

SPECIFICATION

Improvements relating to transmission systems

5 This invention relates to power transmission systems utilising toothed power transmission belts co-operating with toothed pulleys, and also relates to pulleys for use in such a system.

Power transmission systems are known utilising belts having a plurality of alternating teeth and grooves extending generally transversely of the belt and meshing with alternating teeth and grooves in a grooved pulley in order to perform a driving function. Many proposals for such belts and pulleys have been made, and in particular considerable work has been done on designing the optimum shapes for the cross-sections for the teeth and grooves on both the belt and the pulley. For example, Miller U.S. Patent No. 3756091 discloses a positive drive system in which the belt includes relatively closely spaced together driving teeth of a special curvilinear cross-sectional configuration which is operated in conjunction with mating pulley grooves defined between pulley teeth having curvilinear cross-sections which are substantially conjugate to the teeth of the belt. Given a toothed belt in combination with a pulley the conjugate form of the belt tooth is that tooth form described on the pulley which corresponds to the volume between the belt and the pulley which is not swept out by the belt tooth as the belt moves into contact with the pulley. For any given belt tooth the conjugate form of pulley tooth can readily be determined graphically. Use of conjugate teeth on the pulley, desirably with small deviations from a true conjugate by the removal of additional material in the tip area of the tooth, is desirable as it ensures that the belt and pulley teeth are able to engage and disengage without interference.

For the purposes of this specification a groove formed between adjacent conjugate teeth will hereinafter be referred to as a conjugate groove.

Belt and pulley combinations as disclosed in the Miller U.S. patent are now in general use and have been found to give excellent results where the toothed pulley has, for example, 30 grooves or more and where such grooves are on 8 mm pitch. In practice this limitation imposes a minimum pulley diameter for any given tooth pitch and side combination, below which diameter belt life could be adversely affected depending on operating load and condition.

In some drive applications it would be advantageous to be able to use pulleys of less than the previous minimum diameter as in this way higher angular velocities may be achieved for the pulleys, and power transmission systems that are more compact and of lower weight can be designed because of the use of smaller pulleys. The object of the invention is to provide a power transmission system that is practical with small diameter toothed pulleys, for example 8 mm pitch pulleys having less than 30 grooves, while still being useful for larger pulleys with 30 grooves or more.

According to the invention we provide a pulley and flexible drive belt in combination, the drive belt

having a plurality of spaced teeth, each of which is curvilinear and of given length in longitudinal cross-section and the pulley comprising a plurality of teeth separated by grooves, each groove being symmetrical about its radial centreline and having a substantially U-shaped longitudinal cross-section, in which the ratio of belt tooth shear area to pulley land area is from 50:1 to 1:1 and the cross-sectional form of each pulley tooth and groove deviates from the conjugate form derived from the belt tooth in the following respects:-

- a) the spacing between the facing flanks of the pulley teeth is such that the pulley groove is wider than the conjugate groove;
- b) the shape of each flank includes a curved line that is, or approximates to, an arc of a circle drawn from a centre lying within the groove and differs from the shape of the flank of the conjugate tooth; and
- c) the shape of the tip of each pulley tooth is modified so that there is greater clearance between the tip and the root of the belt tooth than there is with the conjugate tooth.

Desirably the shear area ratio is less than 15:1.

Preferably the cross-sectional form of each pulley tooth and groove also deviates from the conjugate groove form in that the depth of each pulley groove is less, desirably 1% to 15% less, than the height of each belt tooth.

Preferably the arcs which form, or approximate to, the curved lines of each flank have radii smaller than the corresponding arcs that would form the corresponding curved lines of the conjugate groove, to allow the belt teeth to engage and disengage the pulley grooves without interference.

Preferably the ratio of belt tooth shear area to belt land area of any belt used in such a system is between 4.69:1 and 1:1, and desirably less than 3.5:1.

The invention will be better understood from the following specific description given in conjunction with the accompanying drawings in which:-

Figure 1 is a longitudinal cross-sectional view looking transversely of a positive drive of this invention showing a belt in engagement with two co-operating pulleys;

Figure 2 is an enlarged fragmentary longitudinal cross-sectional view of a pulley;

Figure 3 is an enlarged fragmentary longitudinal cross-sectional view of a mating pulley and belt with the belt wrapped round the pulley under a no load condition; and

Figure 4 is a view corresponding to Figure 3 but with the belt wrapped round a conjugate form of pulley.

As seen in Figure 1 an endless belt 10 engages driving and driven pulleys 11 and 12. The belt 10 is provided with tensile member 13 comprising a plurality of turns of a continuous strand of filamentary material. The tensile member 13 carries substantially the entire working load imposed upon the belt 10, and up to the maximum load for which the belt is designed, the tensile member 13 is substantially inextensible. U.S. Patent No. 2507852 to Case may be consulted for a more detailed description of

16 this general class of toothed belt and pulley system. The belt further includes a backing layer 14 and a protective jacket (not shown) extending over the entire toothed surface of the belt. A thin layer of elastomeric or other material (not shown) between the jacket and the tensile member 13 may be added to improve adhesion in the land areas of the belt. The belt may be made in any one of a number of ways, but it is preferable to use the method described in U.S. Patent No. 3078206 to Skura, the entire contents of which are incorporated herein by reference. An alternative method for manufacture of the belt is described in the Case U.S. Patent No. 2507852.

15 Figure 2 shows a typical profile of pulley tooth and groove according to the invention. The profile of the tooth and groove is made up as follows. Each groove is of substantially U-shaped longitudinal cross-section and is formed by two non-intersecting curved lines 21 and 22, each approximating to an arc of a circle, connected at the base of the groove by a first connecting line or base pulley segment 23. The arc 21 is drawn from a centre 24, is of radius R1 and extends from point A to point B. The arc 22 is drawn from centre 25, is of radius R2 and extends from point C to point D. The centres 24 and 25 are displaced from each other and lie to opposite sides of the radial centre line X-X of the pulley groove. The centre 24 and the arc 21 drawn from that centre lie to the same side of the centreline X-X, and similarly the centre 25 and arc 22 drawn from that centre lie to the same side of the centreline X-X. The radii R1 and R2 are equal, and the centres 24 and 25 lie at equal radial distances from the centre of the pulley and similarly at equal heights d1 from the base of the groove. The centres 24 and 25 furthermore lie at equal distances d2 to the opposite sides of the centreline X-X.

The first connecting line 23 forming the base of the groove and joining points A and C is constituted by an arc of a circle having radius R3 and drawn from a centre (not shown) lying on the extension of the centreline X-X of the groove.

Each pulley tooth tip is formed by two further non-intersecting curved lines 26 and 27 each approximating to an arc of a circle, connected by a fourth connecting line or peripheral pulley segment 28. The arc 26 is drawn from centre 29, has a radius R4 and extends from point E to point F. The arc 27 is drawn from centre 30, has radius R5 and joins points G and H. The centres 29 and 30 are displaced one from another, lie at equal distances d3 from a tangent to the outside diameter of the pulley at the centreline Y-Y of the tooth, lie at equal distances d4 to opposite sides of the centreline and lie at equal radial distances from the centre of the pulley. The radii R4 and R5 are equal. The fourth connecting line 28 is part of an arc of a circle having radius R6 drawn from a centre lying on the extension of the centreline Y-Y.

The arc defining part of the groove and the arc 26 defining part of the pulley tip are joined on the pulley flank by a second connecting line or first pulley flank segment 31 joining points B and E, the segment 31 being an arc of a circle having radius R7. Similarly the arc 22 of the groove is joined to the adjacent arc

32 of the respective tooth tip by a third connecting line or second pulley flank segment 33 extending between points D and H'. The profile from point H to point H' is repeated around the circumference of the pulley to define the other teeth and grooves.

In designing the pulley groove and tooth form it is desirable that the length AC of the first connecting line 23 at the base of the groove be no more than 60% and preferably less than 35% of the length AB or CD of either arc 21 or 22. The lengths BE and DH' of each of the second and third connecting lines 31 and 33 should desirably both be no more than 60% and preferably no more than 35% of the length AB or CD. Each arc 21 and 22 must extend to a height d5 on the tooth flank that is at least 25% and desirably at least 40% of the depth d6 of the groove. The centres 24 and 25 from which the arcs 21 and 22 are drawn preferably lie at a height d1, that is at least 50% and desirably at least 65% of the depth d6 of the groove.

The groove and tooth form can vary somewhat from that shown. In particular the centre 24 and arc 21 drawn from that centre can lie to opposite sides of the line X-X. The centre 29 and arc 26 drawn from that centre can lie to opposite sides of the line Y-Y, and similarly centre 30 and arc 27 can lie to opposite sides of the line Y-Y.

The connecting lines 23, 31, 33 and 28 are all shown as being concave with respect to the body of the pulley, but any or all of these segments may be straight lines or may be convex with respect to the body of the pulley. It is desirable that a line 34 that is an extension of the third connecting line 33 if this is straight, or tangent to the centre of line segment 33 if this is curved, make an angle α to the centreline X-X of the groove that is 20° or less. A similar extension of, or tangent to, the second connecting line 31 will make an equal and opposite angle to the centre line.

Figure 3 shows part of a belt wrapped around a pulley having the tooth and groove form shown in Figure 2, the belt being under no load. In longitudinal cross-section each tooth 40 of the belt is substantially composed of two circular arcs 41 and 42 of equal radius R8 and R9 crossing at a point 42a on the centreline X-X of the tooth cross-section. The centres of curvature 43 and 44 from which the arcs 41 and 42 are drawn are located on a line 45 that extends substantially parallel to the tensile member 13 in the longitudinal direction of the belt. The extent of the arcs 41 and 42 is such that they extend to the line 45. The centres of curvature for the arcs 41 and 42 are displaced on opposite sides of the centreline X-X from their corresponding arcs by an amount that is generally equal to or less than 10% of the radius of curvature of the arcs 41 and 42. A land area 46 connects the ends of the two root regions 47 and 48 of adjacent teeth. The length of each tooth is defined as the length between consecutive land areas, i.e. the length indicated as J-K in Figure 3. The root regions when seen in cross-section are circular arcs having equal radii R10 and R11.

Figure 4 shows the same belt of Figure 3 wrapped, under no load, around a pulley having teeth of true conjugate form to the belt teeth. A comparison of Figures 3 and 4 will illustrate how the pulley tooth and groove form of the invention differs from the

conjugate tooth and groove form. In the pulley according to the invention the spacing between the facing flanks of adjacent pulley teeth is such that the groove formed between those teeth is substantially wider than the width of the conjugate groove shown in Figure 4. This avoids interference between the leading flank of the pulley tooth and the trailing flank of the belt tooth. The shape of the flank of each pulley tooth shown in Figure 3 differs from the shape of the flank of the conjugate tooth shown in Figure 4 and this different shaping again assists in avoiding interference between the belt and pulley teeth.

One of that contributing factors to this different shaping is the radii R1 and R2 of the non-intersecting arcs 21 and 22 of the pulley groove according to the invention are smaller than the radii of the arcs to which the flanks of the conjugate tooth approximate.

The depth of the groove between adjacent pulley teeth in the pulley of the invention is less than the depth of the groove in the conjugate pulley, and is thus less than the height of a tooth of the belt. This is shown clearly in Figure 3 where the tip of the belt tooth is shown as overlapping the base of the pulley groove. Obviously this will not happen in practice and the belt tooth will be distorted due to this contact with the bottom of the pulley groove. It is preferred that the pulley groove depth be between 1% and 15% less than the belt tooth height. The shape of the tip of each tooth of the pulley according to the invention, as shown in Figure 3, is modified from the conjugate form shown in Figure 4 by making the tip radii of the pulley of the invention substantially greater than the radii of the conjugate teeth. This provides greater clearance between the tooth tip and the root of the belt in the arrangement according to the invention than is present in the conjugate form.

In designing a pulley according to the invention, in addition to the criteria already described it is necessary that the ratio of belt tooth shear area (the area represented by the length of the broken line J-K in Figure 3, which length corresponds to the given length of each belt tooth), to pulley land area (the area represented by the length of the fourth connecting line 28 between points F-G in Figure 2) be between 50:1 and 1:1 and desirably less than 15:1. Put another way, the length of the fourth connecting line F-G is from 2% to 100%, and preferably less than 6.67%, of the given length J-K of each belt tooth. It is also desirable that, in a power transmission system according to the invention, the ratio of the belt tooth shear areas to the belt land area (the area represented by the length of line J-L in Figure 3) be between 4.69:1 and 1:1, and desirably less than 3.5:1. Within the above limitation it is also desirable to use the maximum number of belt teeth per unit length.

By designing a belt and pulley drive in accordance with the criteria given herein it is possible to obtain any or all of the following advantages:- reduced noise, higher angular velocities because pulleys of smaller diameter can be used, higher load capacity, increased life of the belt, more compact power transmission systems since smaller pulleys enable the pulleys in the system to be spaced closer

together, and power transmission systems of lower weight because the pulleys are smaller and so weigh less.

Reference should also be made to our co-pending application No. 48433/78 (2,001,577).

CLAIMS

1. A pulley and flexible drive belt in combination, the drive belt having a plurality of spaced teeth, each of which is curvilinear in longitudinal cross-section, the pulley comprising a plurality of teeth separated by grooves, each groove being symmetrical about its radial centreline and having a substantially U-shaped longitudinal cross-section, in which the ratio of belt tooth shear area to pulley land area is from 50:1 to 1:1 and the cross-sectional form of each pulley tooth and groove deviates from the conjugate form derived from the belt tooth in the following respects:-
 - a) the spacing between the facing flanks of the pulley teeth is such that the pulley groove is wider than the conjugate groove;
 - b) the shape of each flank includes a curved line that is, or approximates to, an arc of a circle drawn from a centre lying within the groove and differs from the shape of the flank of the conjugate tooth; and
 - c) the shape of the tip of each pulley tooth is modified so that there is greater clearance between that tip and the root of the belt tooth than there is with the conjugate tooth.
2. A pulley and drive belt combination according to claim 1 in which the cross-sectional form of each pulley tooth and groove also deviates from the conjugate groove form in that the depth of each pulley groove is less than the height of each belt tooth.
3. A pulley and drive belt combination according to claim 2 in which the depth of each pulley groove is from 1% to 15% less than the height of each belt tooth.
4. A pulley and drive belt combination according to any one of the preceding claims in which the arcs which form, or approximate to, the curved lines of each flank are of smaller radii than the arcs which form or approximate to, corresponding curved lines of the conjugate groove form.
5. A pulley and drive belt combination according to any one of claims 1 to 4 in which the cross-sectional form of the pulley groove further differs from the conjugate groove form in that the arcs forming, or approximating to, the curved lines of each flank do not intersect and are joined by a first connecting line forming the base of the groove.
6. A pulley and drive belt combination according to any one of claims 1 to 5 in which the first connecting line is shorter than either of the curved lines.
7. A pulley and drive belt combination according to any one of claims 1 to 7 in which the cross-sectional form of the pulley groove further differs from the conjugate groove form in that the curved lines of each flank do not intersect the lines forming the shape of each adjacent tooth tip, and are joined



17

conjugate tooth and groove form. In the pulley according to the invention the spacing between the facing flanks of adjacent pulley teeth is such that the groove formed between those teeth is substantially wider than the width of the conjugate groove shown in Figure 4. This avoids interference between the leading flank of the pulley tooth and the trailing flank of the belt tooth. The shape of the flank of each pulley tooth shown in Figure 3 differs from the shape of the flank of the conjugate tooth shown in Figure 4 and this different shaping again assists in avoiding interference between the belt and pulley teeth.

One of that contributing factors to this different shaping is the radii R1 and R2 of the non-intersecting arcs 21 and 22 of the pulley groove according to the invention are smaller than the radii of the arcs to which the flanks of the conjugate tooth approximate.

The depth of the groove between adjacent pulley teeth in the pulley of the invention is less than the depth of the groove in the conjugate pulley, and is thus less than the height of a tooth of the belt. This is shown clearly in Figure 3 where the tip of the belt tooth is shown as overlapping the base of the pulley groove. Obviously this will not happen in practice and the belt tooth will be distorted due to this contact with the bottom of the pulley groove. It is preferred that the pulley groove depth be between 1% and 15% less than the belt tooth height. The shape of the tip of each tooth of the pulley according to the invention, as shown in Figure 3, is modified from the conjugate form shown in Figure 4 by making the tip radii of the pulley of the invention substantially greater than the radii of the conjugate teeth. This provides greater clearance between the tooth tip and the root of the belt in the arrangement according to the invention than is present in the conjugate form.

In designing a pulley according to the invention, in addition to the criteria already described it is necessary that the ratio of belt tooth shear area (the area represented by the length of the broken line J-K in Figure 3, which length corresponds to the given length of each belt tooth), to pulley land area (the area represented by the length of the fourth connecting line 28 between points F-G in Figure 2) be between 50:1 and 1:1 and desirably less than 15:1. Put another way, the length of the fourth connecting line F-G is from 2% to 100%, and preferably less than 6.67% of the given length J-K of each belt tooth. It is also desirable that, in a power transmission system according to the invention, the ratio of the belt tooth shear areas to the belt land area (the area represented by the length of line J-L in Figure 3) be between 4.69:1 and 1:1, and desirably less than 3.5:1. Within the above limitation it is also desirable to use the maximum number of belt teeth per unit length.

By designing a belt and pulley drive in accordance with the criteria given herein it is possible to obtain any or all of the following advantages:- reduced noise, higher angular velocities because pulleys of smaller diameter can be used, higher load capacity, increased life of the belt, more compact power transmission systems since smaller pulleys enable the pulleys in the system to be spaced closer

together, and power transmission systems of lower weight because the pulleys are smaller and so weigh less.

Reference should also be made to our co-pending application No. 48433/78 (2,001,577).

CLAIMS

1. A pulley and flexible drive belt in combination, the drive belt having a plurality of spaced teeth, each of which is curvilinear in longitudinal cross-section, the pulley comprising a plurality of teeth separated by grooves, each groove being symmetrical about its radial centreline and having a substantially U-shaped longitudinal cross-section, in which the ratio of belt tooth shear area to pulley land area is from 50:1 to 1:1 and the cross-sectional form of each pulley tooth and groove deviates from the conjugate form derived from the belt tooth in the following respects:-

a) the spacing between the facing flanks of the pulley teeth is such that the pulley groove is wider than the conjugate groove;
b) the shape of each flank includes a curved line that is, or approximates to, an arc of a circle drawn from a centre lying within the groove and differs from the shape of the flank of the conjugate tooth; and

c) the shape of the tip of each pulley tooth is modified so that there is greater clearance between that tip and the root of the belt tooth than there is with the conjugate tooth.

2. A pulley and drive belt combination according to claim 1 in which the cross-sectional form of each pulley tooth and groove also deviates from the conjugate groove form in that the depth of each pulley groove is less than the height of each belt tooth.

3. A pulley and drive belt combination according to claim 2 in which the depth of each pulley groove is from 1% to 15% less than the height of each belt tooth.

4. A pulley and drive belt combination according to any one of the preceding claims in which the arcs which form, or approximate to, the curved lines of each flank are of smaller radii than the arcs which form or approximate to, corresponding curved lines of the conjugate groove form.

5. A pulley and drive belt combination according to any one of claims 1 to 4 in which the cross-sectional form of the pulley groove further differs from the conjugate groove form in that the arcs forming, or approximating to, the curved lines of each flank do not intersect and are joined by a first connecting line forming the base of the groove.

6. A pulley and drive belt combination according to any one of claims 1 to 5 in which the first connecting line is shorter than either of the curved lines.

7. A pulley and drive belt combination according to any one of claims 1 to 7 in which the cross-sectional form of the pulley groove further differs from the conjugate groove form in that the curved lines of each flank do not intersect the lines forming the shape of each adjacent tooth tip, and are joined

18

to the tooth tip lines by respective second and third connecting lines.

8. A pulley and drive belt combination according to claim 6 in which each of the second and third connecting lines is shorter than either of the curved lines.

9. A pulley and drive belt combination according to any one of claims 1 to 8 in which the ratio of belt tooth shear area to pulley land area is less than 15:1.

10. A pulley and drive belt combination according to any one of the preceding claims in which the ratio of belt tooth shear area to belt land area is from 4.69:1 to 1:1.

11. A pulley and drive belt combination according to claim 10 in which the ratio of belt tooth shear area to belt land area is less than 3.5:1.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1983.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

