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PLANETARY GEARBOX 5R1

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Abstract

The invention relates to transport engineering, transport machines transmission, ground-based transportation system including transport-process machines, automobiles, tractors, etc. The transmission unit currently used in domestic and foreign automobiles - the gearboxes with stepwise change of gear ratios - are characterized by the volumetric sizes and increased metal consumption. Among all types of manual transmissions, the planetary gear trains of small sizes and mass meet the requirements of reduction in machines metal consumption best of all. This is due to the effect of multi-threading and the use of internal toothing. The study, systematization, analysis, synthesis of literature, materials of patent search on the problem under consideration, analysis of the research subject, comparison and grouping of theoretical material on the research problem made it possible to design and simulate the planetary gearbox 5R1.

Keywords

Gearbox – Planetary gear train – Planetary gearbox – Transmission unit – Vehicle

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Introduction

The currently known transmission units (the gearboxes with stepwise change of gear ratios containing gears, shafts, bearings, gear shifting unit used on domestic and foreign car[1]) are characterized by the volumetric sizes and increased metal consumption. Five-speed gear boxes (GB) are widely used both in longitudinal and transverse layout of transmission. They can be three-shaft or two-shaft[2]. The disadvantages of these units are also the metal consumption and design complexity, as well as the fact that for each forward gear, the GB requires its own couple of gearwheels, and for reverse gear - three or four gearwheels. A series of gearwheels increase the GB longitudinal dimensions and metal consumption. Spur gears have a limited load capacity due to a single-contact (single-threaded) mesh. When increasing the transmitted torque it is necessary to increase the center-to-center (between axes) distance that increases the transverse dimensions of GB.

Research methods

Theoretical (study, systematization, analysis, synthesis of literature, materials of patent search on the problem under consideration, analysis of the research subject, comparison and grouping of theoretical material on the research problem, modeling and design of the device; generalization of research results); experimental (methods of the results mathematical processing).

Results and discussion

The use of planetary gear in gearboxes

Among all types of manual transmissions, the planetary gears of small sizes and mass meet the requirements of reduction in machines metal consumption best of all. This is due to the effect of multi-threading and the use of internal toothing. The simple planetary gear train (PGT) consists of three members: sun gear (a) epicyclical wheel (b) and carrier (h) with satellites. PGT is characterized by the internal parameter $K=Z_b/Z_a=1.5\text{-}5$ equal to the ratio between the teeth number of the epicyclical wheel Z_b and the teeth number of the sun gear Z_a. The lesser value of K is limited by the minimum dimensions of satellites, the larger one – by the sun gear.

The simple PGT, in addition to the differential, is mainly used as a single-stage wheel reduction gear of the double hub-reduction final drive (FD) of the drive axle or a compound reduction gear - supplementary gear box at the output of the MSGB (multiple-speed gearbox)[3] which is the most similar to the proposed device. The disadvantage of such PGT is that it implements only two transmissions: the direct when locking the PGT connecting two members by means of shift collar: epicyclical wheels (b) and carrier (h), and slow one in mode $U_{ah}^{b}=K+1$ where U is a gear ratio, the upper index – the member stopped, the lower indices - input and output members of torque. Epicyclical wheel stopped (b), torque is applied to sun gear (a) and removed from carrier (h).

[1] Vehicles: Design, designing and calculation. Transmission. A. I. Grishkevich (ed) (Moscow: Vyshaya shkola,1985); A. S. Litvinov, Car Chassis: Design and the Calculation Elements. A. S. Litvinov, R. V. Rotenberg, A. K. Frumkin (eds) (Moscow: Mashgiz, 1963) y V. I. Nekrasov, Multispeed transmission. Design, designing and calculation: Study guide (Kurgan: Publishing house of Kurgan State University, 2001).

[2] V. V. Osepchugov & A. K. Frumkin, Motor vehicle: Design Analysis, Elements of Calculation (Moscow: Mechanical engineering, 1989).

[3] V.V. Osepchugov & A.K. Frumkin, Motor vehicle: Design Analysis…

There is a planetary supplementary gearbox[4] proposed to be applied in the power drive of heavy motor trucks for improving cross-country power in severe road conditions. The design of planetary set of supplementary gearbox excludes the excess freedom of the floating link of the crown gear due to the fact, that when turning on the lower range it is pressed against the wall of the supplementary gearbox case[5]. The supplementary gearbox design allows you to reduce the dynamic shocks and vibrations. The solution of this problem is provided by the fact that in the supplementary gearbox, in the housing wall groove, the shock absorber with the protrusion is installed. The shock absorber elastically restricts the movement of the gear wheel when holding it with a fork in condition of downshifting. In the ring groove on the outer surface of the gear wheel, the damper is deformed[6]. The foresaid supplementary gearbox contains the planetary gear set assembled in the inner cavity of the housing being attached to the gearbox case, on the output shaft of which the sun gear is installed. This sun gear is kinematically connected with a crown gearwheel having the possibility of displacement in the axial direction by means of fork installed in its outer groove and connected with the shaft of the pneumatic cylinder piston when air supplying under pressure to one of the under piston spaces and the successive wheel teeth toothing through the blocking rings located therein from both sides of satellites mounted in the carrier, with ring gears of clutches, one of which is attached to the fixed inner wall of the housing, and the other - on the constantly rotating link of the series. This design does not reduce the overall dimensions and metal consumption of the vehicle transmission unit.

The transmission system used in the vehicle instead of transmission and clutch was developed. It is easier and more cost-effective since the transmission module requires less number of gear stages for implementing different gear ratios. This system is distinguished by the fact that the first means of clutch is formed by the brake and the means of gear stage shifting is located between the input and the first output and is formed by a planetary gear with at least three rotating members, the first of which is connected to the input, the second rotating member is connected to the first output and the third rotating member is connected with the brake. Additional variant of implementing this transmission system differs in the fact that the first means of clutch is formed by the first clutch and the means of gear stages shifting is located between the input and the first output, and is formed by the main stage of transmissio[7]. Different variants of the vehicles transmission are also represented by patents' domestic and foreign authors[8] and others.

The existing designs of multiple-speed gearboxes (MSGB) have been considered in patents of the domestic and foreign authors[9] and others.

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[4] Patent RU num 2610847 Supplementary gearbox (Authors: Tsvelev, F.A.; Drozdov, P. A.; Morozov, P. I. & Likhachev, D.S.).

[5] A.P. Nedyalkov "Prospects of standard series unified mechanical stepped gearbox with automatic control". Collection of scientific works 'Motor vehicles', vol: 232 (2004): 60-70.

[6] Patent RU num 2610847 Supplementary gearbox (Authors: Tsvelev, F.A.; Drozdov, P. A.; Morozov, P. I. & Likhachev, D.S.).

[7] Patent RU num 2620633 (Authors: Vroemen, B. G. (NL); R.M. van Druten (NL) & Serrarens A. F. (NL)).

[8] Patent RU num 2620633 (Authors: Vroemen, B. G. (NL); R.M. van Druten (NL) & Serrarens A. F. (NL)); Patent RU num 2398992 Transmission for a vehicle (Authors: Murakami, A. (JP); Funakhoshi, M. (JP) & Shiina, T. (JP)); Patent RU num 2138419 Transmission of the vehicle (Authors: Volkov, Yu.K.; Pinigin, B.N. & Fedorov, V.A.) y Patent RU num 2592470 Transmission system for motor vehicle (Author: Forsberg, J. (SE)).

[9] Patent RU num 2268163 Multi-speed gearbox (Author: Nekrasov, V.I.); Patent RU num 2266209 Multi-speed gearbox (Author: Nekrasov, V.I. & Turovets, L.A.); Patent RU num 2397385 Multi-speed

The most similar to the proposed multiple-speed gearbox is the gearbox according to the patent RU No. 2349816[10] which consists of coaxial three-shaft GB. Seven pairs of gears toothed between each other, a number of reverse gears with the intermediate gear on the separate axes, four three-position shift collars and one two-position shift collars provides 16 forward gears and 4 reverse gears. The disadvantages of the described transmission unit are in limiting the vehicle operational and layout characteristics due to the insufficient number of gears and the range of gear ratios, high values of gear ratios of the outer gears that leads to increasing center-to-center distance and transverse dimensions, decreasing meshing accuracy due to the shafts bending with their considerable length that causes the MSGB noise, reduction of efficiency and life.

The gearbox, presented in patents[11] etc. are also developed. They provide increasing the operational characteristics of the vehicle by increasing the range and number of gears.

Planetary gearbox 5R1

The problem to be solved by the proposed device of the GTV (ground transport vehicle) transmission unit is in its dimensions and metal consumption reduction due to more complete use of the kinematic capabilities of the simple three-link PGT.

The essence of the proposed device is as follows: planetary gearbox includes the unit housing, the simple three-link planetary gear train consisting of the sun gear, epicyclical wheel and carrier with satellites that are meshed with the sun gear and the epicyclical wheel. The carrier and epicyclical wheel housing have shafts with ring gears and cut-off clutch of the epicyclical wheel. With this, the input shaft has a three-position ring gear on which the shift collar is installed. The shaft of the sun gear with ring gears on the ends is mounted in the bearing of the ring gear of drive pinion and in the bearing of rear wall of the unit housing with the ring gears. The carrier is mounted on the inlet and outlet of tubular shafts with ring gears. The epicyclical wheel housing is mounted on the input and output coaxial shafts with ring gears. On the front inner wall of the unit housing next to the ring gear of the input shaft, the ring gear with the carrier cut-off clutch or the epicyclical wheel is mounted. Next to the ring gears of output shafts, the drive tubular shaft with the ring gear is mounted on the shaft input and the drive pinion with the ring gear on the shaft output, near the ring gear of the sun gear shaft on which the shift collar is located. The proposed technical solution provides five forward gears and one reverse gear with sufficient range (D=2.62/0.38=6.9) when reducing the sizes and metal consumption compared to standard designs.

gearbox (Authors: Cherepanov, S.V.; Gaev, S.V. & Zakharov, Yu.A.); Patent RU num 2577401 Multi-speed gearbox (Authors: Fellmann, M. (DE); Gumpoltsberger, G. (DE) & Beck, W. (DE)); Patent RU num 2574487 Multi-speed gearbox (Authors: Fellmann, M. (DE); Gumpoltsberger, G. (DE) & Beck, W. (DE)); Patent RU num 2577401 Multi-speed gearbox (Authors: Ziemer, P. (DE); Gumpoltsberger, G. (DE); Bauknecht, G. (DE) & Moore, M. (DE)) y Patent RU num 2310117 Automotive multi-speed gearbox (Authors: Steen, M. (SE) & Karlsson, L. (SE)).

[10] Patent RU num 2621213 16-speed gearbox (Authors: Nekrasov, V.I. & Shyika, A.P.).

[11] Patent RU num 654039 Gearbox of the vehicle (Author: Nekrasov, V.I.); Patent RU num 2581954 Planetary gearbox (Author: Nikitin, V.A.); Patent RU num 2632821 Coaxial gearbox with two clutches (Author: Evdoteev, Yu. L.); Patent RU num 2628016 Gearbox for motor vehicle (Author: Isaichev, V.T.); Patent RU num 2558403 Gearbox (Author: SLAPAK, Dieter (SE)); Patent RU num 2620174 Planetary gearbox (Authors: Volchenko, Yu.I. & Kostyukov, V.A.) y Patent RU num 2634363 Method of producing universal gearbox and its modifications (Author: Evtodeev, Y. L.).

Design of planetary gearbox 5R1

Figure 1 shows a planetary gearbox (PGB) scheme with the simple three-link planetary gear train (PGT) that has four shift collars, shafts of input, output, and cut-off clutches of the PGT three links with ring gears. In the upper part, the shift collars are shown in the state of the 1st speed, in the lower part - 4th speed[12].

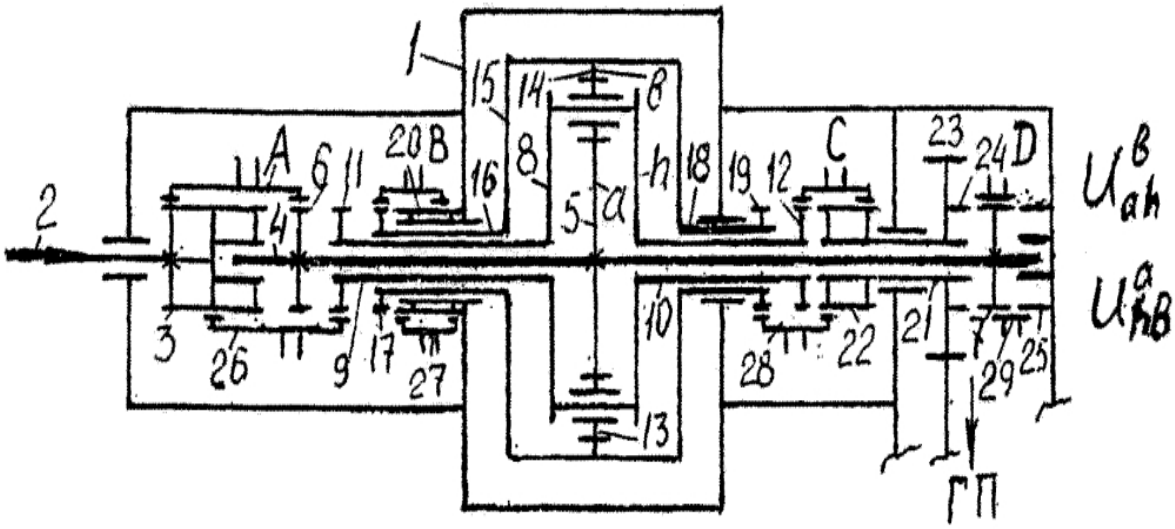

Fig.1

Scheme of the planetary gearbox with the simple three-link planetary gear train: 1 - unit housing - PGB (planetary gearbox); 2 - PGB input shaft; 3 - three-position ring gear of the input shaft 2; 4 - drive of sun gear shaft 5 (a); 5 (a) - sun gear; 6 – ring gear on the input shaft 4; 7 – ring gear on the output shaft 4; 8 (h) - carrier of the PGT (planetary gear train); 9 - tubular input shaft of the carrier 8 (h); 10 - tubular output shaft of the carrier 8 (h); 11 – ring gear of the shaft 9 on carrier 8 input (h); 12 – ring gear of the shaft 10 at the carrier output 8 (h); 13 satellites on the carrier axis 8; 14(b) PGT epicyclical wheel; 15 - epicyclical wheel housing 14, 16 - input coaxial shaft of the housing 15 of epicyclical wheel; 17 – ring gear of the input coaxial shaft 16; 18 - output coaxial shaft of the housing 15 of the ring gear; 19 – ring gear of the output coaxial shaft 18; 20 - three-position ring gear of the housing front inner wall 1; 21 - drive tubular shaft of the drive pinion; 22 - three-position ring gear of the drive tubular shaft 21; 23 - axle drive pinion; 24 - ring gear on the drive tubular shaft output 21; 25 – ring gear of the PGB housing 1 rear wall next to the ring gear 7; 26 (A) three-position shift collar on the ring gear 3 of the input shaft 2; 27 (B) – cut-off clutch of PGT links on the ring gear 20 of the housing 1 front inner wall; 28 (C) shift collar on the drive tubular shaft 21; 29 (D) sift collar on the ring gear 7 of the shaft output 21.

Figure 2 shows the ray diagram of PGB operation for K=1.62[13]. The change in the value of the internal parameter K leads to a change in the kinematic characteristics of PGB. At K=1.62 we obtain equal segments between the gear on the horizontal scale in the logarithmic scale where the values of PGT gear ratios are specified. Vertical ray indicates the torque direct transfer from the engine to the axle drive pinion (GP).

[12] Patent RU num 2621213 Planetary gearbox 5R1 (Authors: Nekrasov, V.I. & Gorshkova, O.O.).
[13] A. S. Litvinov, Car Chassis: Design and the Calculation Elements. A. S. Litvinov, R. V. Rotenberg, A. K. Frumkin (eds) (Moscow: Mashgiz, 1963).

The ray to the right/up characterizes the slow-down mode of PGT, the flatter ray, the higher value of the gear ratio. The ray to the left/up characterizes the accelerating operation mode of PGT, the flatter ray, the lower value of the gear ratio. The ray diagrams are useful for understanding the MSGB operation (multi-speed gearbox) since the value of each ray is constant at all segments of the diagram. Over the ray diagram there is a table of the shift collars position in the different gears. In the upper part of the table, the status of PGT in each gear is shown.

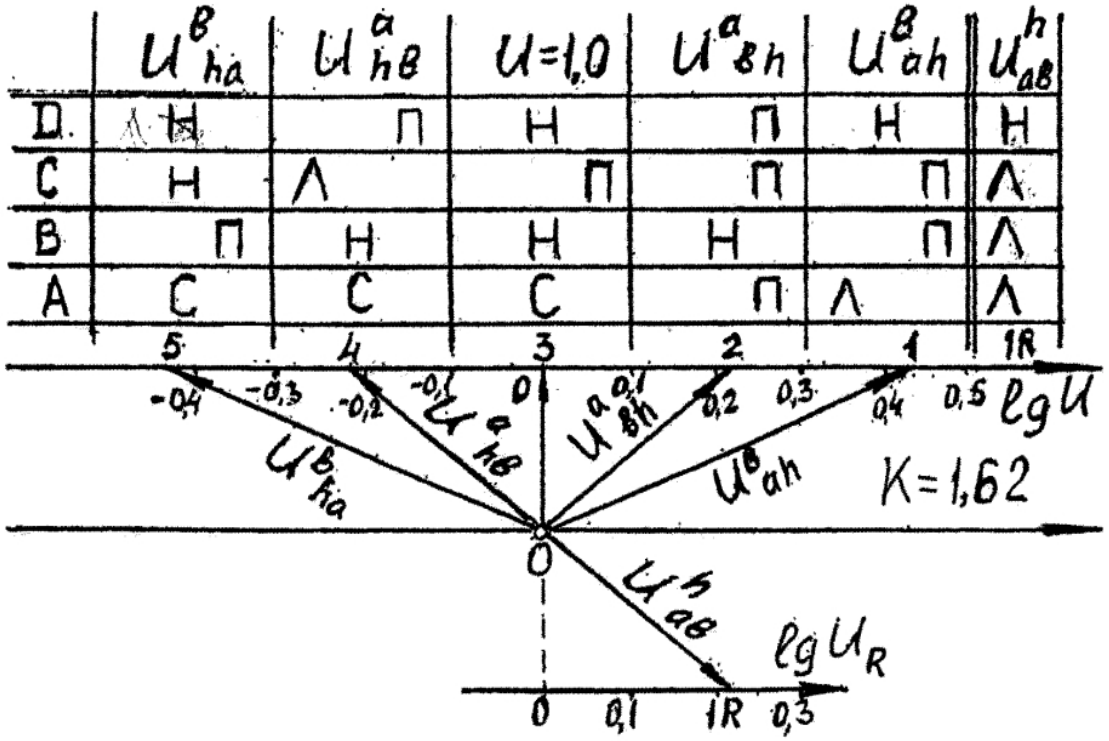

Fig. 2
Ray diagram of the planetary gearbox operation for K=1.62.

In housing bearings of the planetary gearbox 1, the input shaft 2 with attached to it the three-position ring gear 3 and the shaft 4 of the sun gear drive 5 (a) with the ring gears 6 and 7 on the shaft inlet and outlet are located coaxially. The output of shaft 4 can be used like power shaft. On the shaft 4, the tubular shafts of the carrier 8 (h) are installed: input shaft 9 and output shaft 10 with ring gears 11 and 12 on these shafts input and output. On the carrier axes 8, the satellites 13 that are meshed with the sun gear 5 (a) and the epicyclical wheel 14 (b) are located. At the housing input 15 of the epicyclical wheels 14 (b), the input coaxial shaft 16 with the ring gear 17 is secured, and at the output - the coaxial output shaft 18 with the ring gear 19. Over input coaxial shaft 16 on the inner wall of the housing 1 near the ring gear 17, the three-position ring gear 20 is located. On the shaft 4 next to the ring gear 12, the drive tubular shaft 21 is installed with the three-position ring gear 22 at the inlet of this shaft and with the drive pinion 23 of the final drive with the ring gear 24 on the drive shaft output 21. Final drive can be cylindrical, bevel, hypoid. In front of the ring gear 24 beside the ring gear 7 of the shaft 4 on the rear wall of the housing 1, the ring gear 25 is located. Three-position shift collar 26 (A) is installed on the ring gear 3 of the input shaft 2 for selective connection with the ring gear 6 of the sun gear drive 5 (a), with the ring gear 11 of the carrier drive 8 (h) with the ring gear 17 of the epicyclical wheel drive 14 (b).

Shift collar 27 (B) is located on the ring gear 20 of the front inner wall of the housing 1 for the carrier 8 (K) cut-off by the ring gear 11 or the epicyclical wheel 14 (b) by the ring gear 17, the neutral (N) - OFF position - is provided by shift collar installation between the ring gears 11 and 17 or moving it to the wall. Shift collar 28 (C) is installed at the input of drive tubular shaft 21 for selective connection with the ring gear 19 of the output coaxial shaft 18 of the epicyclical wheel 14 (b) or with the ring gear 12 of the output tubular shaft 10 of the carrier 8 (h), neutral (N) state is provided by installing the shift collar between the rings 19 and 12. The shift collar 29 (D) is located on the ring gear 7 on the shaft 4 output of the sun gear 5 for pinion drive 23 when connecting with the ring gear 24 or the sun gear 5 cut-off when connecting with the ring gear 26 of the rear wall of the housing 1.

The simple three-link planetary gear train can provide five gears, without the direction of rotation change, two reverse gears and three gears in the integral (summing) modes when the torque is applied to two links of PGT with different rotation frequency, and removed from the third link.

Operation of planetary gearbox 5R1

The device operates as follows.

First speed. On the ray diagram (Figure 2), this mode is indicated by the flat ray from the point 0 to the right/up point 1. Above this point, the shift collar state is shown (Figure 1, upper position of the shift collars): A - left (L), B and C - right (R), D - neutral (N). In the upper part of the table, the planetary gear train state is shown U_{ah}^{b}=K+1.

The epicyclical wheel 14 (b) is cut-off by the shift collar 27 (C) that closed the ring gears 20 of the front inner wall of the housing 1 and 17 of the tubular shaft 16 of the housing 15 of the epicyclical wheel 14. Torque (Figure 1) from the ring gear 3 of the input shaft 2 is transmitted to ring gear 6 by the shift collar 26 (A), and to the sun gear 5 (a) by the shaft 4. The sun gear 5 (a) rotates the satellites 13 that while running around the epicyclical wheel 14 (b) rotate the carrier 8 (h) with reduced frequency but with increased torque. By means of tubular shaft 10, ring gear 12, and the shift collar 28 (A), the torque is transmitted to ring gear 22, to the drive tubular shaft 21 and drive pinion 23. For K=1.62 gear ratio U_{ah}^{b}=K+1=2.62; lq 2.62=0.42.

Second speed. On the ray diagram, this mode is indicated by the steep ray from the point 0 to the right/up to the point 2. We shift the collar A from the left position to the right (R) position, collar B from the right to the neutral position (N) - OFF - to the wall of the housing 1 (Figure 1, bellow). In the upper part of the table, the PGT state Ub_{h}^{a} is shown. Compared to the 1st speed, the links replacement took place: the sun gear 5 (a) is cut-off, the torque is transmitted to the epicyclical wheel 14 (b).

The sun gear 5 (a) is cut-off by the clutch 29 (D) that closed the ring gears 25 of the housing rear wall 1 and 7 of the shaft 4 (Figure 1, from the right). The torque from the ring gear 3 of the input shaft 2 is transmitted to the ring gear 17 by the shift collar 26 (A); to the epicyclical wheel 14 (b) - by tubular shaft 16 along housing 15 that rotates the satellites 13, and they, in their turn, running around the sun gear 5 (a), rotate the cage 8 (h), and further like at 1st speed with reduced frequency, but increased torque. For K=1.62, the gear ratio is U_{bh}^{a}=(K+1)/K=2.62/'1.62=1.62; 1.62 lq=0.21.

Third speed – direct. On the ray diagram, this speed is represented by a vertical ray, from the point 0 to the point 3. We shift the collar A from the right position to the intermediate (I) position, collar D - from the right to the neutral position (N). By the shift collar, the torque is transmitted from the ring gear 3 to the ring gear 11 of the tubular shaft 9 of the carrier 8, along the carrier 8 and further like at 2nd speed.

Fourth speed. On the ray diagram, this mode is indicated by the steep ray, from the point 0 to the left/up to the point 4. We shift the collar D from the right position to the left (L) position, collar D - from the neutral position (N) to the right (R), with this, in comparison with the 2nd speed, the replacement of the input links and output torque took place. The sun gear 5 (a) is cut-off by the shift collar 29 (D). Torque is transmitted to the carrier 8 (h), like at the 3rd speed that rotates the satellites 13. Running along the cut-off sun gear 5 (a), they rotate the epicyclical ring 14 (b) along the housing 15 to the coaxial shaft 18, the ring gear 19; by the shift collar 28 (C) - to the ring gear 22 and further, like at the previous speeds but with increased frequency and reduced torque. For K=1.62, the gear ratio is U_{hb}^{a}=K/(+1)=1.62/2.62=0.62; lq 0.62=-0.21.

Fifth speed. On the ray diagram, this mode is indicated by the flat ray, from the point 0 to the left/up to the point 5. We shift the collar B from the neutral (N) position to the right (R), collar C - from the left position to neutral N), collar D - from the right to the left (L), with this, in comparison with the 1st speed the replacement of the input links and output torque took place. Epicyclical wheel 14 (b) is cut-off by the clutch 27 (C) that closed the ring gearss 20 of the front inner wall of the housing 1 and 17 of the coaxial shaft 16 of the housing 15 of the epicyclical wheel 14. Torque (Fig. 1), from the ring gear 3 of the input shaft 2, by the shift collar 26 (A) is transmitted to the carrier 8 (h) like at the 3rd speed that rotates the satellites 13, and running along the cut-off epicyclical wheel 14 (b), they rotate the sun gear 5 (a), then along the shaft 4 to the ring gear 7 by the shift collar 29 (D) to the ring gear 24 and the driver gear 23 but with increased frequency and reduced torque. At K=1.62, the gear ratio U_{ha}^{b}=1/(K+1)=1/2.62=0.38; lq 0.38=-0.42.

Reverse gear 1R. On the ray diagram (Figure 2), this mode is indicated by the steep ray from the point 0 to the right/down to the point 1. The state of the shift collar is shown in the rightmost column of the table: A, B and C - left (L), D - neutral (N). In the upper part of the table, the PGT state U_{ab}^{h}=-K is shown. The 'minus' sign indicates the rotation direction change of the drive pinion 23 in comparison with the drive shaft 2. Compared to the 1st speed forward, the state of the PGT output and cut-off links changed. The carrier 8 (K) is cut-off by the clutch 27 (C) that closed the ring gears 20 of the front inner wall of the housing 1 and 11 of the tubular input shaft 9. Torque (Figure 1) from the ring gear 3 of the input shaft 2 is transmitted to the ring gear 6 by the shift collar 26 (A), and by the shaft 4 - to the sun gear 5(a). The sun gear 5 (a) rotates the satellites 13, that revolving on the axis of the carrier 8 (h) rotate the epicyclical wheel 14 (b) in the opposite direction with the reduced frequency but with increased torque. Further, like at the 4th speed forward, by means of coaxial shaft 18, the ring gear 19, and the shift collar 28 (C), the torque is transmitted to ring gear 22, to the drive tubular shaft 21 and drive pinion 23. For K=1.62, the gear ratio U_{ab}^{h}=K+1=1.62; lq of 1.62=0.21. Range of the planetary gearbox (PGB) will be $D=U_1/U_5$=2.62/0.38=6.9. Change of K will change the kinematic characteristics of the PGB.

Conclusion

The planetary gearbox includes the gearbox casing, the simple three-link planetary gear train consisting of the sun gear, epicyclical wheel and the carrier with satellites that are

toothed with the sun gear and epicyclical wheel. The carrier and epicyclical wheel housing have shafts with ring gears and the epicyclical wheel cut-off clutch. With this, the input shaft has a three-position ring gear on which the shift collar is installed. The shaft of sun gear with ring gear on the ends is mounted in the bearing of the ring gear of the drive gear and in the bearing of the rear wall of the gearbox case with the ring gear. The carrier is mounted on the inlet and outlet tubular shafts with ring gears. The epicyclical wheel housing is mounted on the input and output coaxial shafts with ring gears. On the front inner wall of the gearbox case next to the ring gears of the input shaft the ring gear with the cut-off clutch of the carrier or epicyclical wheel is mounted. Next to the ring gears of the output shafts, the drive tubular shaft with the ring gears on the shaft input and the drive pinion with the ring gear on the output of this shaft is mounted near the ring gear of the sun gear shaft on which the shift collar is located.

The invention relates to transport engineering, transmission of transport machines, ground-based transportation system including transport-process machines, automobiles, tractors, etc. The technical result - the reduction of dimensions and metal consumption of the vehicle transmission unit due to more complete use of the kinematic capabilities of the simple three-link PGT. Thus, we have obtained a compact transmission unit of low metal consumption that creates better conditions for the engine and transmission layout. We provided the enhancement of the vehicle operational characteristics through increasing the range and number of gears. The proposed technical solution provides five forward gears and one reverse gear with sufficient range (D=2.62/0.38=6.9) with reducing the sizes and metal consumption compared to standard designs.

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