

SPECIFICATION

Toothed pulley and transmission system incorporating same

This invention relates to a pulley and to a power transmission system comprising a belt in engagement with at least one pulley.

5 U.S. Patent No. 2,507,852, to R. Y. Case, describes a power transmission belt comprising an inextensible tensile member having teeth bonded to one side and a protective jacket fabric covering the teeth. The teeth are preferably made of an elastomeric material, such as rubber, and the belt may also include a backing layer of identical or similar material to that which the teeth are constructed.

Many different elastomeric materials have been utilized for the construction of belts made in accordance with the Case patent, some of the more common materials being neoprene and polyurethane. These belts are designed to mesh with toothed pulleys that are constructed of a material having a higher Young's modulus than the elastomeric material used for the construction of the belt. The conventional toothed belt, as described in the Case patent, utilizes a tooth cross-sectional configuration that is essentially trapezoidal and which is very similar to a conventional rack tooth. Many attempts have been made to alter the belt and pulley teeth configurations to relieve the problem of belt failure. In such trapezoidal tooth belts, the common failure is that of tooth shear due to stress concentration. In seeking to reduce tooth shear, U.S. Patent No. 3,756,091 to H. Miller, discloses belt teeth having a cross-sectional configuration which approximates the contour of the one-half order isochromatic fringe in a belt tooth under a defined rated load. The pulley grooves in accordance with the Miller patent are in mating engagement with and are substantially conjugate to the belt teeth. The belt having substantially curvilinear teeth in accordance with the Miller patent reduced belt tooth shear and increased horsepower capacity. One mode of failure in the belt configuration according to Miller may occur because of land wear in the belt, especially with small diameter pulleys. Land wear between the belt teeth is due to abrasion of the protective layer and exposure of the tensile member by action of the pulley tooth against the belt. This land wear leads to premature failure due to a detachment of the teeth from the tensile member and/or a break in the tensile member.

U.S. Patent No. 4,037,485, to Hoback, proposes a solution to the land wear problem. As disclosed in the Hoback patent, the dimensional relationship of the belt teeth and grooves and the pulley teeth and grooves is such that in the longitudinal extent of the belt between the pulleys, the height of the belt teeth is greater than the depth of the pulley grooves while as the belt travels around the pulleys, the extreme outwardly facing portions of the belt teeth which confront the pulleys comes into contact with the portions of the toothed pulley which define the bottom of the pulley grooves. At the same time, Hoback discloses that the belt teeth are compressed to reduce their height so that the extreme radially outwardly facing portions of the pulley teeth come into contact with the portions of the belt disposed between the belt teeth which define the bottoms of the belt grooves.

Relatively early in the operating life of the toothed power transmission belt and pulley as disclosed in Hoback the compressive engagement of the elastomeric teeth against the bottom of the pulley groove results in a substantially permanent deformation of the belt tooth. This deformation is accelerated at elevated operating temperatures such as occur in automotive applications. The deformation results in a significant permanent decrease in the tooth height. The deformed teeth no longer support the tensile member as desired by Hoback. Subsequently the same wear pattern develops in the toothed belt and pulley drive according to Hoback as in the toothed power transmission configuration according to the Miller patent.

According to the present invention we provide a power transmission system comprising at least one pulley with teeth in combination with a flexible drive belt with teeth, the pulley teeth being a non-conjugate form of the belt teeth, the pulley teeth being separated by pulley cavity portions and the belt teeth being separated by belt cavity portions, each pulley tooth in longitudinal cross-section being symmetrical about a pulley tooth center line intersecting with a center of said pulley, said pulley tooth including a pulley tip portion and opposite pulley flank portions extending from said pulley tip portion, the pulley tip portion being defined by first and second circular arcs on opposite sides of said pulley tooth center line, the centers of curvature of said first and second arcs being displaced from each other on a circular arc having a common center with said pulley, a peripheral pulley segment at the outermost portion of said pulley tooth tip joining the first and second arcs, each said pulley cavity being symmetrical about a pulley cavity centerline intersecting with the center of said pulley, said pulley cavity being partially defined by a third circular arc having a center of curvature on the pulley cavity center line, said third circular arc defining a base portion of said pulley cavity and extending from said pulley cavity base portion into the flank portions of adjacent pulley teeth, portions of said first and second arcs extending from the tip portion of said pulley tooth towards the respective flank portions of said pulley tooth, each belt tooth in longitudinal cross-section being symmetrical about a belt tooth center line, said belt tooth including a substantially curved belt tip portion partially defined by fourth and fifth circular arcs extending into opposite flank portions of said belt tooth, said belt cavity being symmetrical about a belt cavity center line and being partially defined by the fourth arc of one belt tooth and the fifth arc of an adjacent belt tooth, said belt cavity having a base portion exceeding the width of said pulley tooth tip, and the center of curvature locations and the radii of said third, fourth and fifth circular arcs being

selected such that in a no-load condition of the belt and the pulley, the depth of said belt tooth along said belt tooth center line measuring from the belt tooth tip to the intersection of said belt tooth center line with a line tangent to consecutive belt cavity base portions exceeds the depth of said pulley cavity along said pulley cavity center line measuring from the intersection of said third arc with said pulley cavity center line to the intersection of said pulley cavity center line with an arc having a common center with said pulley and tangent to the outermost portion of consecutive pulley teeth-tips.

It has been found in accordance with the present invention that the land wear problem of the Miller and Hoback patents can be substantially reduced. The reduction results in an increase in the operating life of the toothed belt. Furthermore, in accordance with the present invention the toothed power transmission drive has improved belt life, even under severe operating conditions such as elevated temperature and torsional vibration environments. The improvement is most beneficial with small pulleys.

The present invention is a pulley for use in conjunction with a flexible drive belt, such as disclosed in Miller.

As used herein, the terms describing the features of the present invention are defined in the patent to Miller.

The present invention reduces the problem of land area wear between belt teeth by changing the pulley configuration to increase the contact area between the pulley tooth tips and the land area of the belt teeth. It further relieves the pressure in the belt tooth land area by providing support for the belt tooth in the pulley groove.

Both the compressive engagement of the belt tooth with the pulley groove and the surface contact ratio as defined, do act individually to reduce land wear in the belt. However, in combination, as more fully described herein, they reduce land wear in the belt to an extent greater than the sum of their individual effects.

The invention will be more clearly understood from the following description read together with the drawing in which:

Fig. 1 is a longitudinal cross-sectional view looking transversely of the preferred embodiment of the cooperating pulleys in accordance with the present invention in engagement with a belt to form a positive drive system;

Fig. 2 is an enlarged fragmentary longitudinal cross-sectional view of the pulley in accordance with the preferred embodiment;

Fig. 3 is an enlarged fragmentary longitudinal cross-sectional view of the pulley of Fig. 2 superimposed on a view of a corresponding conjugate pulley according to the Miller patent; and

Fig. 4 is an enlarged fragmentary longitudinal cross-sectional view of the pulley of Fig. 2 in mating engagement with a belt constructed in accordance with the Miller patent under a no-load condition.

As seen in Fig. 1, the endless belt 10 engages the driving and driven pulleys 11 and 12. Belt 10 is provided with a 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 on the belt 10, and up to the maximum load for which the belt is designed, the tensile member 13 is substantially inextensible. The above cited Case and Miller patents may be consulted for a more detailed description of the principles of this general class of toothed belt and pulley system. The entire contents of the Case and Miller patents are each incorporated herein by reference. 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. 3,078,206 to W. Skura, the entire contents of which are incorporated herein by reference. An alternative method for manufacture is described in the above cited Case patent.

The pulleys 11 and 12 of Fig. 1 as seen in Fig. 2 each comprise a body portion 20 having curvilinear teeth 21 separated by curvilinear cavities 22. The tooth tip 23 viewed in longitudinal cross-section has an outer configuration which is composed of two circular arcs 24 and 25 having displaced centers of curvature 26 and 27 displaced from a tooth tip center line 28. Arcs 24 and 25 have two equal radii 29 and 30 with centers of curvature 26 and 27 displaced equal amounts on opposite side of the center line 28 of the tooth 21 but on the same side as their corresponding arcs. Both centers of curvature are within the pulley tooth. The non-intersecting arcs 24 and 25 are connected by a line segment 31. The arc 24 extends from point A to point B. The arc 25 extends from point C to point D. The centers 26 and 27 lie at equal distances from a tangent to the outside diameter of the pulley at the center line 28 of the tooth, lie at equal distances to opposite sides of the center line 28 and lie at equal radial distances from the center of the pulley. The line segment 31 is part of an arc of a circle having a radius drawn from a center lying on the extension of the center line 28. The center of curvature of line 31 may lie on center line 28, i.e. within the body of the pulley, and in one embodiment may be coincident with the center of the pulley. Alternately the center of curvature of line segment 31 may lie on an extension of center line 28 which is outside the body of the pulley. The line segment 31 is shown as being concave with respect to the body of the pulley, but it may alternatively be a straight line or may be convex with respect to the body of the pulley.

Fig. 3 shows an enlarged fragmentary longitudinal cross-section view of the pulley of Fig. 2 superimposed on a view of a corresponding conjugate pulley according to the Miller patent. This figure emphasizes the difference in the longitudinal cross-sectional profiles of the respective pulley grooves and teeth. Fig. 3 shows the cavity 22 of this invention which is formed by the arc of radius 32 at a center of curvature 33. The arcs 24 and 25 which partially form the pulley tooth tip of this invention are generated by respective radii 29 and 30 having centers of curvature at 26 and 27. The line segment forming the outermost portion of the tooth tip and connecting the arcs 24 and 25, has a length equal to the distance between points B and C. The arc forming the cavity 22 may intersect with the arcs 24 and 25 of this invention at points A and D.

In contrast, the conjugate pulley according to the Miller patent, has a cavity 41 formed by arc having a radius 40 and a center of curvature 39. The arcs 46 and 47 which partially form the pulley tooth tip according to the Miller patent are generated by respective radii 44 and 45 having centers of curvature at 42 and 43. The line segment forming the outermost portion of the tooth tip and connecting the arcs 46 and 47 has a length equal to the distance between points E and F. The arc forming the cavity 41 intersects the arcs 46 and 47 at points G and H.

The length of the line segment BC of the present invention is greater than the length of the line segment EF of the pulley tooth tip according to the Miller patent. The centers of curvature 26 and 27 of the present invention are displaced on opposite sides of the center line 28, a distance greater than the displacement of the centers of curvature 42 and 43 of the pulley tooth tip according to the Miller patent. The cross-hatched area 48 represents the additional material present in the pulley groove and tooth tip profile according to this invention as compared to the same profile according to the Miller patent.

Fig. 4 is an enlarged fragmentary longitudinal cross-sectional view of the pulley of Fig. 2 in mating engagement with a belt constructed in accordance with the Miller patent under a no-load condition. In longitudinal cross-section, each tooth 49 of the belt 50 is composed of two circular arcs 51 and 52 of equal radius 53 and 54 intersecting at a point 55 on the center line 34. The centers of curvature 56 and 57 from which the arcs 51 and 52 are drawn are located on a line 58 as shown in the Miller patent. The extent of the arcs 51 and 52 is such that they extend to the line 58. The centers of curvature 56 and 57 for the arcs 51 and 52 are displaced on opposite sides of the center line 34 from their corresponding arcs by an amount that is generally equal to or less than 10% of the radius of curvature of the arcs 51 and 52. Consecutive belt teeth are each separated by a belt land area.

The depth of the groove 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 depth of a tooth of the belt. This is shown clearly in Fig. 4, 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 contact with the pulley groove. It is preferred that the pulley groove depth be between 1% and 15% less than the belt tooth depth.

In designing a drive according to the invention, in addition to the criteria already described, it is desirable that the surface contact ratio of belt tooth width defined as the width between consecutive land area (i.e. the width represented by the length of broken line 59 between the points J and K in Fig. 4) to the length of the line segment 31 (the width represented by the length of the line BC in Fig. 2) be between 20:1 and 1:1 and desirably between 15:1 and 3:1. Put in other words, the length of line segment 31 must be from 5% to 100% (desirably from 6.67% to 33%) of the width of the belt tooth.

The cross-sectional configuration of cavity 22 has a radius 32 much larger than radii 29 and 30 and has a center 33 which is outside the pulley body and is on a center line 34. The centers of radii 26, 27 and 33 are located on the same or slightly spaced circles 35 and 36 which are concentric with and within an addendum circle 37 tangent to and connecting the outermost portions (line segments 31) of the tooth tips. The circles 35 and 36 are spaced radially inwardly from this circle a distance equal to or less than 30 per cent of the total tooth depth. The total tooth depth is the radial distance between the intersection of line segment 31 and center line 28, i.e. a point on the addendum circle 38 cotangent to and connecting the innermost points of cavity 22. The innermost point of cavity 22 is at the intersection of the arc generated by the radius 32 and the center line 34, i.e. a point on the dedendum circle 38.

The cavity 22 is formed by an arc of a circle having a radius 32 drawn from a center 33 on center line 34. The arc forming cavity 22 may intersect the arc 24 on one side of the overall pulley groove profile and intersect arc 25 on the other side of the profile. The profile of the pulley groove from the intersection of line segment 31 and center line 28 to a corresponding intersection of the next adjacent tooth is repeated around the circumference of the pulley to define the other teeth and grooves.

The total depth of the pulley groove is equal to the distance measured along center line 34 between the intersections of line 34 and the addendum circle 37 and the dedendum circle 38. As shown in Fig. 2, the total depth of the pulley groove is the sum of the length of the radius 32 and the distance d. Preferably the total depth of the pulley groove is not more than 15% less than the depth of the belt tooth which engages with the pulley groove. Consequently the belt tooth may be in compressive engagement with the cavity 22.

In designing the pulley groove and tooth form, it is desirable that the arc forming the cavity 22 smoothly intersect with the arcs 24 and 25. However, in order to provide a smooth transition from the

arc forming the cavity 22 to the arcs 24 or 25 forming a portion of the pulley tooth tip, it may be desirable to provide a connecting line. This connecting line may be similar to line segment 31.

In order to compare the performance of power transmission systems having pulleys according to the invention with those having conventional dimensional relationships, the following procedure was followed. Several positive or synchronous drive belt samples were manufactured by conventional methods using conventional materials well known in the art. All the belts were formed of a neoprene rubber composition having a nylon fabric facing on the belt teeth, and including a tensile member of fiber glass cords disposed substantially on the dedendum line of the belt teeth. The belt samples after manufacture were dynamically tested on toothed pulleys of appropriate dimension and configuration as will be hereinafter described.

Three power transmission systems were tested. These combinations are identified as A, B and C:

Combination A comprises belts and pulleys manufactured strictly in accordance with the Miller patent. These belts and pulleys are sold commercially by UNIROYAL, Inc. as its 8 mm. pitch Powergrip HTD Belt and Pulley system.

The eighteen belt samples produced had the following dimensions as measured in the longitudinal extent of the belt between the pulleys: a pitch between belt teeth of 0.315 inches; a belt tooth width of 0.260 inches; a distance between the belt teeth of 0.055 inches; and a belt tooth of 0.135 inches. The belts were 15 mm. wide and 936 mm. in pitch length.

The pulleys had a tooth depth of 0.142 inches and were substantially conjugate to the belt teeth.

As taught in the Miller patent, the tooth tips had a longitudinal cross-sectional contour composed of two circular arcs connected by a line segment. The line segment length was 0.011 inches. In the resulting power transmission system the line segment is 4.2% of the width of the belt tooth.

Combination B comprises a power transmission system exactly as found in Combination A except that the belt tooth depth had been increased by 0.012 inches (8.9%) to 0.147 inches. This corresponds to the teachings in U.S. Patent No. 4,037,485 to Hoback. Seven belt samples were made.

Combination C comprises a power transmission system in accordance with the present invention. The belt has the same dimensions as the belt in Combination A. The pulley tooth had a depth of 0.130 inches; the pulley cavity had a radius of curvature of 0.106 inches. The line segment length was 0.020 inches.

Table 1 is a comparison of the key dimensions of Combinations A, B and C and the resulting compression of the belt teeth.

TABLE I

	Combinations		
	A	B	C
Belt Tooth Width	.260	.260	.260
Belt Tooth Depth	.135	.147	.135
Pulley Tooth Depth	.142	.142	.130
Line Segment Length	.011	.011	.020
Line Segment Length (as percentage of belt tooth width)	4.2%	4.2%	7.7%
Percent Belt Tooth Compression (Belt Tooth Depth-Pulley Tooth Depth) Pulley Tooth Depth	0%	3.4%	3.7%

Each belt sample was mounted on a dead weight flex tester having a two pulley arrangement consisting of a driver and a driven pulley each having an outside diameter of 2.160 inches. The driver pulley was operated at 350 rpm with a force between pulley shaft centers of 250 lbs. The test was conducted at ambient temperature. The belts were tested to failure unless otherwise indicated. The lapsed time to the nearest hour of each group of belt samples to failure is shown in Table II.

TABLE II

Life on Test, Hours

	A	B	C
	83.4	59.0	298.4 (test suspended)
	46.9	117.2	690.7
	65.5	99.1	187.6
	75.7	120.8	233.4
	54.2		258.5
Average	65.1	99.0	345.1

III. The test was repeated in an environmental chamber held at 190°F. The results are shown in Table III.

TABLE III

Life on Test, Hours

	A	B	C
	93.0	118.2	196.2
	87.9	98.5	105.7
	82.0	117.5	129.3
	103.4		171.8
Average	91.6	111.4	162.0

5 The results in Tables II and III clearly show that the pulley-belt Combination C having the pulley to 5
belt relationship of this invention provides a significantly improved belt life over Combinations A and B.
This improvement was shown on the tests made at ambient temperature and on the tests made on
accelerated tests at 190 deg. F.

10 The only significant variable in the comparative tests was the relationship of the pulley dimensions 10
to the belt dimensions. Combination B had belt teeth that were greater in depth than the depth of the
corresponding pulley grooves. Combination C also had belt teeth that were greater in depth than the
depth of the corresponding pulley grooves. However, the line segment length of the Combination C
pulleys was substantially greater than that of the line segment lengths of the Combination A or the
Combination B pulleys. The pulley of the prior art Combinations A and B had inadequate line segment
15 lengths causing the belt to be subjected to excess stress on the tensile members. This excess stress 15
caused abrasion of the belt between the belt teeth and the failure resulted primarily from excessive wear
in this area.

20 In the pulleys of Combination C, the line segment length was of sufficient length to distribute the 20
load over a larger area and thus reduce the stress in the area between the belt teeth. Consequently,
wear in the area of the belt between the teeth was reduced, and the belt life was significantly increased 20
at both ambient and elevated temperatures.

25 The pulley described herein may be used in combination with toothed belts other than that 25
disclosed in the patents to Case, Miller and Hoback. The longitudinal cross-sectional contour of the
individual belt teeth may be trapezoidal, curvilinear or wedge-shaped or a combination or a modification
of these contours. The belt may also have teeth on both sides of the tensile member.

Reference is directed to our co-pending application No. 48434/78.



CLAIMS

1. A power transmission system comprising at least one pulley with teeth in combination with a flexible drive belt with teeth, the pulley teeth being a non-conjugate form of the belt teeth, the pulley teeth being separated by pulley cavity portions and the belt teeth being separated by belt cavity portions, each pulley tooth in longitudinal cross-section being symmetrical about a pulley tooth center line intersecting with a center of said pulley, said pulley tooth including a pulley tip portion and opposite pulley flank portions extending from said pulley tip portion, the pulley tip portion being defined by first and second circular arcs on opposite sides of said pulley tooth center line, the centers of curvature of said first and second arcs being displaced from each other on a circular arc having a common center with said pulley, a peripheral pulley segment at the outermost portion of said pulley tooth tip joining the first and second arcs, each said pulley cavity being symmetrical about a pulley cavity centerline intersecting with the center of said pulley, said pulley cavity being partially defined by a third circular arc having a center of curvature on the pulley cavity center line, said third circular arc defining a base portion of said pulley cavity and extending from said pulley cavity base portion into the flank portions of adjacent pulley teeth, portions of said first and second arcs extending from the tip portion of said pulley tooth towards the respective flank portions of said pulley tooth, each belt tooth in longitudinal cross-section being symmetrical about a belt tooth center line, said belt tooth including a substantially curved belt tip portion partially defined by fourth and fifth circular arcs extending into opposite flank portions of said belt tooth, said belt cavity being symmetrical about a belt cavity center line and being partially defined by the fourth arc of one belt tooth and the fifth arc of an adjacent belt tooth, said belt cavity having a base portion exceeding the width of said pulley tooth tip, and the center of curvature locations and the radii of said third, fourth and fifth circular arcs being selected such that in a no-load condition of the belt and the pulley, the depth of said belt tooth along said belt tooth center line measuring from the belt tooth tip to the intersection of said belt tooth center line with a line tangent to consecutive belt cavity base portions exceeds the depth of said pulley cavity along said pulley cavity center line measuring from the intersection of said third arc with said pulley cavity center line to the intersection of said pulley cavity center line with an arc having a common center with said pulley and tangent to the outermost portion of consecutive pulley teeth tips.
2. A power transmission system according to claim 1 in which the peripheral pulley segment at the outermost portion of the pulley tooth tip is a circular arc having a radius equal to the distance between the outermost portion of the pulley tooth tip and the center of the pulley.
3. A power transmission system according to claim 1 in which the peripheral pulley segment at the outermost portion of the pulley tooth tip is a straight line.
4. A power transmission system according to claim 1 in which the peripheral pulley segment at the outermost portion of the pulley tooth tip has a length that is from 6.67% to 33.33% of the longitudinal cross-sectional width of each belt tooth.
5. A power transmission system substantially as herein described with reference to Figure 4 of the accompanying drawings.