United States Patent

Stade

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[54] **WORM DRIVE WITH CYLINDRICAL WORM**

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[73] Assignee: **Firma Herbert Lidner GmbH,** Berlin, Germany

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[30] **Foreign Application Priority Data**

Nov. 27, 1969 Germany..........P 19 60 464.9

[52] **U.S. Cl.**.......................................**74/427,** 74/468

[51] **Int. Cl.**............................**F16h 1/08,** F16h 57/04

[58] **Field of Search**..........................74/427, 458, 468

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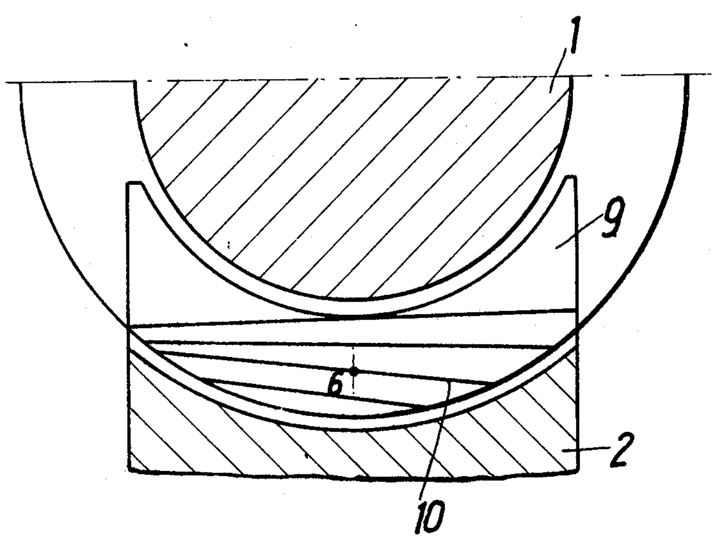
Primary Examiner—Leonard H. Gerin

Attorney—McGlew and Toren

[57] **ABSTRACT**

A worm drive is formed of a cylindrical worm which meshes with a worm wheel, and the cylindrical worm has cycloidally shaped flanks. The combined configurations of the worm and worm wheel provides two lines of contact between their corresponding flanks when they are in meshed engagement.

3 Claims, 21 Drawing Figures



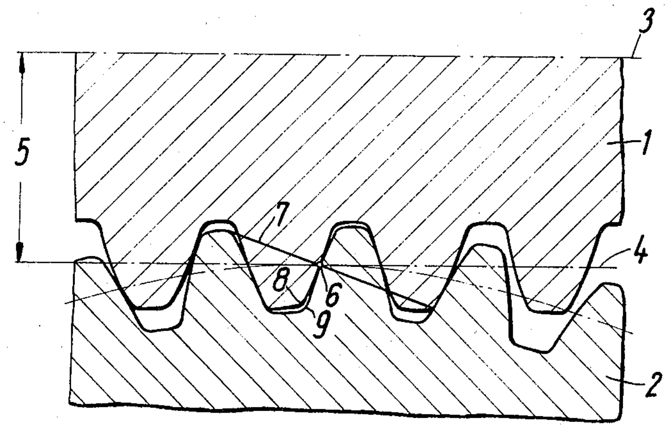


Fig.1

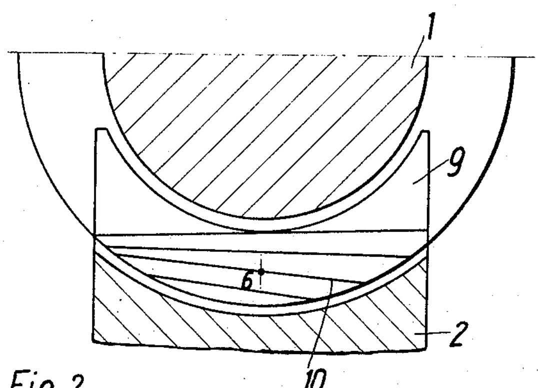


Fig.2

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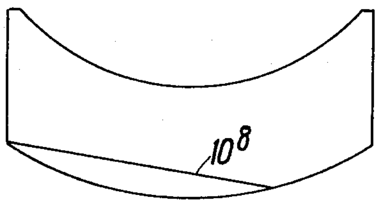

Fig. 3h

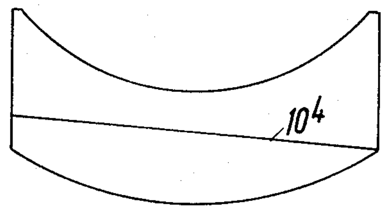

Fig. 3d

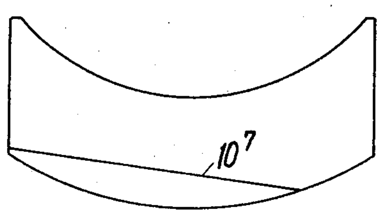

Fig. 3g

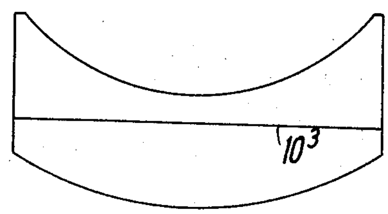

Fig. 3c

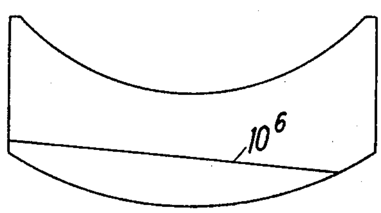

Fig. 3f

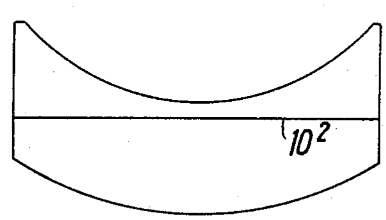

Fig. 3b

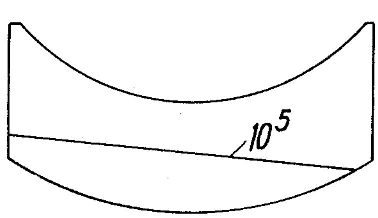

Fig. 3e

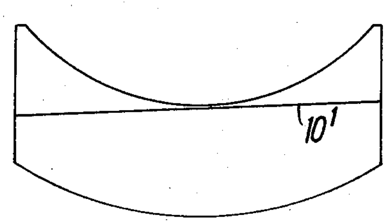

Fig. 3a

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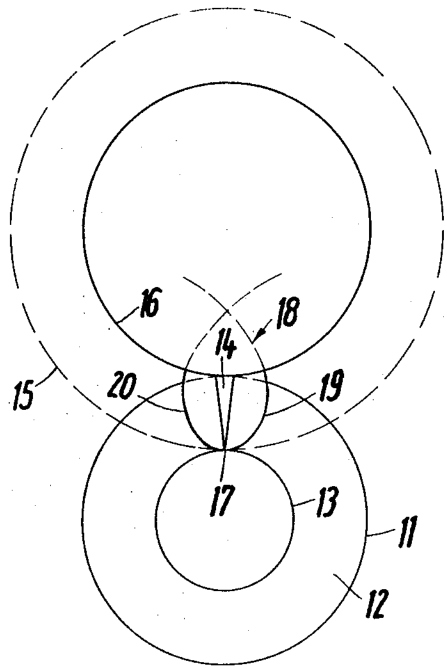

Fig. 4

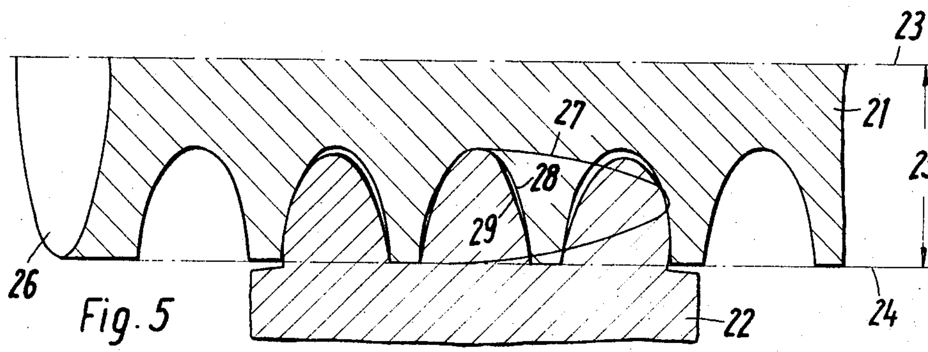

Fig. 5

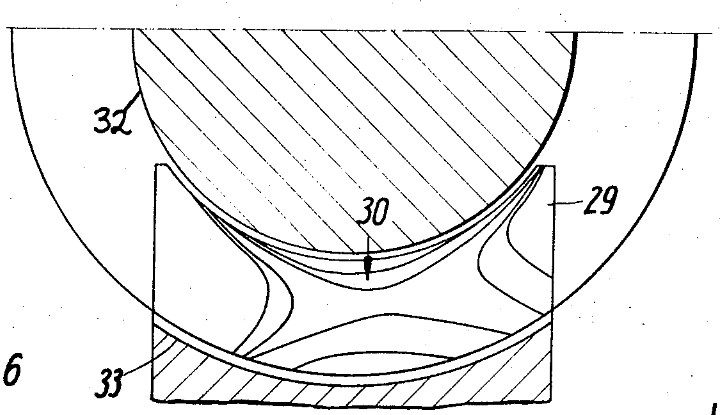

Fig. 6

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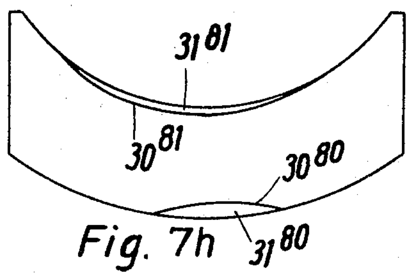

Fig. 7h

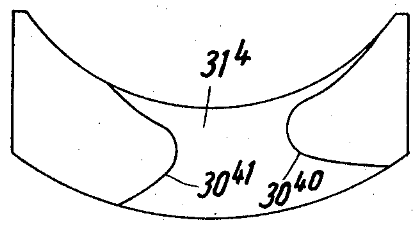

Fig. 7d

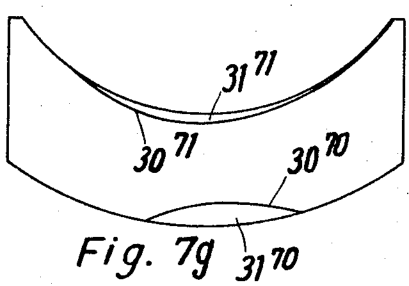

Fig. 7g

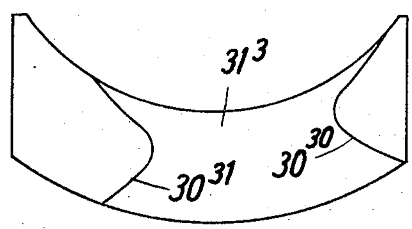

Fig. 7c

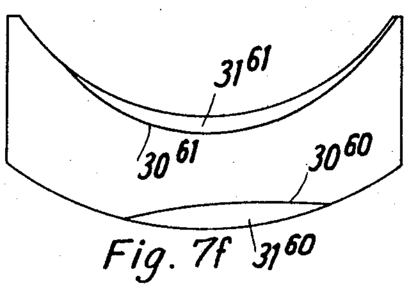

Fig. 7f

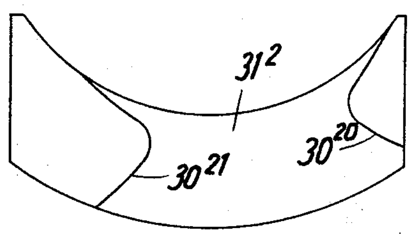

Fig. 7b

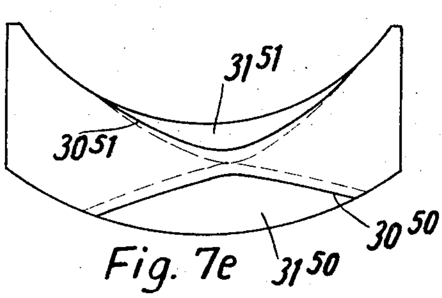

Fig. 7e

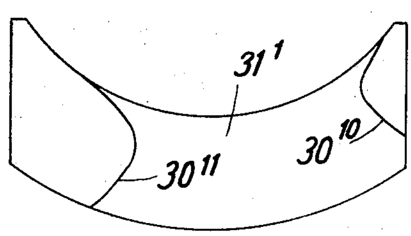

Fig. 7a

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WORM DRIVE WITH CYLINDRICAL WORM

SUMMARY OF THE INVENTION

The present invention is directed to a worm drive with a cylindrical worm and, more particularly, it is directed to a cylindrical worm having cycloidally shaped flanks.

Worm drives including cylindrical worms have been known in the past. In all worm drives, the shape of the worm wheel flanks is determined by the shape of the flanks on the worm. In operation, the worm meshes with the worm wheel and both of them form the worm drive. The input is transmitted to the worm wheel through the medium of the tooth flanks of the worm drive rolling on one another.

Worm drives are known which exhibit, in the longitudinal center section of the worm, a trapezoidal straight line flank profile of the worm teeth (trapezoidal worms) or a trapezoidal-convex flank profile of the worm teeth (involute worm). Further, there are also known worm drives with a trapezoidal-concave flank profile of the teeth, which are called hollow flank worms.

The flanks or sides of the worm are usually milled and subsequently ground to provide a better surface quality. For supplying reproducible worms, identical and interchangeable, in large production batches, the worm flanks and, in addition, the flanks of the worm wheel must be developed using milling cutters and then ground to shape by dressing the grinding wheels so that the same profile is formed each time, regardless of the diameter of the member being shaped.

Known involute worm drives meet this specification. Such worm drives are preferred in practice because they are reproducible. However, involute worm drives have the disadvantage of inadequate flank contact which occurs only along a line of contact between the flanks on the worm and the flanks on the worm wheel.

In worm drives, the lines of contact are those lines on the flank surfaces along which the worm tooth flank and the worm wheel tooth flank touch in the momentary angular positions of the worm drive. When the worm is rotated, which in turn rotates the worm wheel, the position and shape of the lines of contact vary as the meshed engagement of the teeth change.

As mentioned above, in involute worm drives, there is a single line of contact between the contacting flank surfaces which must transmit the driving force. Essentially, in such worm drives, the line of contact is straight and, as a result, the desired lubricating pressure cannot develop between the mutually contacting flank surfaces. Accordingly, involute worm drives experience a power loss due to the friction which occurs between the contacting flanks of the teeth on the worm and on the worm wheel.

The same disadvantages as mentioned above, occur in trapezoidal worms.

Compared to both the trapezoidal and the involute worms, the hollow flank worms show a better bearing or contacting behavior. Due to the hollow shape of the worm wheel, the flank profiles of the teeth, under load, are in contact with each other in a somewhat larger area, however, even in this hollow construction only one line of contact exists between the adjacent tooth flanks. Due to the hollow profile of the tooth on the worm, the line of contact runs convex to the root of the tooth on the worm wheel. This arrangement favors the development of lubricating pressure and diminishes the power loss as compared to involute worm drives. However, in spite of this particular advantage, the hollow flank worm drive has the important disadvantage that the production of identical worms is extremely difficult.

Therefore, for production considerations, involute worm drives are preferred, especially where interchangeability is required.

Accordingly, it is the primary object of the present invention to improve the profile flank of worms so that they can transmit greater torque and output as compared to previously available worm drives, and also to afford a more economical production of identical worms for purposes of interchangeability.

To overcome the problems experienced in the prior art, the present invention proposes worm flanks having a cycloidal shape in the front section of the worm.

The cycloidal shape of the worm flanks achieves a mutual embracing of the tooth flank profiles which is an improvement even over that of the hollow flank worm, because the contact between the tooth flanks of the worm and the worm wheel occur over a pair of lines of contact while the teeth are in meshed engagement. Additionally, oil chambers or spaces are formed between the worm flank and the worm wheel flank due to the plural lines of contact and in the oil chambers formed the oil pressure required for hydro-dynamic lubrication is developed and its build up is favored by the capillary action of the flanks disposed in close engagement.

By utilizing the worm drive configuration disclosed in the present invention, it is possible to transmit greater torque and output than has been possible in the past.

The cycloidally shaped worm drives can be reproduced by milling and grinding with the result that identical and interchangeable cycloidally shaped worms are producible in large quantities. Advantageously, the pitch line of the cycloidal worm coincides with a line along its outer circumference. This arrangement causes the two lines of contact, as well as the line of engagement, to run approximately symmetrical to the center of the tooth of the worm in its axial section.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which there is illustrated and described a preferred embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWING

In the drawings:

FIG. 1 illustrates a known involute worm drive showing the worm in axial section and also illustrating the line of engagement between the worm and the worm wheel;

FIG. 2 is a transverse section of the involute worm drive illustrated in FIG. 1 with the lines of contact on the tooth flank of the worm wheel illustrated;

FIGS. $3a$—$3h$ indicate the lines of contact of the tooth flanks on the involute worm drive, as shown in FIGS. 1 and 2, as the worm and worm wheel are in meshed engagement in successive phases of rotation;

FIG. 4 is a schematic illustration of the generation of cycloidal flanks for a worm;

FIG. 5 illustrates a cycloidal worm drive, in accordance with the present invention, showing the worm in axial section and with the line of engagement between the flank surfaces of the worm and worm wheel being displayed;

FIG. 6 is a transverse sectional view of the cycloidal worm drive shown in FIG. 5, with the lines of contact on the tooth flank of the worm wheel illustrated; and

FIGS. $7a$—$7e$ show the lines of contact between the flank surfaces of the worm and the worm wheel of the cycloidal worm drive illustrated in FIGS. 5 and 6 during the successive phases as the worm and worm wheel rotate in meshed engagement.

DESCRIPTION OF THE PRIOR ART

In FIGS. 1 to 3, a prior art involute worm drive is shown composed of an involute worm **1** in meshed engagement with a worm wheel **2** and with the axis of the worm designated by the reference character **3**. The pitch line **4** of the involute worm **1** is located at a distance **5** from the axis **3** of the worm. The pitch line **4** extends through the center **6** of the common tooth height on the worm. A line of engagement **7** is shown between the involute flanks **8** on the worm and the involute flanks **9** on the worm wheel. In FIG. 2, the multiple lines of contact **10** between the flank surfaces of the worm and worm wheel, as they rotate in meshed engagement, are shown. The lines of contact **10** represent, in time sequence, the lines along which the flanks **8** of the worm and the flanks **9** of the worm wheel contact in the different momentary angular positions of the worm wheel **2**. In each time interval of rotation only a single line of contact **10** results on the flank surface **9** of the worm wheel and it is along this line of contact that the torque and output is transmitted. As illustrated in FIG. 2, the lines of contact **10** are essentially straight.

The series of lines of contact **10**, shown in FIG. 2, are illustrated in successive phases in FIG. 3. The worm and, therefore, the worm wheel are each turned through identical angles of rotation. As the worm drive operates, the successive lines of contact $\mathbf{10^1}$ to $\mathbf{10^8}$ are provided, as indicated in FIGS. $3a$ to $3h$.

DETAILED DESCRIPTION OF THE INVENTION

In FIG. 4, there is illustrated, in a schematic manner, the production of cycloidal worms. In a front end section of a worm, the flanks of the cycloidal worm are genuine cycloids, they are developed on a circular disk **11** having an outside diameter **12** and a root diameter **13** when a tool **14** with a tool point **17** and having an outside diameter **15** and a root diameter **16** rolls on the circular disk **11**. In this schematic arrangement, the root diameter **16** rolls on the outside diameter **12** of the circular disk, and the tool point **17** describes the cycloid **18** as the tool **14** continues its rolling action. Accordingly, the tool point **17** removes an amount of material from the circular disk **11** so that a gap is formed which is limited by the cycloid flanks **19** and **20**. By fictitiously joining extremely thin tools so that their points lie in a helical line, a generating tool screw would be formed which would produce a worm with cycloidal flanks. By guiding the point of a truing diamond of a worm grinding machine along the generating helical line of the tool points **17**, the flanks of the grinding wheel so dressed will exactly grind flanks of a cycloidal worm. The worm and worm gear are identical. The manufacture of cycloidal gears by grinding is disclosed in the co-pending U.S. Pat. application, Ser. No. 45,442, filed June 11, 1970.

In FIGS. 5 to 7, the contact between the flanks of the cycloidal worm drive are illustrated when the worm and worm wheel or gear are in meshed engagement.

In FIGS. 5 and 6, a cycloidal worm **21** is arranged in meshed engagement with a worm wheel **22**. The axis **23** of the worm is shown and the pitch line **24** of the cycloidal worm **21** is spaced at a distance **25** from the worm axis. The distance **25** corresponds to the radius of the outside surface of the worm and the pitch line extends along an axially extending line lying on the outer periphery of the worm. The line of engagement **27** between the flank surfaces on the worm and the worm wheel extends symmetrically from the center of the tooth on the worm wheel. The disposition of the line of engagement **27** indicates that, in every rotary position of the worm wheel, two points of contact exist between the corresponding flanks of the cycloidal worm and the worm wheel. In FIG. 6, the lines of contact **30** are shown during the meshed engagement between the worm and worm wheel. The lines of contact develop on the flank surface **29** of the worm wheel as the worm rotates about its axis and the lines represent, in a time sequence, the lines along which the flank **28** of the worm and the flank **29** of the worm wheel touch at the momentary angular positions of the worm wheel. During each time interval of the meshed engagement of the worm and worm wheel, there is two lines of contact **30** on the flank surface **29** of the worm wheel by which the torque and output of the worm are transmitted to the worm wheel.

The series of lines of contact **30**, displayed in FIG. 6, is shown in a series arrangement in FIG. 7. As the cycloidal worm and the worm wheel are rotated through identical angles, there results, in succession, the lines of contact $\mathbf{30^{10}}$ and $\mathbf{30^{11}}$, $\mathbf{30^{20}}$ and $\mathbf{30^{21}}$, $\mathbf{30^{30}}$ and $\mathbf{30^{31}}$, $\mathbf{30^{40}}$ and $\mathbf{30^{41}}$, $\mathbf{30^{50}}$ and $\mathbf{30^{51}}$, $\mathbf{30^{60}}$ and $\mathbf{30^{61}}$, $\mathbf{30^{70}}$ and $\mathbf{30^{71}}$, and $\mathbf{30^{80}}$ and $\mathbf{30^{81}}$. In each of the momentary angular positions of the worm wheel, each of these pairs of lines of contact transmit the torque and output from the worm with the result that the amount of torque and output transmitted is substantially greater than had been possible in the prior art.

As shown in FIG. 7a, the lines of contact $\mathbf{30^{10}}$ and $\mathbf{30^{11}}$ have a definitely inwardly curved configuration and are located in the right-hand and left-hand lateral areas of the tooth flanks. As the worm drive rotates, as shown in FIGS. $7b$ to $7d$, the lines of contact $\mathbf{30^{20}}$ and $\mathbf{30^{21}}$, $\mathbf{30^{30}}$ and $\mathbf{30^{31}}$, and $\mathbf{30^{40}}$ and $\mathbf{30^{41}}$, move towards one another forming an oil chamber **31** which becomes increasingly narrower from the oil chamber $\mathbf{31^1}$ shown in FIG. $7a$ to the oil chamber $\mathbf{31^4}$, shown in FIG. $7d$. As rotation continues from the position shown in FIG. $7a$, through that shown in FIG. $7b$, the lines of contact come into contact with one another, note the dashed lines in FIG. 7*e*, and then proceed to move upwardly and downwardly away from one another, as shown in FIGS. 7*e* to 7*h*. As shown in FIGS. 7*e* to 7*h*, a pair of oil chambers are provided between the flank surfaces, that is, the oil chambers 31^{50} and 31^{51}, 31^{60} and 31^{61}, 31^{70} and 31^{71}, and 31^{80} and 31^{81} as displayed in FIGS. 7*e* to 7*h*. As indicated in these Figures, the oil chambers become increasingly narrower in the direction of the worm root **32** and of the worm wheel root **33**, note FIG. **6**.

The oil chamber 31^{4}, as shown in FIG. 7*d*, separates into the oil chambers 31^{50} and 31^{51}, as shown in FIG. 7*e*, as the worm drive rotates.

The oil pressure required for hydro-dynamic lubrication is built up in the oil chambers which continue to narrow during rotation, and the pressure build up is assisted by the capillary action developed by the closely arranged flank surfaces of the worm drive.

By comparison, it is not possible for oil chambers to develop in the involute worms illustrated in FIGS. 1 to 3.

What is claimed is:

1. A worm drive comprising a cylindrical worm and a worm wheel, said cylindrical worm having cycloidally shaped flank surfaces, said worm wheel having teeth with flanks shaped in correspondence with the flanks on said worm for meshed engagement therewith.

2. A worm drive, according to claim **1**, wherein the pitch line of said worm coincides with a line extending in an axial direction along the exterior circumferential surface of said worm.

3. A worm drive comprising a cylindrical worm and a worm wheel, said cylindrical worm having cycloidally shaped flank surfaces, said worm wheel having teeth with flanks shaped in correspondence with the flanks on said worm for meshed engagement therewith, said worm wheel flanks and said worm flanks being in contact along two lines of contact when in meshed engagement for transmitting torque between said worm and said worm wheel, and at least one oil chamber being formed between said worm and said worm wheel for developing hydrodynamic lubrication.

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