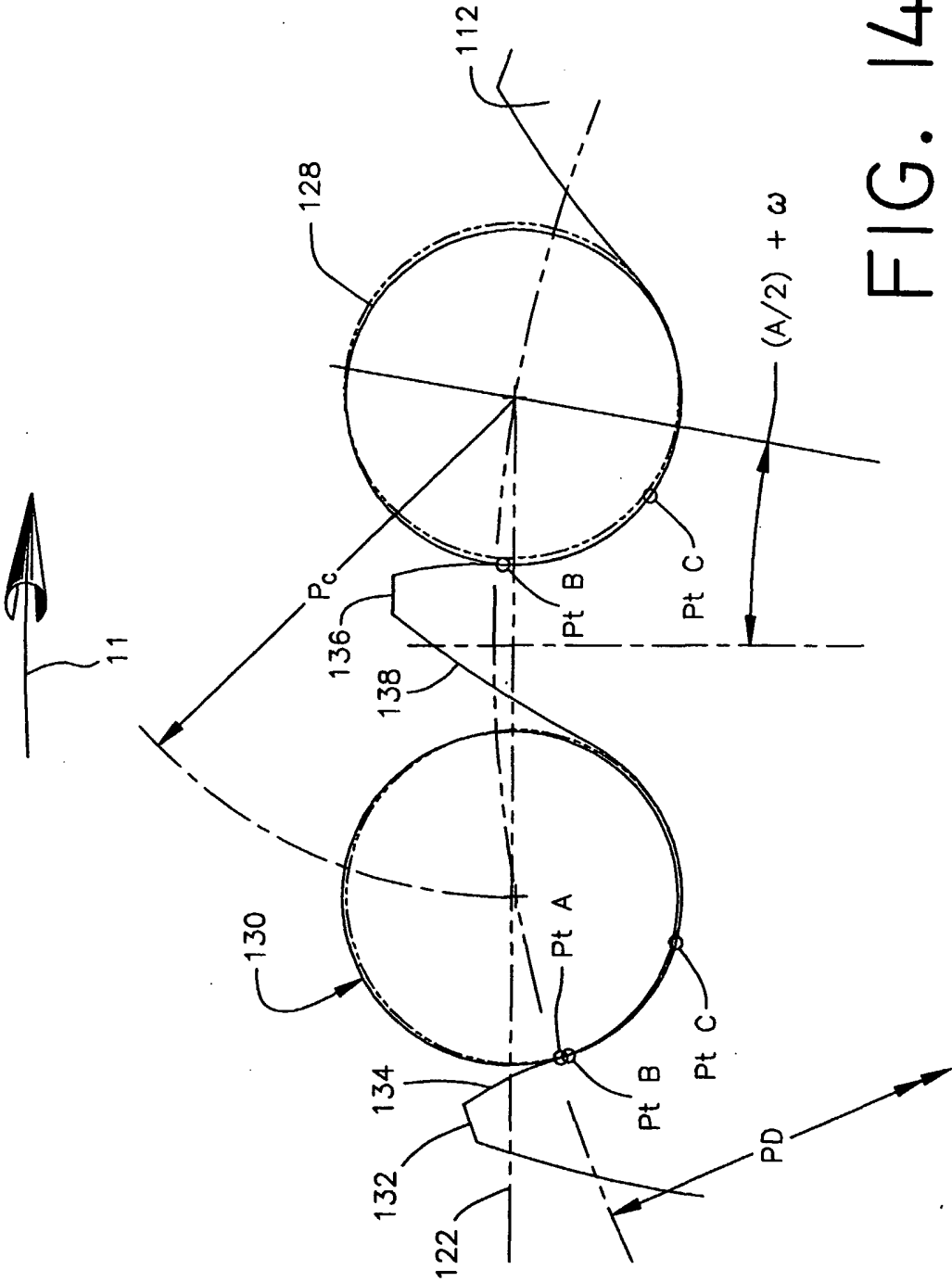


FIG. 14a

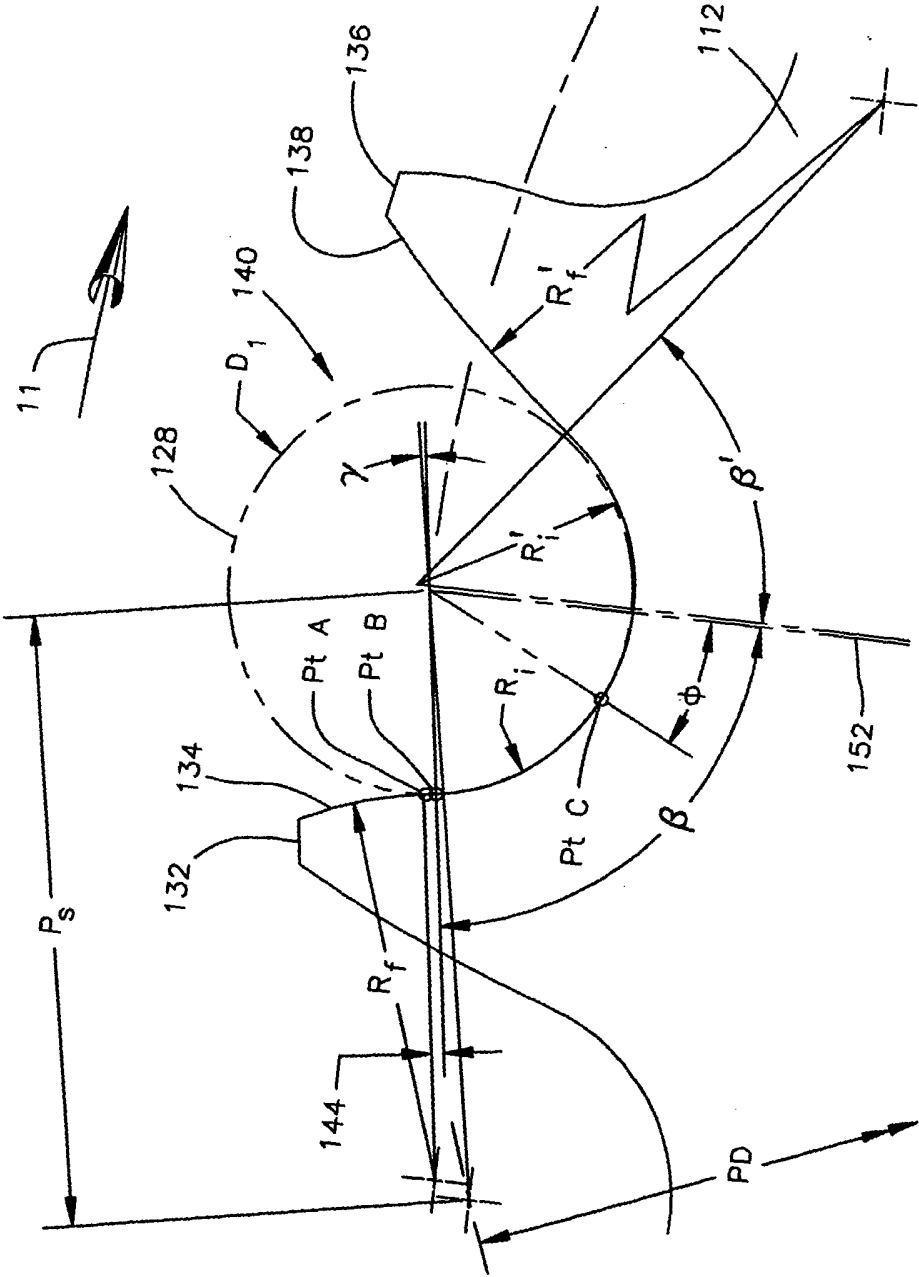


FIG. 15

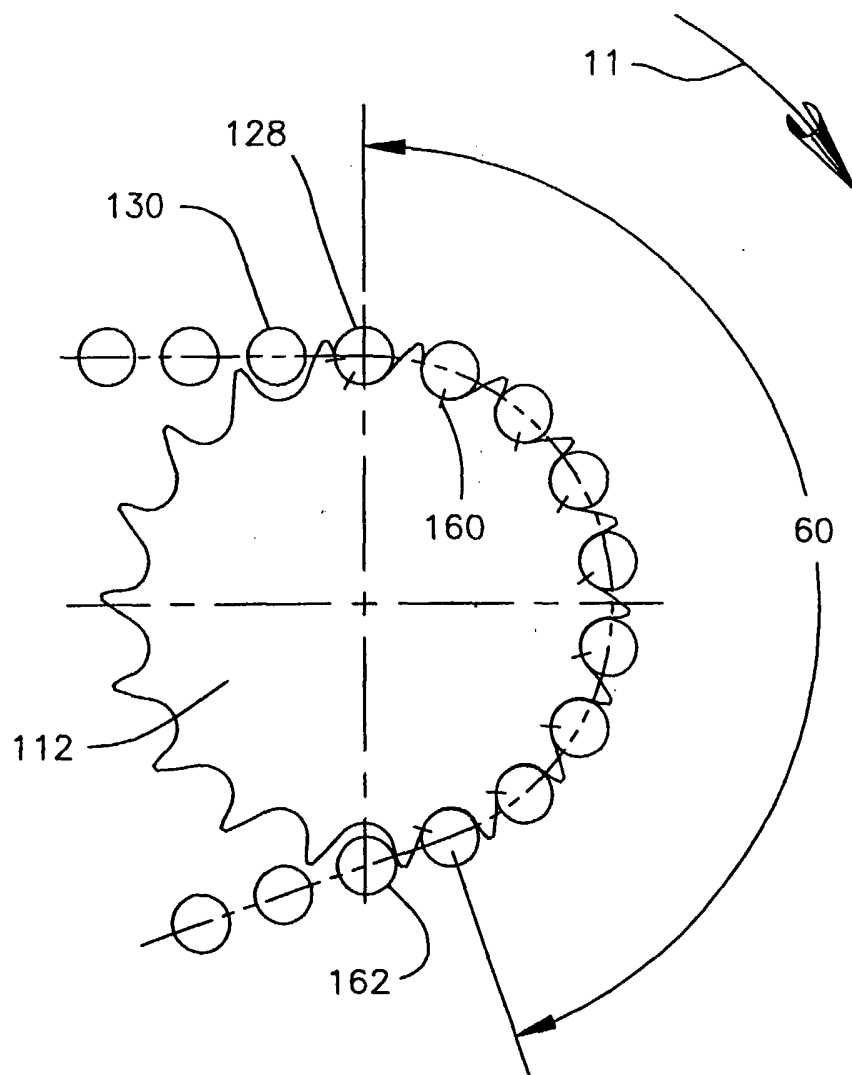


FIG. 16

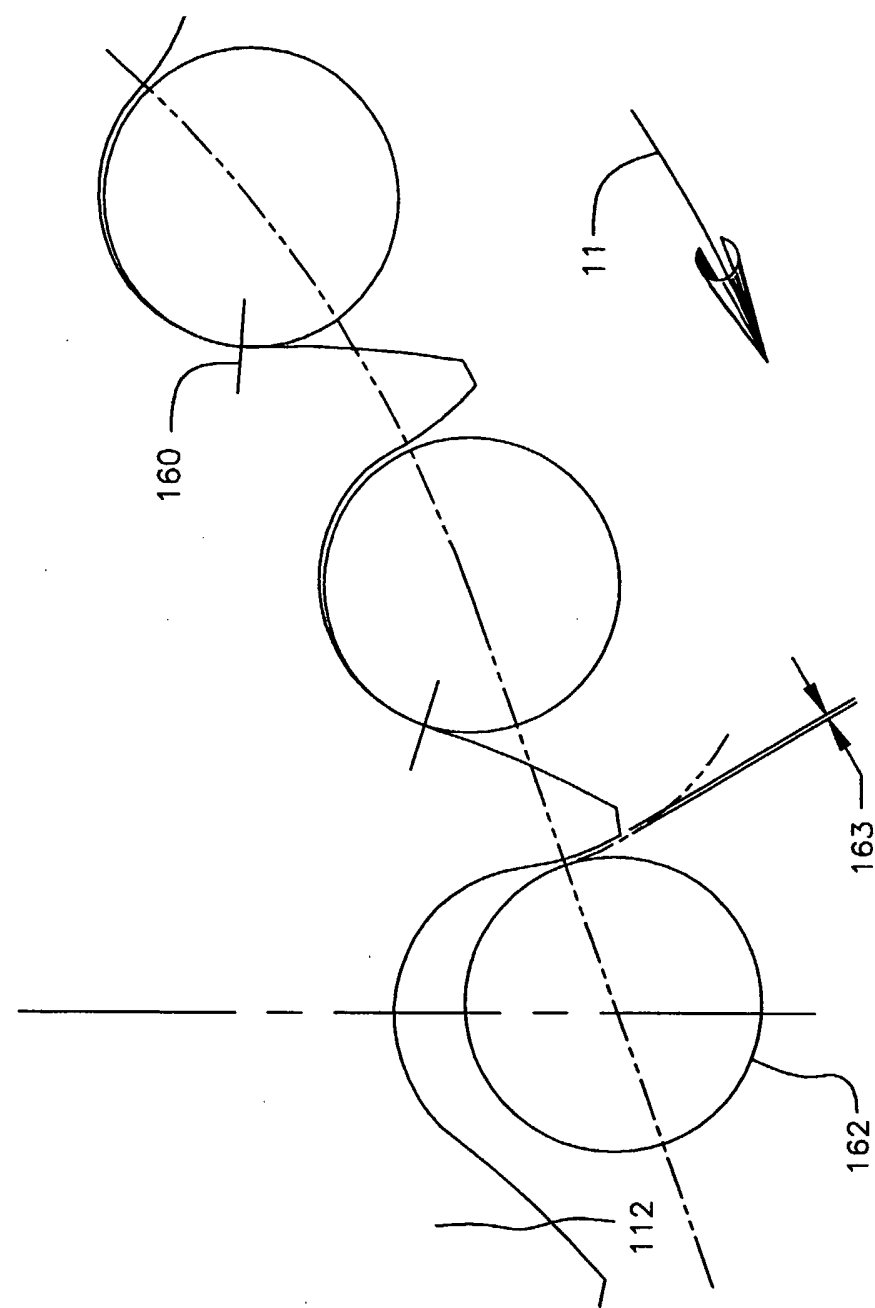


FIG. 17

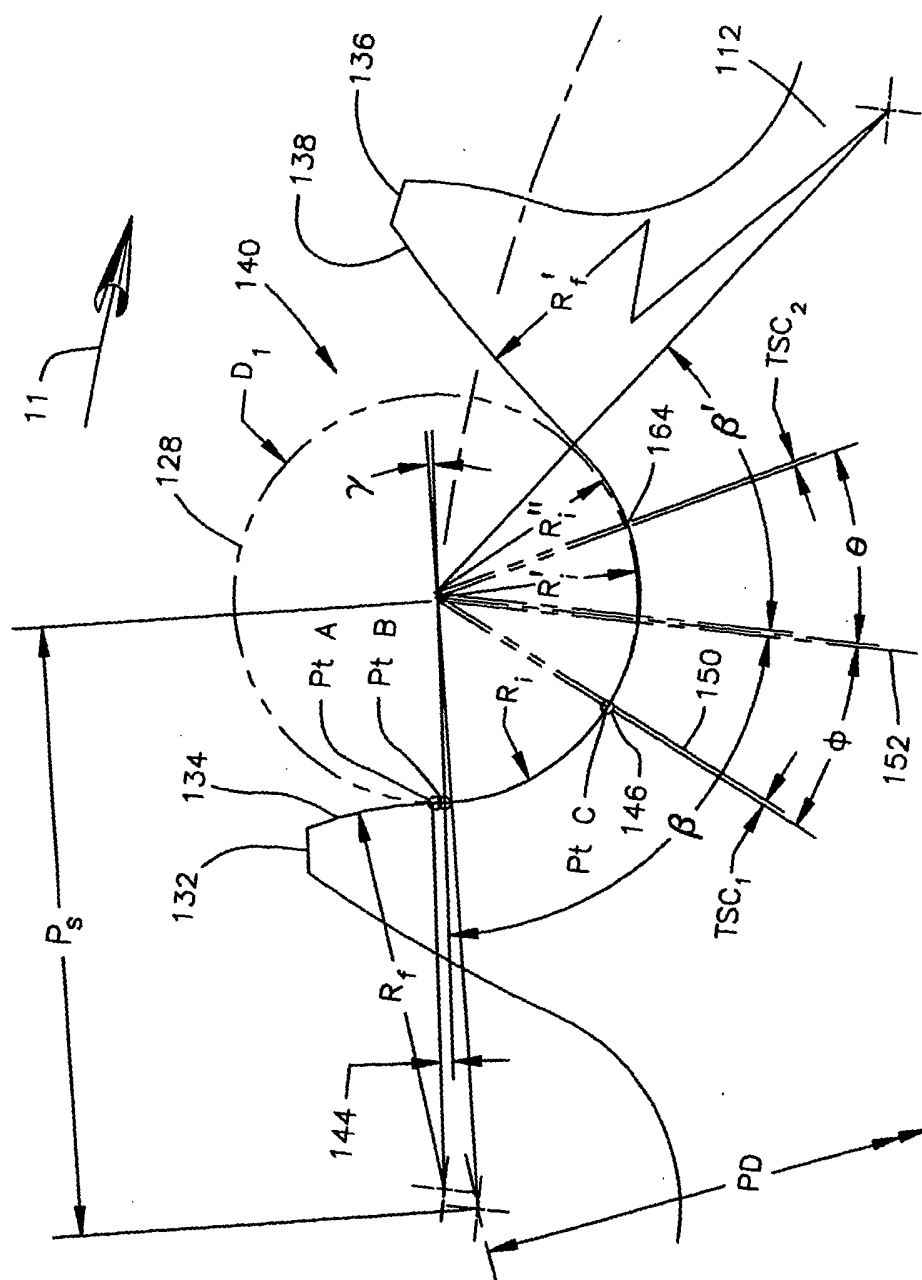


FIG. 19

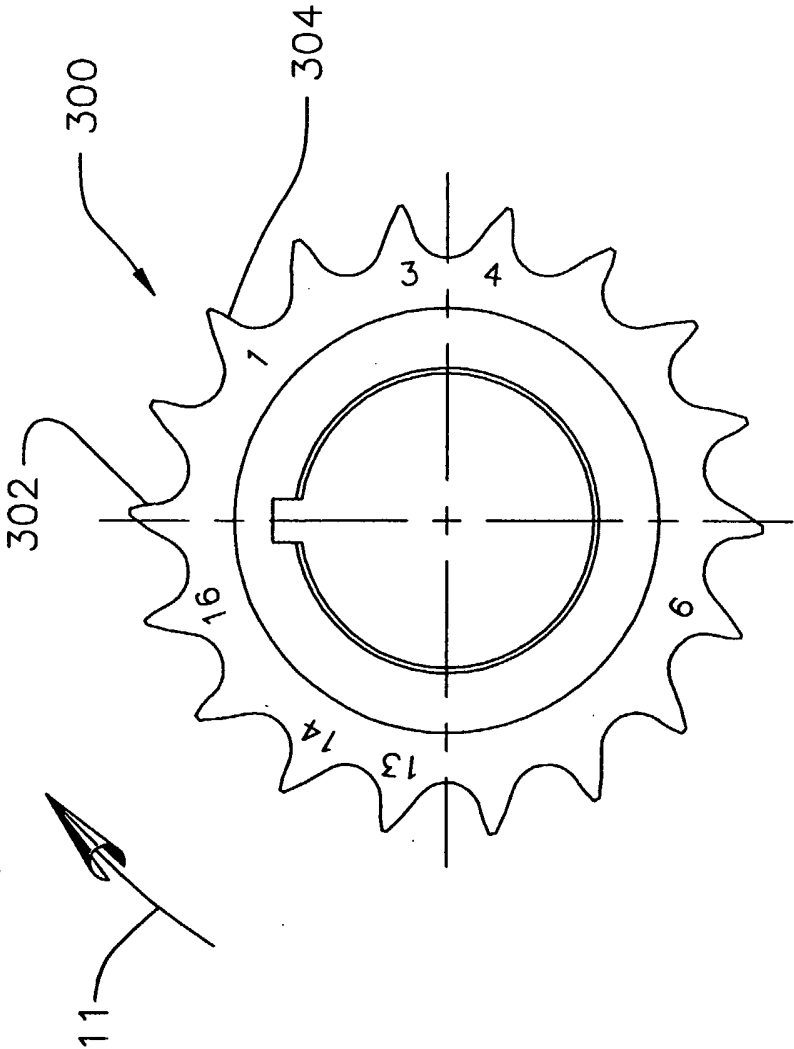


FIG. 20

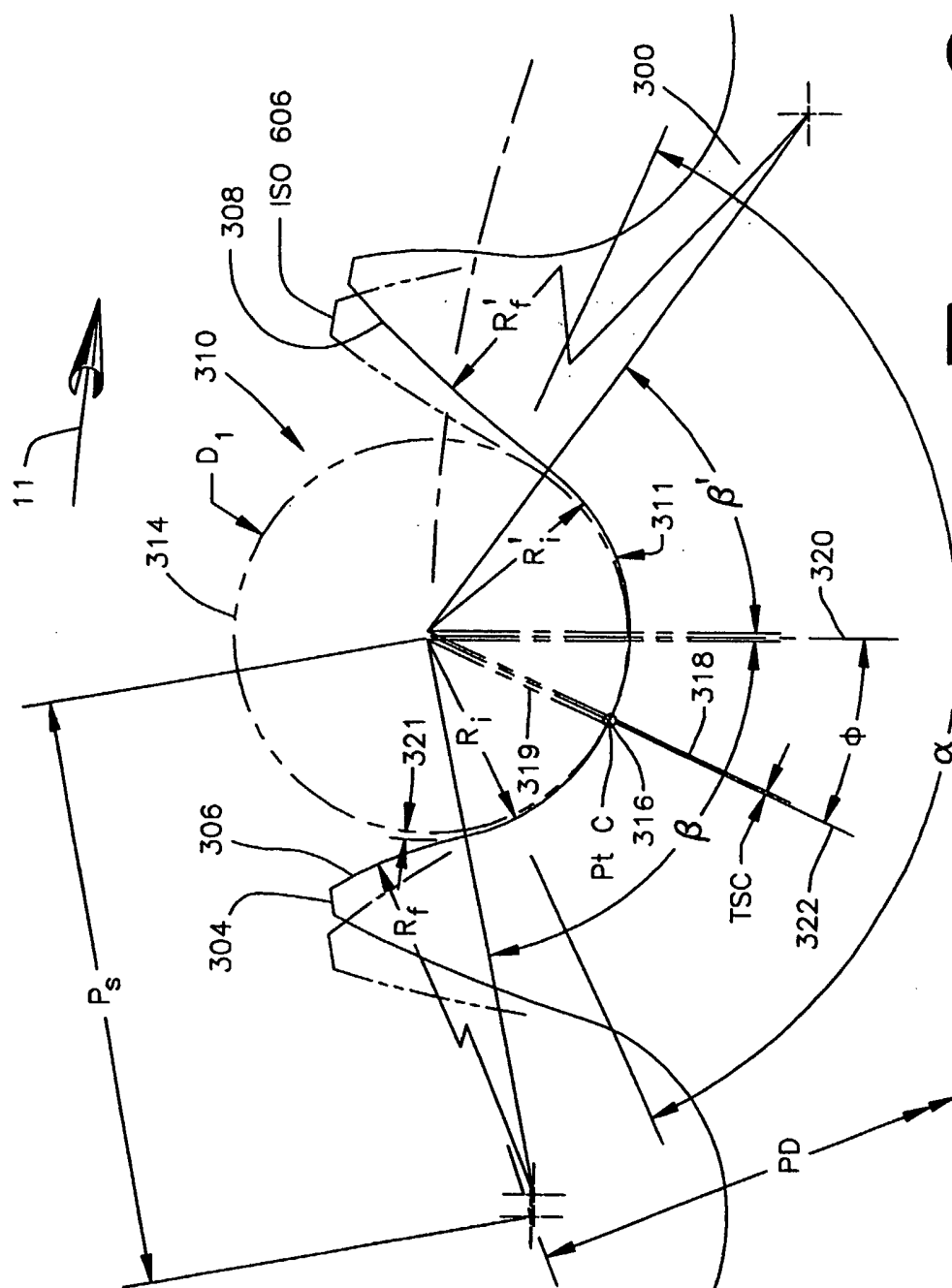


FIG. 21

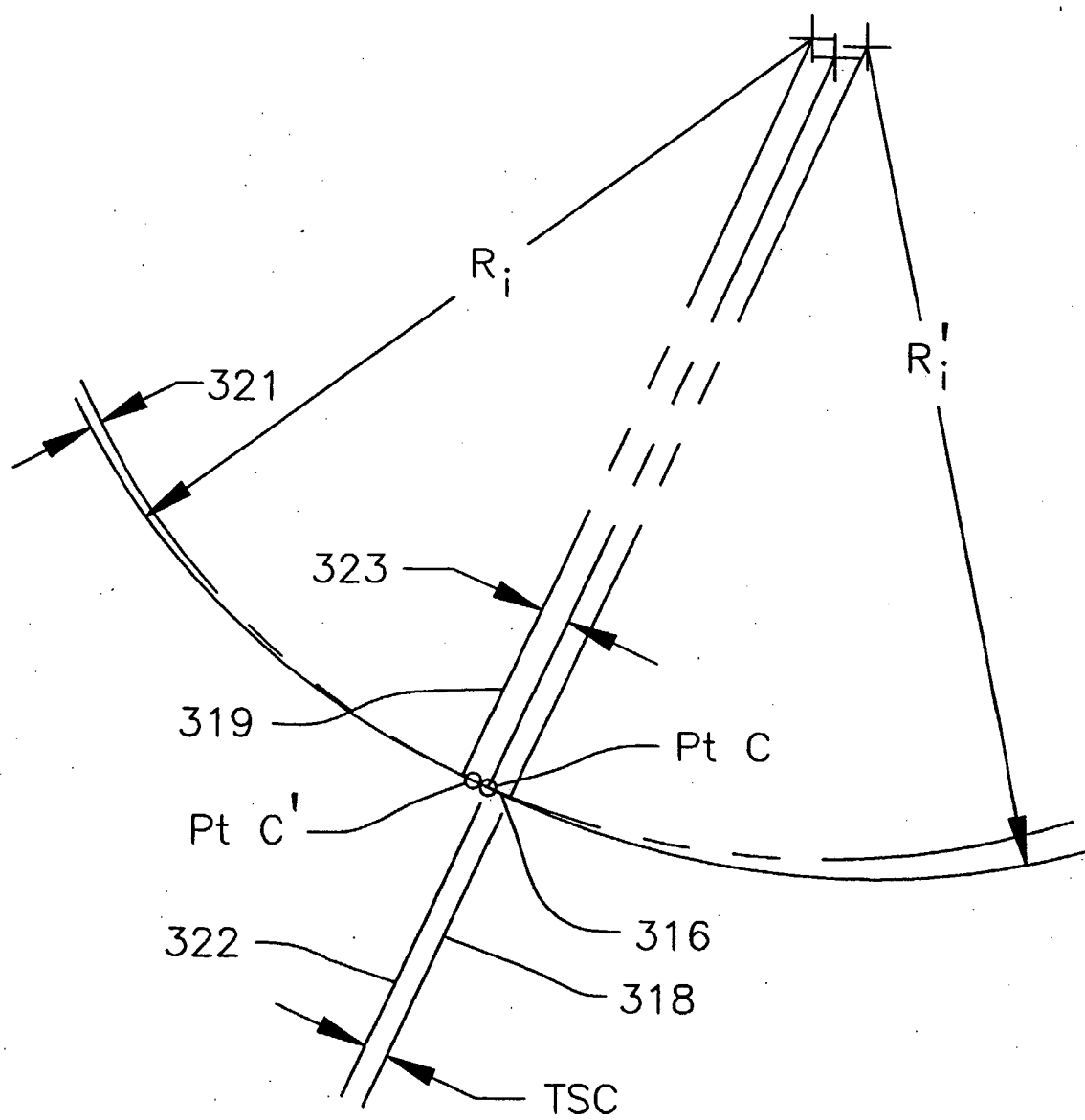


FIG. 21a

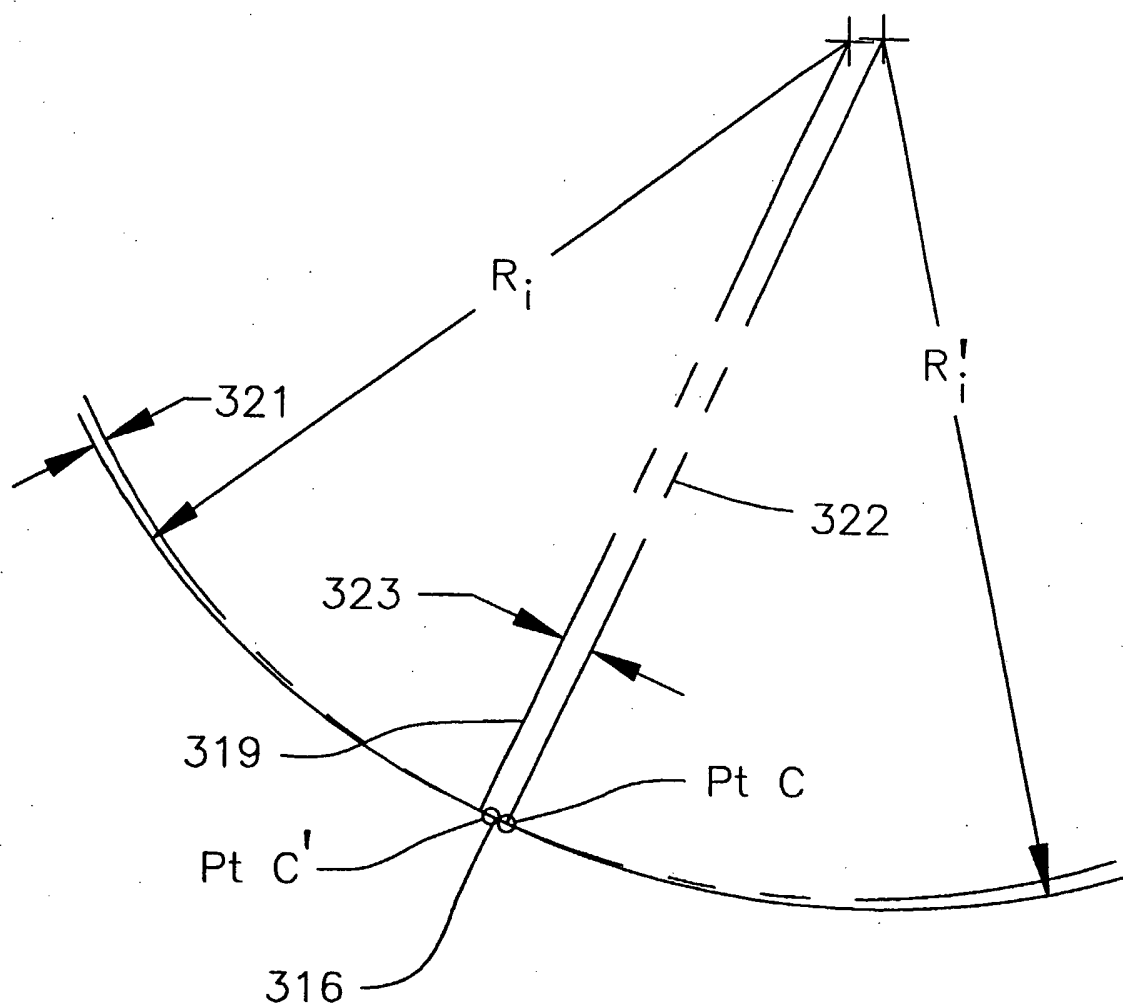


FIG. 22

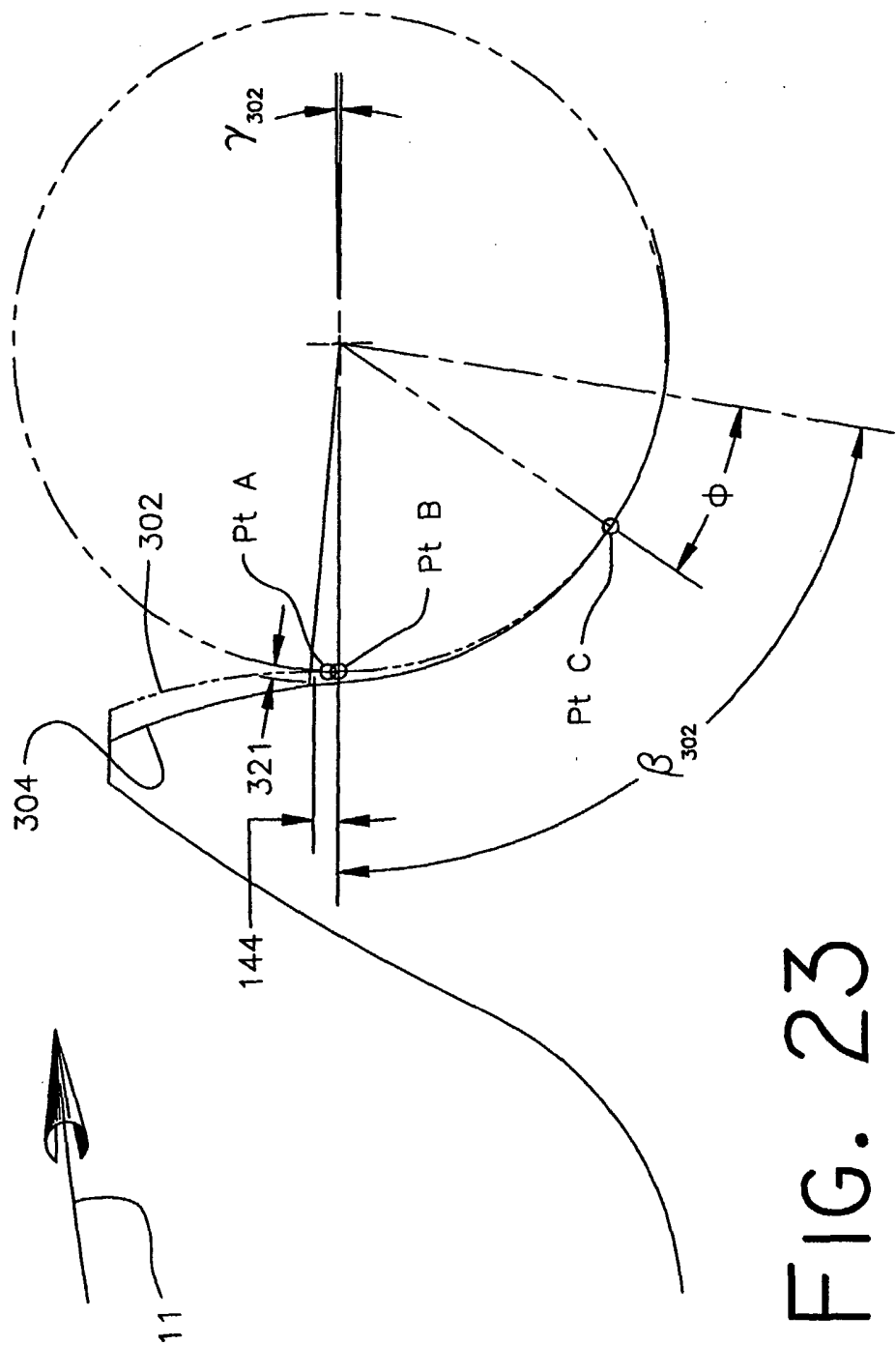


FIG. 23

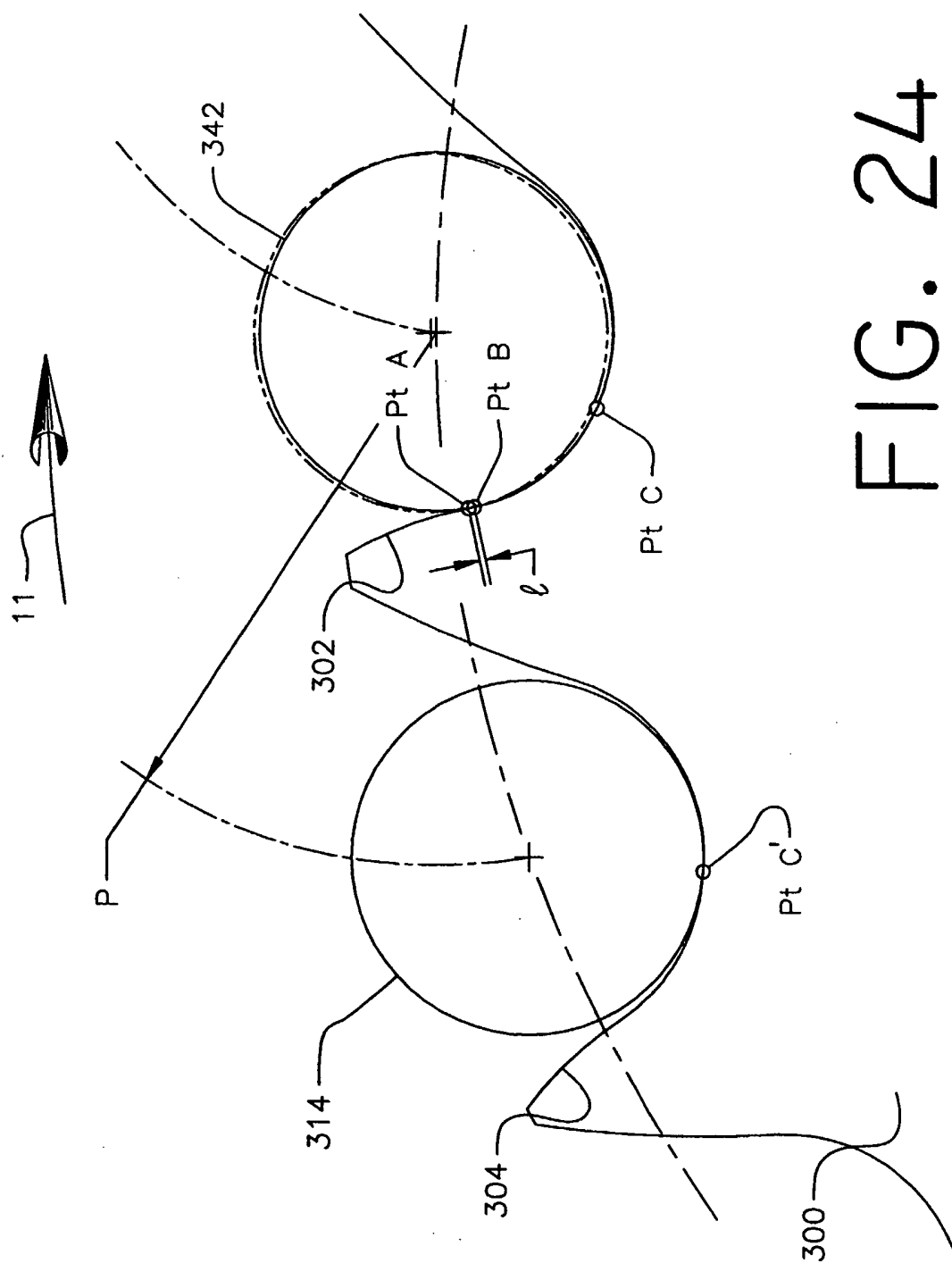


FIG. 24

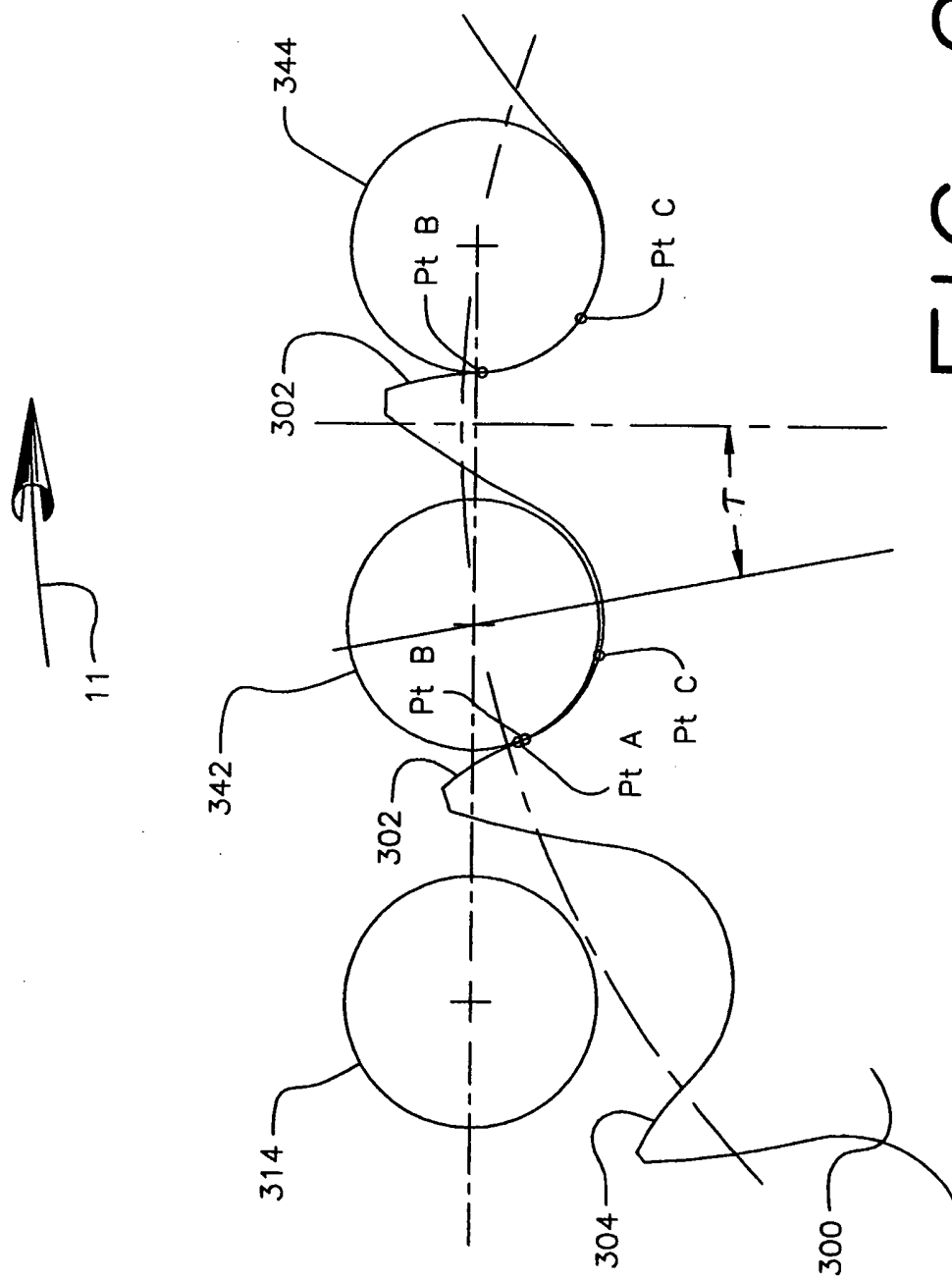


FIG. 25

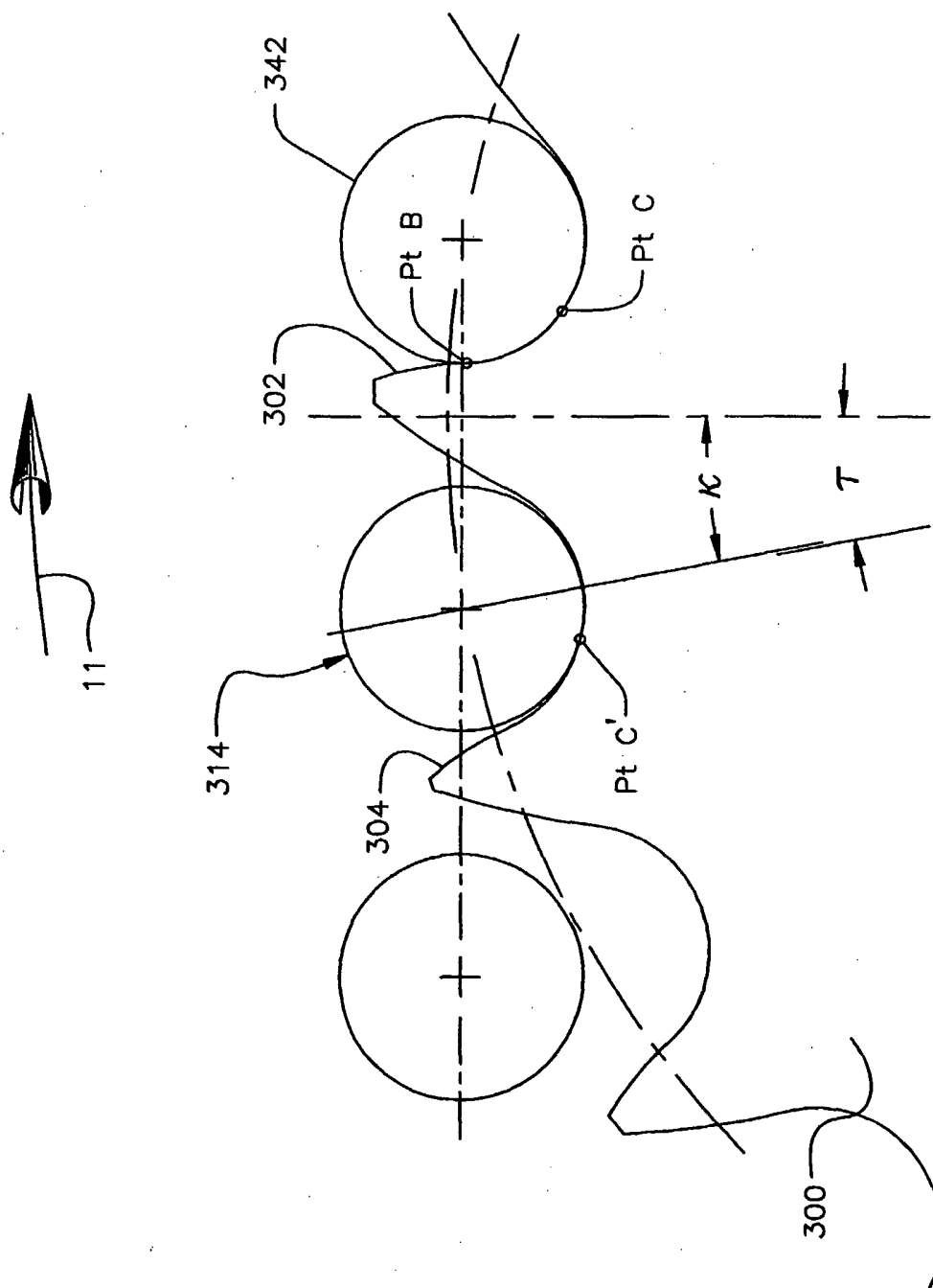


FIG. 26

ISO

Z	A	α		γ	
		(MIN)	(MAX)	(MAX)	(MIN)
18	20.000	115.00	135.00	22.500	12.500
19	18.947	115.26	135.26	22.895	12.895
20	18.000	115.50	135.50	23.250	13.250
21	17.143	115.71	135.71	23.571	13.571
22	16.364	115.91	135.91	23.864	13.864
23	15.652	116.09	136.09	24.130	14.130
24	15.000	116.25	136.25	24.375	14.375
25	14.400	116.40	136.40	24.600	14.600
26	13.846	116.54	136.54	24.808	14.808
27	13.333	116.67	136.67	25.000	15.000
28	12.857	116.79	136.79	25.179	15.179
29	12.414	116.90	136.90	25.345	15.345
30	12.000	117.00	137.00	25.500	15.500

Fig. 27
PRIOR ART

ASYMMETRICAL

1

2

3

Z	A	β		γ		β		γ	
		(MAX)	(MIN)	(MAX)	(MIN)	(MAX)	(MIN)	(MAX)	(MIN)
18	20.000	73.75	6.25	80.00	0	82.00	-2		
19	18.947	74.08	6.45	80.53	0	82.53	-2		
20	18.000	74.38	6.63	81.00	0	83.00	-2		
21	17.143	74.64	6.79	81.43	0	83.43	-2		
22	16.364	74.89	6.93	81.82	0	83.82	-2		
23	15.652	75.11	7.07	82.17	0	84.17	-2		
24	15.000	75.31	7.19	82.50	0	84.50	-2		
25	14.400	75.50	7.30	82.80	0	84.80	-2		
26	13.846	75.67	7.40	83.08	0	85.08	-2		
27	13.333	75.83	7.50	83.33	0	85.33	-2		
28	12.857	75.98	7.59	83.57	0	85.57	-2		
29	12.414	76.12	7.67	83.79	0	85.79	-2		
30	12.000	76.25	7.75	84.00	0	86.00	-2		

Fig. 28

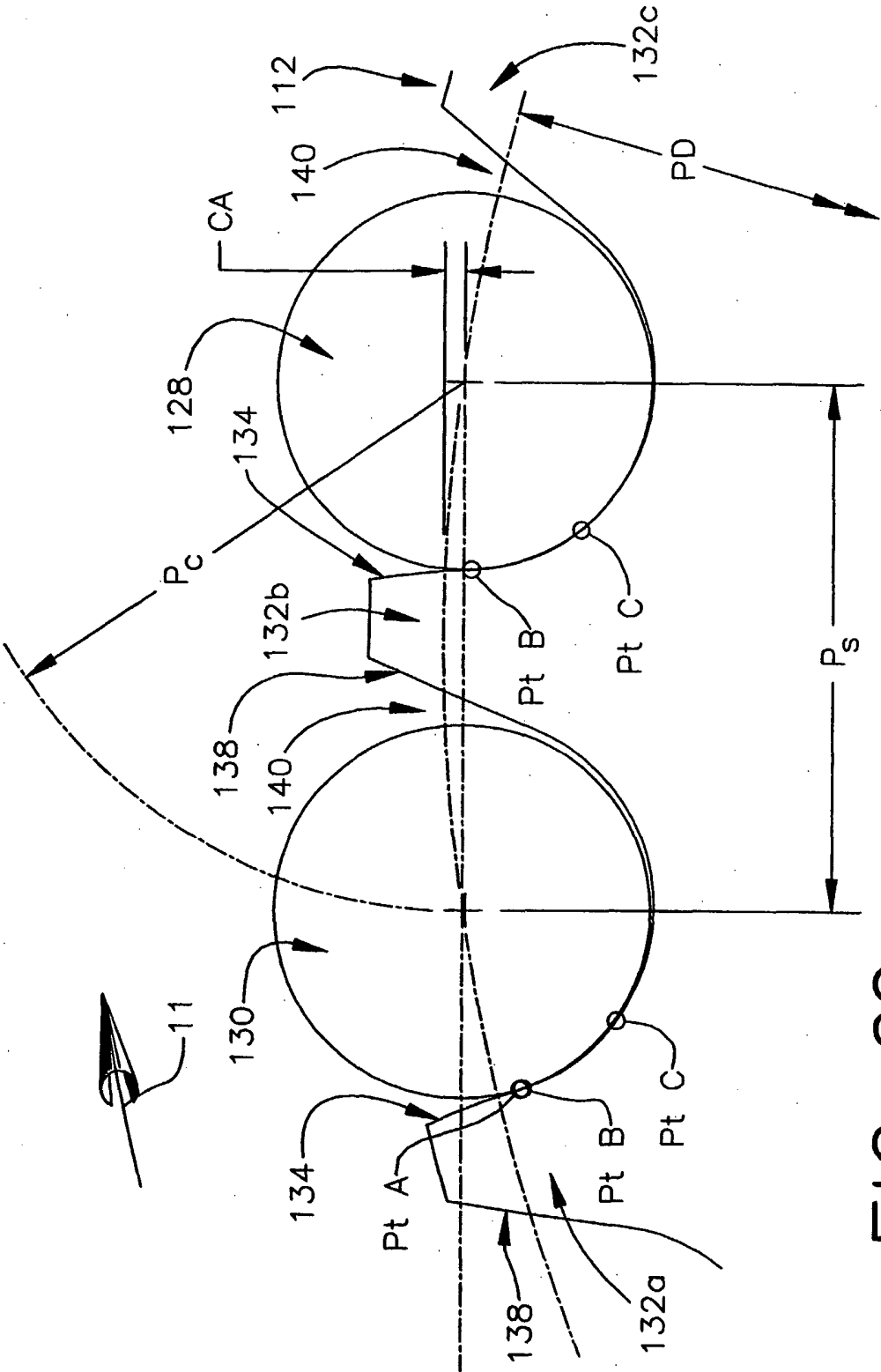


FIG. 29

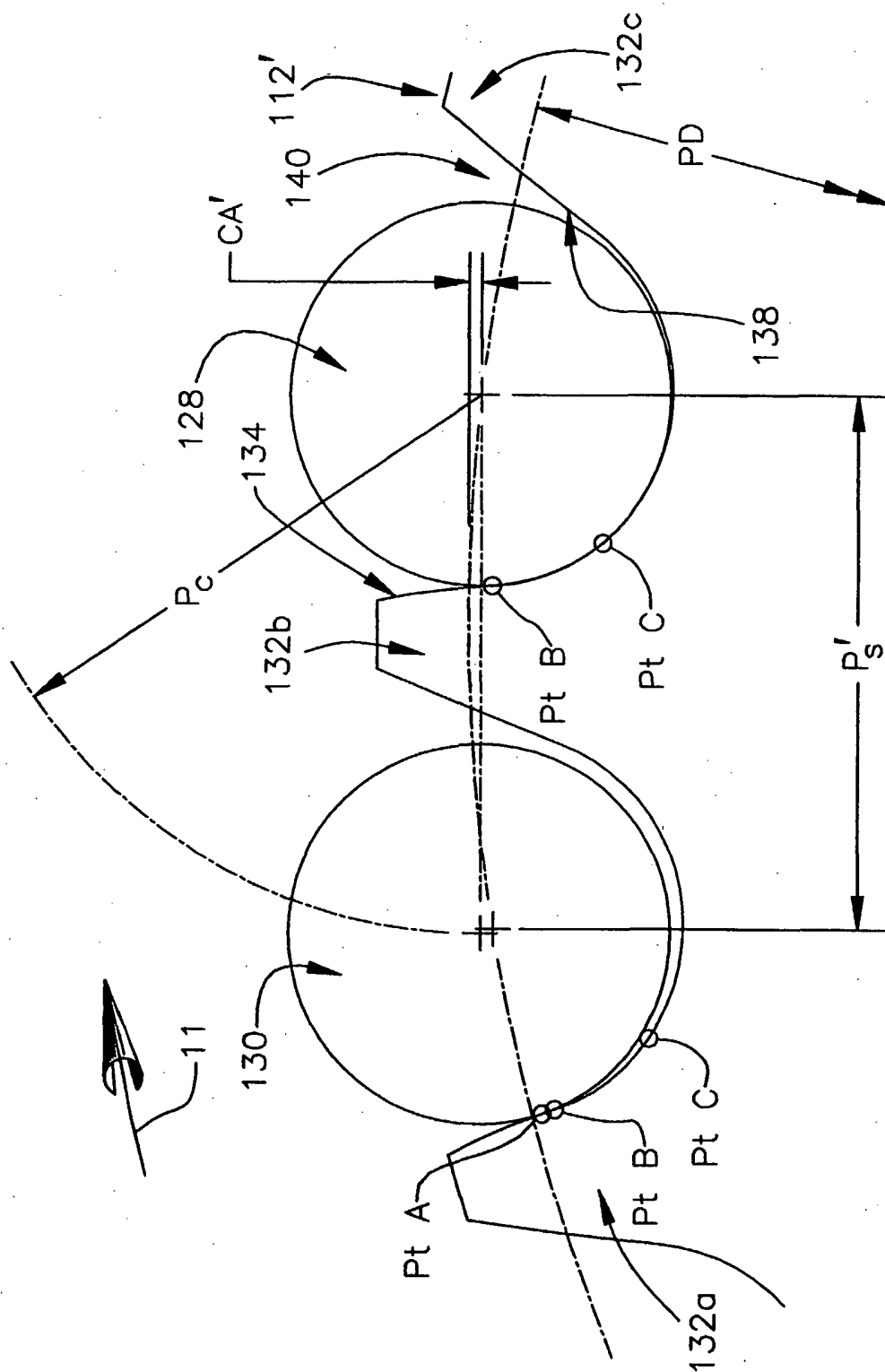


FIG. 30

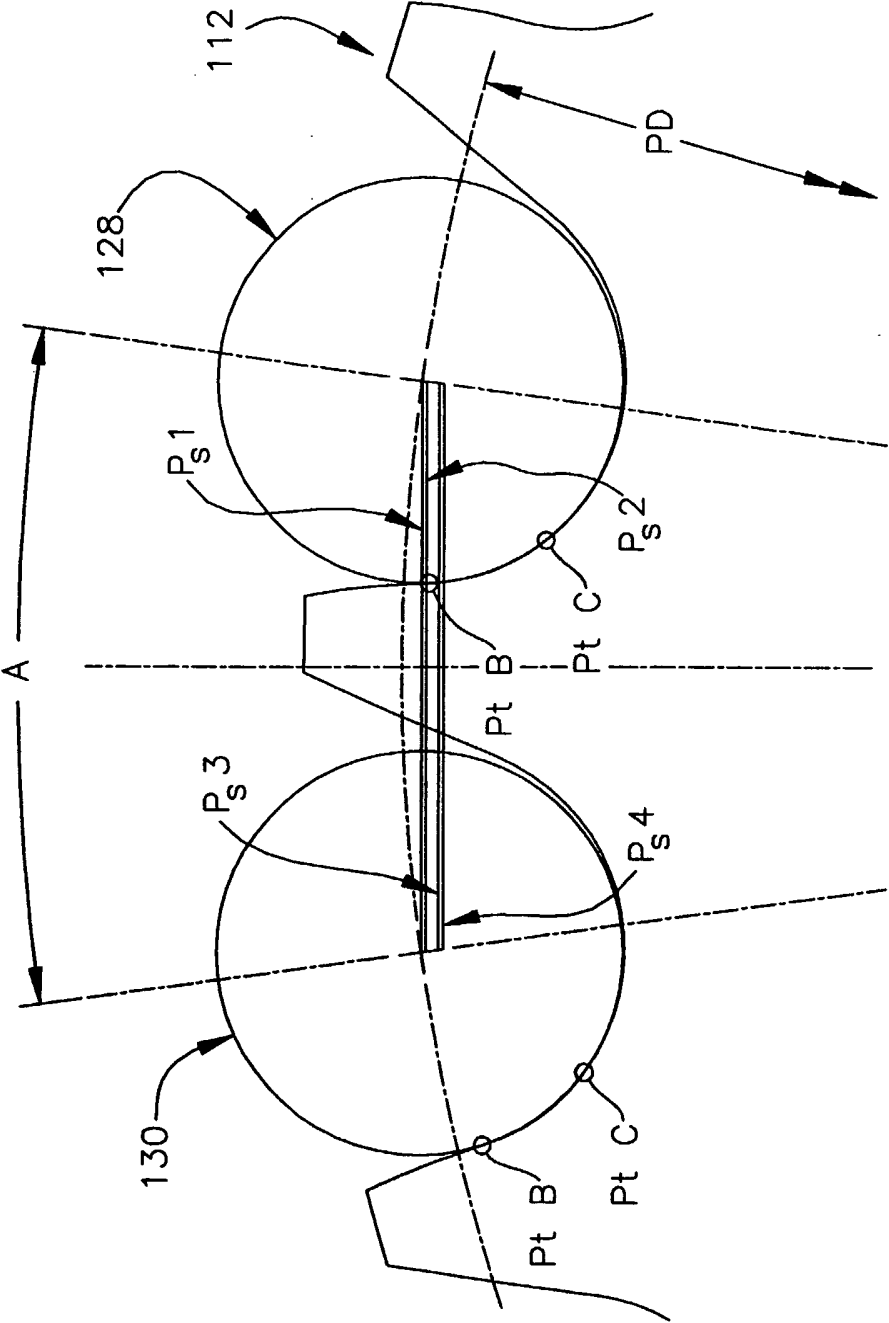


FIG. 31