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We, TOROTRAK (DEVELOPMENT) LIMITED, of 101 Newington Causeway, London, SE1 6BU, England, being the applicant in respect of Application No. 72507/91 state the following:-


The Person nominated for the grant of the patent has entitlement from the actual inventor by assignment.

The person nominated for the grant of the patent is the applicant of the application listed in the declaration under Article 8 of the PCT.

The basic application listed on the request form is the first application made in a Convention country in respect of the invention.

By our Patent Attorneys,  
WATERMARK PATENT & TRADEMARK ATTORNEYS

29th June, 1994

  
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- (56) Prior Art Documents  
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- (57) Claim

1. A rotatable disc ~~Fig. 1~~ formed with a coaxial part-toroidal race, ~~Fig. 2, 3, 4, 5~~, and suitable for use as the input or output disc of the variator for a transmission of the toroidal-race rolling-traction type, characterised in that the torus radius ~~Fig. 1~~ of the race, that is to say the radius of curvature of the race measured at a chosen point on the race and in a plane including the disc axis, decreases as the distance of that point from the disc axis diminishes.

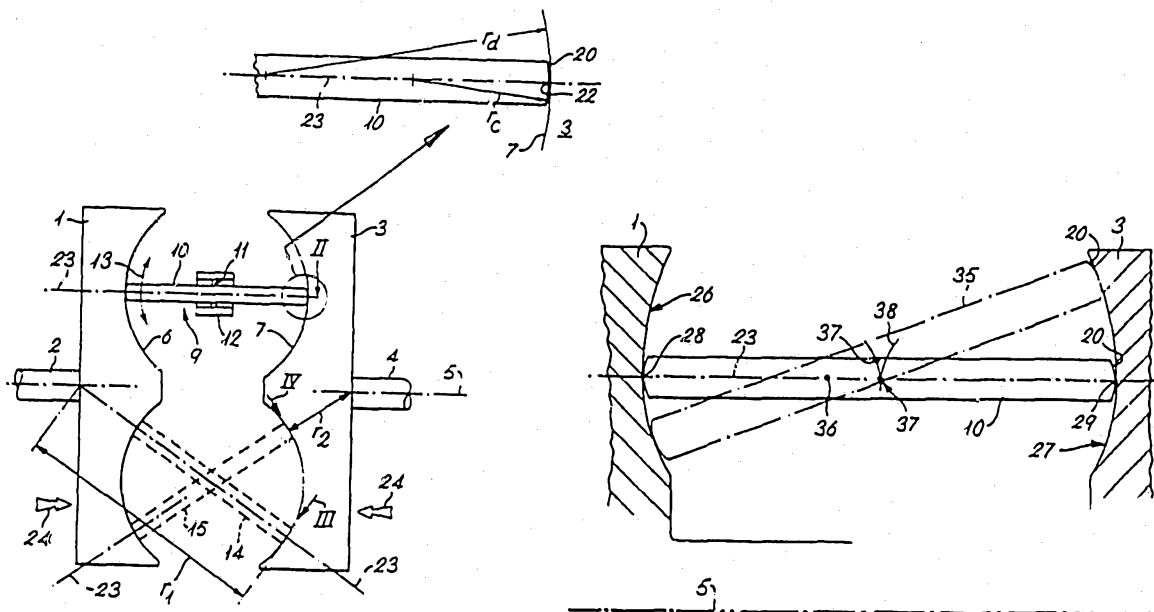
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<p>(21) International Application Number: <b>PCT/GB91/00243</b> (22) International Filing Date: <b>30 January 1991 (30.01.91)</b> (30) Priority data: <b>9002060.3</b> <b>30 January 1990 (30.01.90)</b> <b>GB</b> (71) Applicant (for all designated States except US): <b>TOROTRAK (DEVELOPMENT) LIMITED [GB/GB]; 101 Newington Causeway, London SE1 6BU (GB).</b> (72) Inventor; and (75) Inventor/Applicant (for US only) : <b>FELLOWS, Thomas, George [GB/GB]; 1 Greenbrook Avenue, Hadley Wood, Hertfordshire EN4 0LS (GB).</b> (74) Agent: <b>STABLES, Patrick, Antony; Patents Department, National Research Development Corporation, 101 Newington Causeway, London SE1 6BU (GB).</b></p>		<p>(81) Designated States: <b>AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH, CH (European patent), CM (OAPI patent), DE, DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NL (European patent), NO, PL, RO, SD, SE, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.</b>  <b>Published</b> <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>

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(54) Title: IMPROVEMENTS IN OR RELATING TO TRANSMISSIONS OF THE TOROIDAL-RACE ROLLING-TRACTION TYPE



## (57) Abstract

A rotatable disc (1, 3) formed with a coaxial part-toroidal race (26, 27, figure 5) for use as the input or output disc of the variator for a transmission - especially of the full toroidal kind - of the toroidal-race rolling-traction type, in which the torus radius ( $r_d$ ) of the race, that is to say the radius of curvature of the race measured at a chosen point on the race and in a plane including the disc axis, decreases as the distance of that point from the disc axis (5) diminishes. Such decrease of the torus radius may be either continuous or discontinuous.

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IMPROVEMENTS IN OR RELATING TO TRANSMISSIONS  
OF THE TOROIDAL-RACE ROLLING-TRACTION TYPE

This invention relates to continuously-variable-ratio transmissions of the toroidal-race rolling-traction type. In the variator, that is to say the ratio-varying component, of such a transmission, coaxial and rotatable input and output discs  
05 confront each other, each disc being formed with a part-toroidal race coaxial with the disc itself, the races being complementary and thus conforming to different parts of the surface of a single common torus. Rollers of variable orientation roll in contact with both races, and transmit drive between them. When the  
10 roller contacts the output disc at a greater radius (relative to the common axis of the discs) than that at which it contacts the input disc, the output disc will rotate slower than the input disc. Conversely, when the corresponding radius at which the roller contacts the input disc is the greater, the output disc  
15 will rotate faster than the input disc. It relates in particular to such transmissions of the so-called "full toroidal" kind in which the races are so shaped that contact between the roller and a race can take place at a radius, measured from the common axis of the discs, that is substantially greater than the  
20 corresponding radius of the centre of the common torus. It is a characteristic of a transmission of the full toroidal type, that the direction of the normal reaction at each point of contact between a race and a roller passes through the roller centre.

In the accompanying diagrammatic drawings, Figure 1 is a  
25 section through the variator of a known transmission of the toroidal-race rolling-traction type and the full toroidal kind, taken in a plane including the transmission axis, and Figures 2, 3 and 4 are local views taken in the directions indicated by arrows II, III and IV in Figure 1. Figure 1 shows an input disc  
30 1 mounted on an input shaft 2, and an output disc 3 mounted on an output shaft 4. Shafts 2 and 4 share a common axis 5. Input disc 1 is formed with a part-toroidal race 6 and output disc 3 with a corresponding race 7. Although by torus we mean any

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ring-shaped body generated by rotating any closed plane figure of generally curved outline about a generator line sharing a common plane with the figure but lying outside its outline, in the typical known variator as shown in Figure 1 the surfaces of races 05 6 and 7 conform to the surface of the special case of a torus generated by rotating a circle around axis 5, the circle and the axis lying in a common plane at all times. A set of rollers - typically three in number - roll in contact with both of races 6 and 7 and transmit drive between them with reversal of direction, 10 so that the direction of rotation of shaft 4 is always opposite to that of shaft 2. One of such rollers is shown at 10; each such roller rotates about an axle 11 which is mounted to rotate in a carriage 12. When carriage 12 is tilted as indicated by arrow 13, by means not shown but well known in the art, the ratio 15 transmitted from disc 1 to disc 3 is varied.

In the upper half of Figure 1 the roller 10, shown in full lines in the position referenced 9, lies with its diameter parallel to axis 5. Disc 3 therefore rotates at the same speed as disc 1, although with opposite sign. If roller 10 is tilted 20 to the position shown in broken lines at 14 in the lower half of the Figure disc 3 will rotate slower than disc 1. Conversely if the roller is tilted to the position shown in broken lines at 15, disc 3 will rotate faster than disc 1.

As is shown in the arrowed enlarged view attached to Figure 1, the rim 20 of roller 10 is rounded at a radius  $r_c$ , known as the roller cross-radius and measured in a plane including the variator axis 5, that is smaller than the local torus radius  $r_d$  of the race 7 measured in the same plane. In practice,  $r_d$  is likely to be, say, twice  $r_c$ . Unless the position of the roller 25 centre is otherwise constrained the normal to the common tangent to the two curves at the centre 22 of the contact between roller and disc will pass through the roller centre.

Figures 2 to 4 illustrate, with exaggerated proportions, the nature of the contact between the roller and one of the races (in 35 this case the output race 7), when the roller is in the positions

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shown at 9, 14 and 15 in Figure 1, and when viewed as in the diametral plane 23 of the roller in each case. In each case the contact is as between two curves, both lying in the diametral plane 23 of the roller. The first of these is the circumference of the roller, which is a circle of constant radius  $r$ . The second curve approximates to the arc of a circle in the small region of the contact: the radius of this circular arc is therefore the "local radius" of the race, measured in the diametral plane. When the roller is in position 9 the contact is as between first (9) and second (16) circles of radius  $r$  and infinity, as Figure 2 shows. The radius of the second circle is infinite because the diametral plane of the roller lies parallel to the axis 5, and the surface of the second circle is therefore a straight line. When the roller is in position 14, as shown in Figure 3, the contact is as between first (14) and second (17) circles of radius  $r$  (convex) and  $r_1$  (concave),  $r_1$  being the local disc radius at the point of contact. Figure 4 shows that when the roller is in position 15 the contact is as between first (15) and second (18) circles of radius  $r$  (convex), and  $r_2$  (convex),  $r_2$  again being the local disc radius at the point of contact.

The contact between disc and roller is usually through the medium of an intervening film of traction fluid. Also, due to the axial load which is applied to the discs (as indicated at 24 in Figure 1) to urge them and the rollers into the necessary traction transmitting engagement, the effective engagement between roller and disc will be an area contact.

Generally, the area of contact between roller and race for any given loading is determined by the four radii already mentioned: roller radius  $r$ , roller cross-radius  $r_c$ , torus radius  $r_d$  and the local disc radius ( $r_1$  or  $r_2$ ) measured in plane 23. Each of the four radii just referred to is to be considered as having the magnitude that exists in the uncompressed state, i.e. before the application of any load between the disc and the roller. The smaller the area of the contact the higher the stress, and the shorter the life of the contacting components.

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Smaller areas, however, tend to give higher efficiency. Where the plane of the roller is parallel to the axis 5, as in position 9 of Figure 2, the two points of contact between the roller and the races 6 and 7 are equidistant from the variator axis 5, and the local disc radii  $r_1$  and  $r_2$  at the two points of contact are also both equal and are infinite in magnitude. As soon as the ratio changes so that the roller contacts one race at an inner contact (i.e. closer to axis 5) and the other race at an outer (more distant) contact, local disc radius  $r_2$  at the inner contact becomes smaller and the contact as seen in plane 23 is as between two convex circles: the area of contact therefore diminishes. At the outer contact however, the area of contact between the roller and a now-concave surface, of local radius  $r_1$ , progressively increases as the magnitude of  $r_1$ , like that of  $r_2$ , progressively falls. According to the invention, such a progressive change in the two areas of contact, and the consequent stress set up in the disc, is modified by causing the local torus radius  $r_d$  of the two races to vary from point to point. At the inner contact the effect of a small convex local disc radius  $r_2$  can be offset by reducing  $r_d$ , and so increasing the area of contact. To compensate, the local torus radius  $r_d$  at the outer contact is increased. In accordance with the theory already referred to, this is likely to result in little overall change in efficiency, with a drop at the inner contact roughly compensated for by a rise at the outer contact. However, a net gain in fatigue life can be obtained because life is inversely proportional to a high power of stress and tends, therefore, to be dominated by conditions at the inner contact. The invention is thus to be contrasted with the teaching of such prior patent specifications as GB-A-673168, in which the transmission is not "full toroidal" but instead of the so-called "half toroidal" type, and in which the local torus radius changes in the opposite sense and for quite different reasons.

The invention is defined by the claims, includes a disc and variator as described with reference to the accompanying drawings, and will now be illustrated with reference to Figure

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5 in which roller 10, with its rim 20 rounded as before, is again shown (as in full lines in Figure 1) with its diametral plane 23 parallel to the axis 5. Input and output races 26 and 27, between which the roller transmits drive, are mirror images one of the other, so that the input and output discs 1 and 3 rotate at the same speed but in opposite directions, as they did before when the roller was in position 9 in Figure 1. Also as before, the points 28, 29 on races 26 and 27, at which those races make contact with the roller, lie on the plane 23. However, the curvatures of races 26, 27 are no longer uniform. Instead, those curvatures, inboard and outboard of points 28 and 29 respectively, are such that if roller 10 is tilted anti clockwise to a position as indicated in broken lines at 35, the curvatures of the two races conform to arcs of circles centered at a point 36 which lies on diameter 23 but is displaced from roller centre 37 so that the curvature of the inboard part of each race, viewed in a plane including axis 5, is tighter than that of the outboard part. In simple terms the effect of this compound curvature of each disc is to modify the disc/roller contact inboard of the line 28-29 so as to enlarge the effective area of contact between roller and disc and relieve the high stress already referred to. Conversely, outboard of the line 28-29, disc/roller contact is modified so as to diminish the effective area of contact between the roller and the disc, but the diminution will be insignificant because conditions at the inner contact are dominant as already explained.

In Figure 1, where the races 6, 7 conform to a common torus of truly circular cross-section, the centre of the roller 10 always lies on the centre circle of that torus. Where the disc races are of compound curvature, according to the invention, the centre 37 of the roller and the effective centre of the common torus will no longer be confined to the circumference of a single circle drawn around axis 5. Instead, as the roller tilts between the two extremes of its range of movement, the roller centre and effective torus centre will be required to move along a locus the



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shape of which is indicated roughly by the line 38 in Figure 5, and means must of course be found to mount the roller carriage 12 (Figure 1) and its operating mechanism to permit that movement. Where the races conform to toruses of different cross-sections, 05 the shape of the locus could of course be different also.

The invention is not limited to the kind of races actually shown in the simple example of Figure 5, where for each of races 26 and 27 two different curvatures meet discontinuously at the line 28-29. A continuous change of effective radius, from the 10 most outboard extremity of the race to the most inboard, may be more advantageous, and yet other strategies of curvature variation may be adopted to achieve other desired balances between efficiency and life. Curvature variations are, however, subject to two fundamental limitations. The curvature of the 15 outboard part of one disc must be related to the curvature of the inboard part of the other disc, so that the contacts between the roller and the races always lie in the diametral plane (23) of the roller, and, and the mounting of the roller carriage must allow the roller centre the freedom of movement that it requires 20 to permit that coincidence between the contacts and the diametral plane.

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## CLAIMS

1. A rotatable disc ~~(1, 2)~~ formed with a coaxial part-toroidal race, ~~(26, 27, Figure 5)~~, and suitable for use as the input or output disc of the variator for a transmission of the toroidal-race rolling-traction type, characterised in that the torus radius ~~(Fig. Figure 1)~~ of the race, that is to say the radius of curvature of the race measured at a chosen point on the race and in a plane including the disc axis, decreases as the distance of that point from the disc axis diminishes.
2. A disc according to Claim 1 characterised in that the torus radius of the race decreases continuously.
3. A disc according to Claim 1 characterised in that there is a discontinuous change in the torus radius of the race as the disc axis is approached.
4. A disc according to Claim 3 characterised in that the torus radius of the race has a constant value over that part of the race lying more than a predetermined distance from the disc axis, and a different and lesser constant value over the remainder of the race.
5. A variator for a transmission of the toroidal-race, rolling-traction type, characterised by including two complementary rotatable discs (input and output) according to any of the preceding claims.
6. A variator for a transmission of the so called "full toroidal" variety of the toroidal-race rolling-traction type, in which the direction of the normal force of reaction at each contact between a race and a traction-transmitting roller always passes through the roller centre, ~~and~~ characterised by including two complementary rotatable discs (input and output) according to any of Claims 1 to 4.

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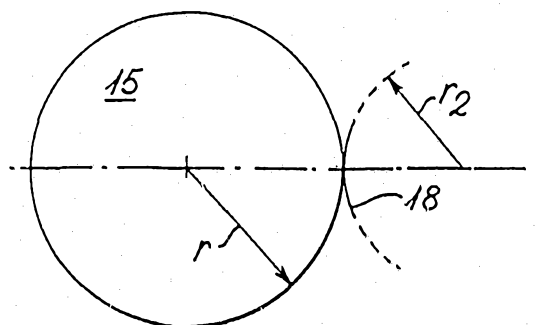


Fig. 4

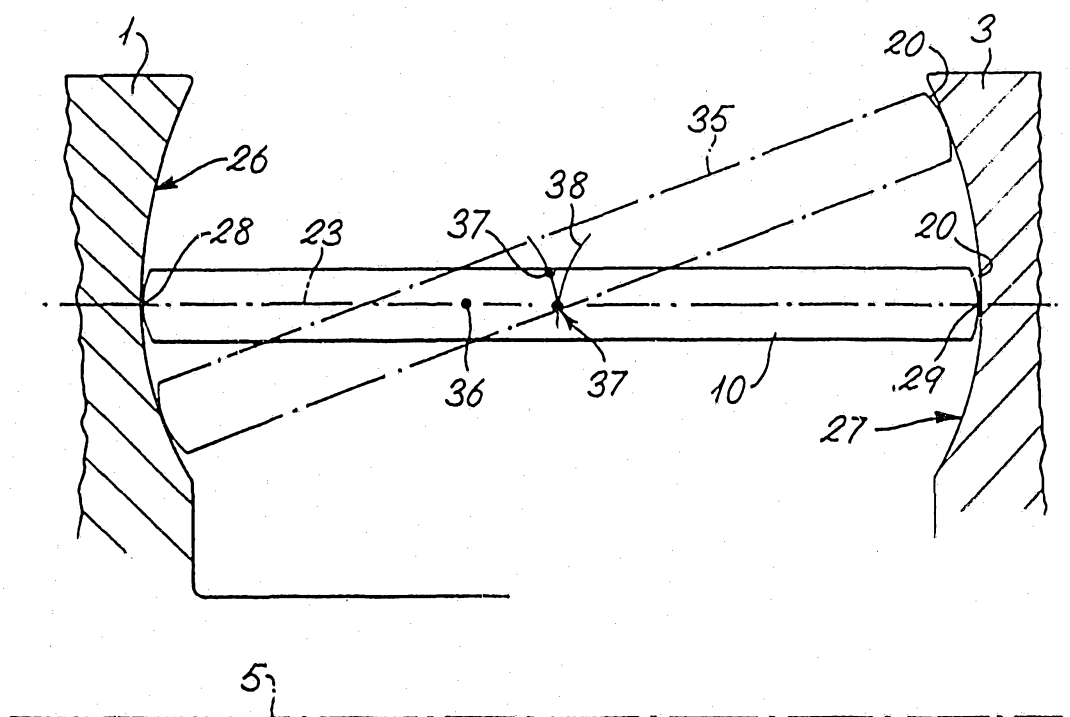
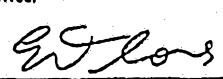


Fig. 5

## INTERNATIONAL SEARCH REPORT

PCT/GB 91/00243

International Application No

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC Int.Cl. 5 F16H15/38 ; F16H15/28		
II. FIELDS SEARCHED		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
Int.Cl. 5	F16H	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
III. DOCUMENTS CONSIDERED TO BE RELEVANT <sup>9</sup>		
Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of its relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	US,E,20801 (WINFIELD D. GOVE) 19 June 1938 see page 3, lines 15 - 69; figure 5	1, 3, 4, 7, 8 6
A	---	
A	US,A,4484487 (CHARLES E. KRAUS) 27 November 1984 see figure 1	1
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<p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"R" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
23 MAY 1991	27.06.91	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	FLORES E. 	

ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO.

PCT/GB 91/00243

SA 44863

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.  
The members are as contained in the European Patent Office EDP file on  
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23/05/91

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-E-20801		None	
US-A-4484487	27-11-84	EP-A- 0172276	26-02-86
		JP-A- 59133860	01-08-84