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MAY 4, 1943.
BY A. P. C.

C. A. H. MULDER
EPICYCLIC GEAR
Filed Sept. 6, 1939

Serial No.
293,631

5 Sheets-Sheet 1

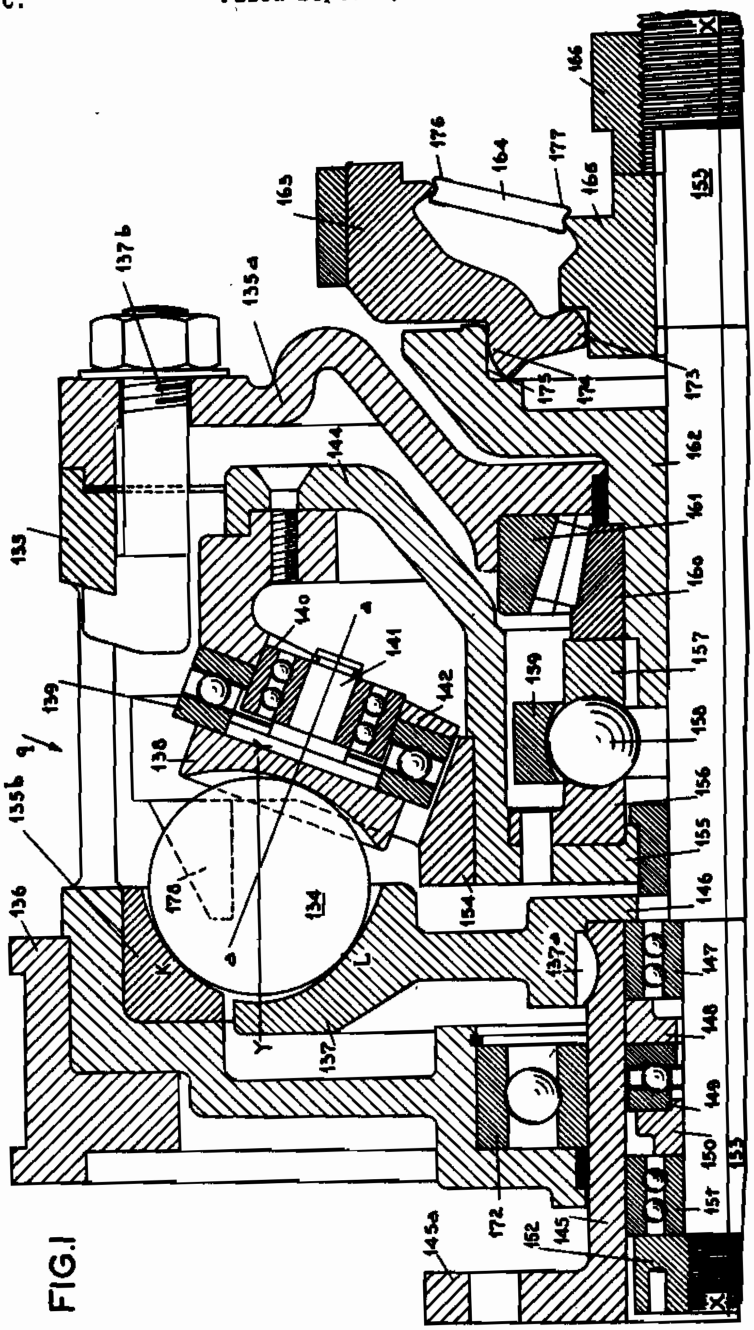

FIG.1

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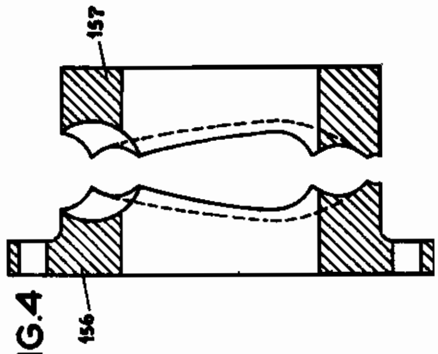

FIG.4

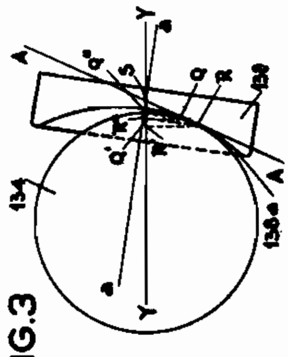

FIG.3

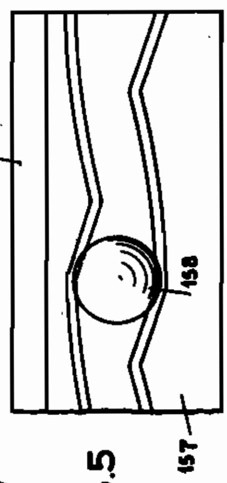

FIG.5

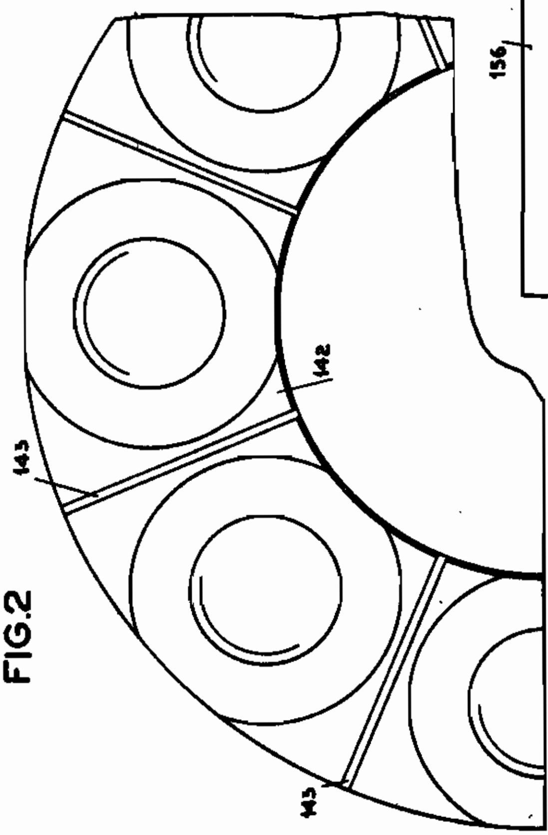

FIG.2

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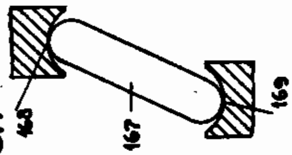
FIG.7



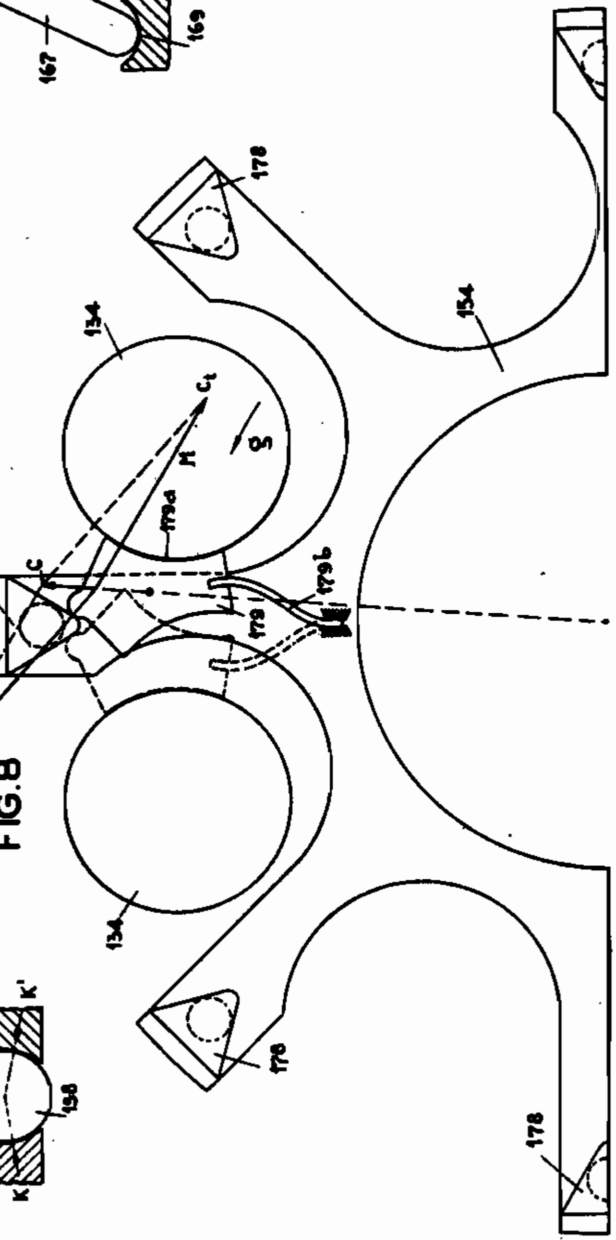


FIG.8

FIG.6

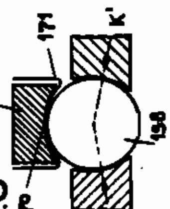


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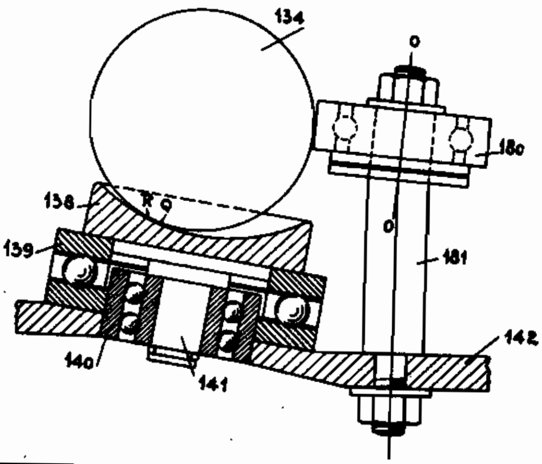
FIG.9



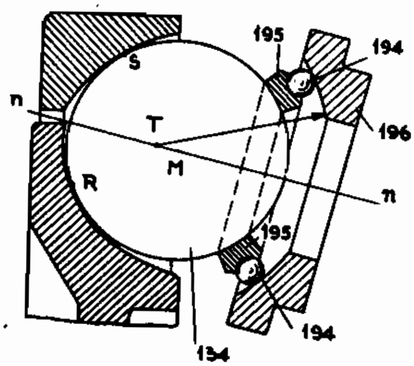


FIG.12

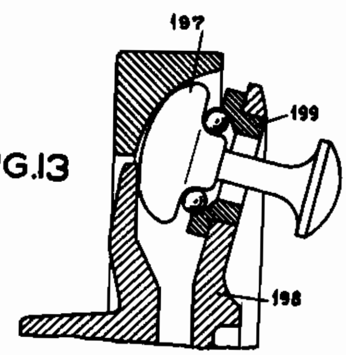


FIG.13

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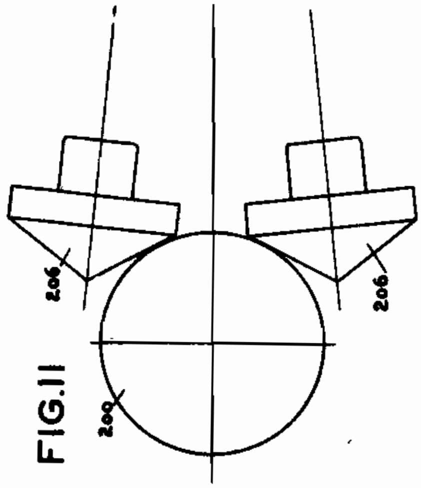

FIG.11

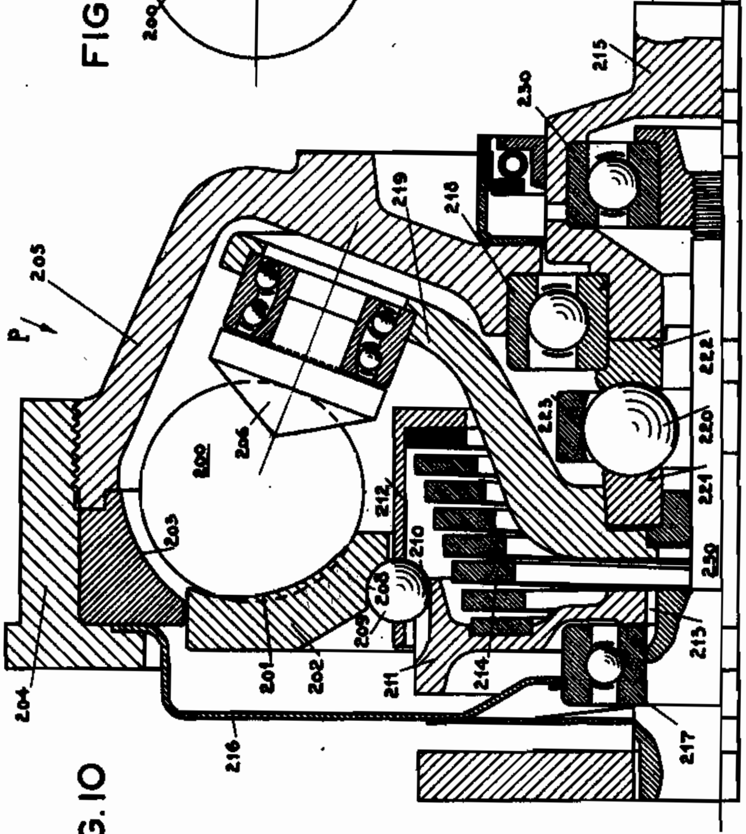

FIG.10

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ALIEN PROPERTY CUSTODIAN

EPICYCLIC GEAR

Cornelis Andries Heero Mulder, Utrecht, Netherlands; vested in the Alien Property Custodian

Application filed September 6, 1939

My invention relates to a gear in which the power is transmitted by means of round intermediate bodies, cooperating in a rolling manner with co-axial races mounted on two bodies and which are so guided with respect to a third body that their axes of rotation make no rotary movement with respect to this body.

The device in which the invention is completely applied is a speed gear with an automatic adjustment of the gear ratio, which is particularly suitable for a motorcar.

The purpose aimed at by the invention has been aspired to by many inventors, without all means and their composition according to the invention, described hereunder, having become known, whereas thus important advantages are obtained with respect to that which was obtained so far.

According to the invention the intermediate bodies are clamped between the surfaces cooperating with them by means of one or more screw (helicoidal) bearings, of which they do not constitute a part and which, independent of the torques transmitted by them, achieve axial power-operations between the three bodies.

Here and in the following by a screw-bearing is understood a device, containing elements which, with respect to each other can make a screwing (helicoidal) movement.

In an embodiment the places of the intermediate bodies with respect to the said third body are determined in such a manner that they can rotate about their own axes of rotation which intersect the axis of the co-axial races, that is the main-shaft of the system, and which, when varying the gear ratio, are subjected to relative displacements in planes passing through the main-axis.

In an embodiment a variation of the gear ratio is accompanied by an axial displacement of the co-axial surfaces with respect to each other.

In an embodiment each intermediate body cooperates in a rolling manner with one or more surfaces of rotation of one or two members connected rotatably, if desired, self-adjustably, with the third body.

In another embodiment each intermediate body bears on a row of balls, which bear in a race connected with the third body.

In an embodiment between the three bodies, with which the intermediate bodies cooperate, one or more elastic members, and/or screw-bearings, and/or a centrifugal-governor have been arranged, allowing an axial displacement of one of the bodies with respect to at least one of both the others.

In an embodiment the intermediate bodies serve as weights, the centrifugal action of which influences the gear-ratio which adjusts itself automatically.

All the above-mentioned and especially both last mentioned embodiments lend themselves particularly well for an automatic regulation of the gear ratio according to the invention, in which it is considered as a characterising feature that the gear ratio is determined by the relative position of elements which is dependent on forces operating in opposite directions, which increase in such a manner with respect to the torque exerted by the driving or the driven shaft and at the same time with the number of revolutions of one of these shafts, that an efficient regulation for the use of the speed-gear aimed at is obtained.

Yet the part of the invention, indicated by this characterising feature, can also be applied in other than the above mentioned embodiments.

According to the invention the adjustment of the gear-ratio in accordance with the position of the meant element(s) may take place directly or by means of a servomotor.

As standard for the primary or secondary couple for instance the position of a member may be used which governs the power supplied by a driving engine (in an automobile motor for instance the gas pedal) or the position of which is influenced by this power (for instance the position of a pressure indicator in the suction line, the position of the elastically suspended motor with respect to the auto frame) or an axial force-action, such as occurs in a speed-gear according to Dutch Patent 33,517 (U. S. Patent 1,897,436) owing to the converging arrangement of the surfaces with which the intermediate bodies cooperate or by an axial force-action exerted by a "screw-bearing" of a kind as will be further elucidated hereunder.

In developing the invention for autocars the idea has been started from that to avoid noise, wear and tear, heat-development and loss of energy, at all moderate and high speeds it is preferred to drive with a direct drive, unless the slope of the road or the desired acceleration give cause to apply reduced gearing. From this it follows that in the direct drive at any moderate and high speed it is desired to be able to transmit a couple which is at least large enough to conquer on a horizontal or slightly sloping road the road- and air-resistance. The road-resistance is practically independent of the velocity and the air-resistance is about proportional to the square thereof, so that the couple of forces necessary to drive with uniform speed on a horizontal or slightly sloping road, is to be considered as constant+a value, increasing with the square of the speed c. q. of the secondary number of revolutions. As standard for this value according to the invention efficient use can be made of centrifugal-action or oil-pressure, for instance derived from the action of a gear pump, which indeed are proportional to the square of the number of revolutions, whereas for the constant to be added thereto, for instance a constant (if desired, adjustable in accordance with the carload) spring-tension comes into consideration, giving an initial tension to the system. The centrifugal-action or oil-pressure, which is a standard for the primary or secondary number of revolutions and the obtained couple of forces can be derived, resp. measured from the driving as well as from the driven or another shaft. Instead of the centrifugal action or oil-pressure also another, for instance an electric force-action can be used as standard for the primary or secondary number of revolutions.

A simple embodiment of a part of the invention is obtained by dimensioning in a construction according to the figures 21 and 22 or 24 and 25 of the just mentioned patent resp. according to figure 1 of the Dutch patent specification 83 399 (U.S.219 087) the spring **47**, resp. **19** in such a manner and by giving them such a bias that their action together with the centrifugal-action of the balls **40**, resp. **10** and with the axial force excited by the primary couple owing to the converging adjustment of the surfaces **63**, resp. **65** resp. **12** produces a suitable dependence between the secondary number of revolutions, the primary couple and the gear-ratio. It goes without saying that the choice of the profile shapes and of the mutual position of the surfaces, with which the balls cooperate, influences the just mentioned dependence.

The embodiment of the invention in a construction according to the figures 21 and 22 of the Dutch patent 33 517 has the drawback that the balls **40** exert a considerable sliding and/or rolling friction on the surfaces **63**.

This drawback is much reduced by constructing these surfaces corresponding to that patent as rotatable cylinder manties **65** in the figures 24 and 25 resp. according to the patent application 83 399 as cone-mantles **12** and **12a** in the figures 1, 2, 5 and 6.

Yet the balls, also on these mantle-surfaces, still exert a spinning friction, because the point of intersection of the axes of rotation of a ball and the mantle surface, with which it cooperates lies rather far from their mutual point of contact.

This objection is avoided in the construction according to figure 1 of this application.

The inertia action and friction-resistances, prejudicial to a smooth and yet stable regulation, which in the device indicated in this figure oppose to the adjustment of the gear ratio may be reduced according to the invention, by constructing the device in such a manner that instead of the action of a separate centrifugal-governor, just as in the above-discussed application of the invention in a construction according to the Dutch patent 33 517 the centrifugal action of the round intermediate bodies, (planets), transmitting the power from the primary race to the secundary shaft, is used as an indication of the secundary number of revolutions.

By means of the description of the figures embodiments according to the invention and valuable particulars will be further elucidated. For a good understanding of these embodiments the above mentioned Dutch patent specification 33 517 and the Dutch patent application 83 399 (U.S.A.219 087) are also referred to.

Figure 1 is a partial (upper part) cross-section of a construction according to the invention;

Figure 2 is a view from the left in figure 1 against the secundary *g* head (**142**), that is to say the body or assembly connected with the secundary shaft (normally the driven shaft) with which the planets cooperate;

Figure 3 is a view, according to the arrow *q* in figure 1, of a planet (ball) with the associated clamping body;

Figures 4–7 elucidate the constructions of a screw-bearing;

Figure 8 represents the construction applied in figure 1 for compensation of the centrifugal-force acting on the planets;

Figure 9 shows another embodiment of a planet with some of the surfaces cooperating therewith;

Figure 10 is a partial cross-section of another embodiment.

Figure 11 shows how a planet in figure 10 cooperates with two clamping surfaces, seen according to the arrow *p*;

Figures 12 and 13 are other embodiments of a planet with some of the surfaces cooperating therewith;

In figure 1 each ball (planet) **134** cooperates with a reaction member **135**, carrying a brake drum **136**, further with a primary surface **137**, which by means of the key **137a** is connected with the driving (primary) shaft **145** and with a secundary surface **138**.

With the brake drum cooperates a brake or coupling, by means of which the house and the reaction-member **135** in the positions with reduced gear ratio is braked or blocked. At the gear ratio 1:1 and during stationary running of the motor coupled with the flange **145a**, the brake releases the reaction race **135** and the latter can rotate with the planets, resp. opposite to the direction of rotation of the motor.

Automatically operating constructions of brakes and couplings for this purpose have been described in the Dutch patent application 83 399.

The secundary surface, with which each ball cooperates, has been constructed as a cup **138** rotatable about the axis *a—a*. The cup bears on a pressure bearing **139** and the shaft **141**, which has been secured to the cup, is supported in a ball-bearing **140**. The assembly of cup and bearings has been mounted on a resilient part **142** of a cup-carrier **144**.

Figure 2 shows, how, separated by saw-cuts **143**, a number of parts **142** have been formed which depend freely from the periphery of the carrier **144**. The resilient support of the cups attends to such a self-adjustability of the cups that the load is evenly distributed over the planets.

Figure 3 shows a view on the ball **135**, drawn in the figure 1 with the associated cup **138** (according to the arrow *q* in figure 1). From this it appears that the axis of the cup is at an angle with the line indicated by *x—x* in figure 1. The axis of rotation *a—a* of the cup thus crosses the shaft of the device *x—x*. It intersects however the axis $y—y$ of the ball 134 in the point S (figure 3). The shape of the concave cup-surface 138 and of the screw-surfaces of 156 and 157, between which there are three balls 158, which members also determine the equilibrium of the part 144, have been chosen in such a manner that the tangent surface A—A in the point of contact (properly speaking a small surface of contact, which has been indicated in the figure by the points R and Q) passes through the point S. This means that the ball in RQ cooperates with the cup in an analogue manner as two conical toothed wheels ($RR':QQ'=RR'':QQ''$, in which RR', etc. represents lines perpendicular to the axes $y—y$ resp. $a—a$) in other words that the small surfaces RQ can roll over each other without slip and without spinning friction. When now care be taken that when varying the gear-ratio, that is to say when shifting the points L and K (figure 1) the pressures of the surfaces on each other are always large enough and that the above-mentioned proportional equation is complied with, neither slip nor spinning friction can ever occur between ball and cup.

This is very well possible according to the invention, namely by taking care that when varying the gear ratio the balls are shifted together with the cups with respect to the primary surface 137, whereby then also the reaction member 135 undergoes an axial displacement. This takes place amongst others by means of the screw-bearing 156, 157, 158, 159. As shown by figures 4–7 the three balls 158 of this bearing run in sloping paths of the races 156 and 157.

For compensation of mutual differences of the races of the three balls and/or of a slight deviation from the co-axiality of the parts 156 and 157, (also) under influence of an unsymmetric load of the part 157 if any, the ring 159 adjusts itself somewhat excentrically so that the balls begin to run on different radii. Due to this a (slight) difference may occur in their rotating movement. This difference is not always eliminated when returning so that one of the balls return somewhat earlier than both the others into the deepest point of its path, hence passes this deepest point before the other balls reach their lowest point. When going to and fro for a long time this difference sometimes becomes larger and larger, so that finally undesired jamming occurs and the equal distribution of forces over the three balls aimed at is not at all obtained. The deviation may even become so large that one of the balls becomes totally unloaded and rolls to the deepest point of its range in the part 157. If this happens when the part 156 is at a considerable angle from its lowest position thus a large deviation occurs in the angles between the radii to the balls due to which the uniformity of the screw in movement aimed at, is disturbed.

To avoid this drawback the ring 159 has been provided with three small convex-shaped cavities (for instance in small pieces of thin copper 171 at 170 (Figure 6) having radii of curvature which are somewhat larger than those of the balls 158, so that these near their poles (of the rotation) lie in the small cavities and rotate herein during the screwing movement. Thus the angles between the radii to the balls can no more get a large deviation of 120°, whereas the light rolling motion remains safeguarded because the contact-pressure against the small cavities need only be small.

It be stated here that these balls 158 and the sloping races can be replaced by unround, for instance approximately elliptic bodies 167 (Figure 7), which can run into grooves 168 and 169 and push off thereon.

For experimenting purposes this construction has the advantage that then the shape of the unround bodies can more easily be modified, than the shape of the sloping surfaces 158 and 157 which is much more expensive and time-consuming.

The reaction-member 135 (Figure 1) is connected at 137*b* with a disc 138*a*, which is rotatable about the member 162 by means of a conical roller-bearing 181–180. Further the reaction member is supported on a ball-bearing 172, which is shiftable over the primary shaft 145. The centrifugal weights 183 are, by means of joint surfaces 173, supported on the member 165 keyed to the secondary shaft 153 and by means of joint surfaces 174 they are supported in a recess 175 of the member 162. The recess 175 forms one side of a recess in the member 162 which recess has a square section.

Against the centrifugal weights 163 press the edges 176 of rubber blocks 164 which on the other side are supported with their edge (a shield frame) 177 on the member 165.

The rubber blocks press the centrifugal weights 163 (in this embodiment one should think of four blocks) outwards in a biassed manner. In operation this force-action is increased by the centrifugal forces on the parts 163. Corresponding axial-forces are exerted on the parts 165 and 162 by the lever arms 173 and 176.

The part 146 of the primary surface bears against a ball bearing 147. In the space between the secondary shaft 153 and the primary shaft 145 still a radial ball bearing 151, an axial pressure bearing 149 and distance pieces 148—140, as well as a locking nut 152 are mounted.

In Figure 1 is to be seen that the axial force actions are taken up in the circuits 134, 136, 139, 142, 144, 155, 156, 157, 160, 162, 163, 165, 153, 152, 151, 168, 149, 148, 147, 146, 137, 134 and 134, 136, 139, 142, 144, 155, 156, 158, 157, 160, 161, 135*a*, 135, 135*b*, 134.

In the construction according to Figure 1 the influence of the centrifugal forces acting on the balls 134 can be compensated as follows.

With the cup carrier 144 a member 154 is connected having fingers 175 (Figures 1 and 8), which seize between the balls 134. Pressure members 178 are flung outwards by the centrifugal force (vide force C, Figure 8). They are guarded from falling inwards because by means of a spring 179*b* they are connected to the body 154. The pieces 179 press at the one side against the finger 176 and at the other side with a cup-shaped part 179 against the ball 134. The component C_t of the centrifugal force acting on the pressure pieces 178 drives the balls in their clamping space against the action of the centrifugal force acting on the balls. When the motor is braked, hence when the secondary shaft starts a driving action the balls 134 are pushed in the direction of the arrow *g* in another clamping space (compare the cups 136). Then the pressure pieces 178 slip below and past the finger 176 in the dotted position according to Figure 8 (the spring 179*b* too has been drawn in dotted lines) and press the balls 134 against the centrifugal force acting thereon in the clamping space appertaining to the situation in which the secondary shaft exerts a driving action.

In the construction according to Figure 9 the balls 134 are always pressed into the same clamping spaces by means of either or not self-adjusting counter rollers 180. Further means to compensate the centrifugal forces on the balls are not necessary here. Each small roller 180 has been mounted on a spindle 181, which has been secured in a resilient part 142 of the cup carrier 144.

When the secondary shaft acts in a driving manner the couple of forces can be transmitted to the balls 134 and further to the primary shaft by means of the counter rollers 100.

Here the centrifugal forces on the balls are not compensated in a literal sense by a force excited in a direction opposite to that C-force.

Now just this circumstance can be used according to the invention to obtain the desired influence of the number of revolutions on the couple to be transmitted, without separate centrifugal weights being necessary for this.

In the construction according to Figure 10 the centrifugal weight-governor 163 according to Figure 1 has been omitted which still offers the advantage that detrimental inertia- and friction-actions, if any, which, when braking with the motor might cause an alternating action with the inertia-action of the auto, cannot occur either.

In the construction according to Figure 10 twelve balls 200 cooperate with a race 201 of a body 202, with a race 203 in the house 204, 205. Further each ball 200 cooperates with two rotatable cones 206 and 207 (see also Figure 11) the shafts of which intersect the main-axis $x—x$ of the construction and which bear in such a manner in the carrier 219 that between each two of the balls 200 there is a cone 206. The body 202 is provided with a race 208, which is part of a toroidal-surface and cooperates with three balls 209, which are at mutually equal distances in three uniformly shaped grooves 210 of a body 211 which has been secured to the driving shaft 250 by means of cannelures 213.

The balls 208 with the grooves 210 and the race 208 constitute a screw-bearing which turning to the right (seen from the left hand side according to the axis $x—x$) exerts an axial force on the part 202, which is directed to the right in the figure.

The balls 209 are gripped in a cage 212. In the holes of the cage 212 small cups may be arranged the shape of which is so determined with respect to the balls 209 that between the ball-surface and the cup a good oil-film-lubrication is obtained.

Between the cage 212 and the body 211 a flexible spring is mounted, which acts parallel to the screwbearing 209—210, because it exerts such a couple of forces on the cage 212 that the ball 209 represented in the figure is pressed backwards as far as the represented position, in which the contact points of the planets 200 and the part 202 nearly lie on the axes of rotation of the planets. These are the diameters, which pass the point of intersection of the axes of the conuses 206 with main axis $x—x$ (direct drive position).

The house comprises two parts 204—205 connected with screw-threads and a resilient front-plate 216, which has some initial tension and tries to press the body 203 in the figure to the right, that is to say, in a position with reduced gear-ratio.

The house is supported on two ball-bearings 217 and 218 and can rotate about the main-axis $x—x$.

Round the house a maximum brake or maximum coupling is arranged by means of which the house in the positions with reduced gear ratio of the transmission is braked or is coupled with a stationary body, for instance the frame of an autocar. At the gear ratio 1:1 (direct drive) and at stationary running of the motor coupled with the shaft 250 the brake releases the house and this can rotate with the planets.

Automatically operating constructions of brakes and couplings for this purpose have been described in the Dutch patent application 83,399. The cones 206, situated each at both sides of a planet 200 are rotatably supported on a somewhat resilient disc 219. This disc may again be provided with saw-cuts (vide Figure 1) so that radially resilient parts are formed, which make an equal distribution of the load over all planets possible.

Between the secondary (driven) shaft 215 and the body 219 there is again a screw-bearing 220—223 for instance as described before with reference to Figures 4–7. Further an axial pressure bearing 230 is mounted between the primary and secondary shaft between 250 and 215).

The screw-bearing comprises three balls 220, races 221 and 222 and cage 223. This screw-bearing as well as that according to the Figures 4–6 has surfaces constituting parts of helicoidal surfaces with right and left pitch. The pitch angles, dependence of the requirements of regulation the apparatus should satisfy are chosen in such a manner that when the shaft 250 is driven by the motor according to the arrow P, the body 219 screws in the figure to the left so that also the body 202 is moved to the left in the figure under influence of the forces exerted thereon by the balls 200. During this operation the cage 212 is adjusted with respect to the part 211 against the action of the spring-force 214 by means of the balls 209 according to the arrow P.

The planets 200 are pressed to the left and towards the axis $x—x$ into a position in which the gear ratio is smaller than 1:1.

Due to the screwing actions of the grooves 210 and the screw bearing 221, 220, 222 the planets 200 are clamped between the surfaces 201, 203 and 200 in such a manner that they cannot slip with respect to any of these surfaces.

The centrifugal force on the planets 200 has the tendency to move the planets outwards and in the figure to the right, thus to bring the device into the direct drive position against the force-action just considered.

The shape and the position of the surfaces 201, 203, 206, 210, 221 and 222 the number and the size of the balls and the characteristics of the spring 214 and of the resilient plate 216 can be chosen in such a manner that the device, as well when the power of the motor is positive as when it is negative, automatically adjusts itself in all circumstances to an efficacious gear ratio.

The initial tension of the plate 216 has the purpose to displace the house 204, 205 somewhat to the right when the balls 200 do not exert on the surface 203 forces, the axial components of which surpass said initial tension. Because of that when the secondary shaft is at rest, so that no centrifugal forces act on the balls, a position with a small gear ratio will be obtained so that the motor can rotate stationary without having to exert the couple, which otherwise would be necessary to bring the device out of the direct drive position. This is of importance for the stationary rotation of the motor.

Instead of the cups 138 (Figures 1 and 9) or of the cones 206 with their supports also a construction according to (Figure 12) can be used.

Here the ball 134, by means of a ring 195 and the small balls 194, bears against a spherical cup 196, which cannot rotate about its axis and is connected to the part 142, resp. 216. The center of curvature of said cup is a point T, which is situated in such a manner with respect to the center M of the ball 134 that the latter can move just as in the above described constructions, somewhat towards or from the main-axis x—x. The small balls 194 can also cooperate directly with the ball 134 c. q. with a groove ground in the ball 134 instead of with the ring 195.

Figure 13 illustrates that the planet bodies need not always be balls. Here each planet body 193 cooperates by means of small balls with a cup 199 connected with the secondary head 199.

Obviously the application of the invention is not limited to the described embodiments. It can also be used entirely or partially for other purposes, for instance in aircraft, in electro-motors, machines for tooling purposes, lifting machines, etc.

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