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Five-Stage Electric Starter

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Abstract*: This article classifies and analyzes the existing electric starters, their advantages and disadvantages. A five-stage starter is proposed which improves performances of engines of land vehicles. Operation of the five-stage electric starter is discussed, ray path diagrams are presented for its two internal parameters: K = 4 and K = 1.62, variation of the internal parameter K leads to variation of kinematic properties of the electric starter with planetary reducer. The five-stage starter is intended for expansion of performances of land vehicles. The formulated target is achieved by starting cold engine with high viscosity motor oil at low rpm, and by increase in rpm of crankshaft for preliminary oil supply to friction units before engine start which takes place under optimum conditions.

Index Terms: five-stage electric starter, planetary mechanism, planetary reducer, engines of land vehicles.

I. INTRODUCTION

Internal combustion engines (ICE) of vehicles are equipped with starter with battery-driven electric motor, the electric motor shaft is equipped with a freewheel clutch which upon engine start is engaged with gear wheel by special device installed on engine flywheel. When the engine is activated, the gear by the same device is disengaged with the gear wheel on flywheel. Electric starters are available characterized by direct drive of main shaft to flywheel drive gear. Such starter design requires for high-torque electric motor characterized by high sizes and weight. This stipulates high current and high capacity battery [1]. Electric starters are available with ordinary planetary reducers between drive shaft and flywheel drive gear. Herewith, high rpm electric motors with lower metal intensity can be installed, the planetary reducer is used only as a one-stage reducer [2]. The drawback of this design is limited engine specifications, namely, reliability and operation lifetime. This is attributed to the lack of preliminary oil supply to friction surfaces before engine startup. Cold engine startup equals to vehicle run from hundreds to thousands of kilometers. The starter [3] is available comprised of electric motor, planetary reducer with damping elements of elastic material and drive shaft connected with gear, herewith, the sun gear of reducer is connected with the electric motor, carrier and pinion gear by drive shaft installed in roller bearing with fastener, and crown gear – with reducer body where longitudinal grooves are provided for installation of damping elements. In order to reduce labor intensity and to increase reliability, the damping elements are made in the form of L-shaped insertions, the outer surface of the crown gear has grooves, whereas horizontal elements of the L-shaped insertions are located simultaneously in body grooves, and vertical elements of the insertions are located between the edge of crown gear and fastener of roller bearing. This design is also characterized by some disadvantages, that is, complicated pattern and limited reliability. The starter with planetary reducer has been developed according to the patent [4] and is comprised of middle part, front part and cover, traction relay detachably connected with the housing, traction electric motor comprised of stator mounted on internal housing side, one edge of it is capable to rotate in the support located in the cover and the other edge is inserted into the central hole of sun gear of planetary reducer with possibility to transfer torque, herewith, the sun gear is flexibly connected by satellites with the pinion carrier which is integrated with the starter output shaft, its other edge is fixed in the housing front part and its middle part is engaged with the freewheel clutch rigidly connected with main gear of ICE flywheel drive and cinematically connected by fork with the traction relay, herewith, the crown gear is made in the form of metallic ring with internal teeth, it is engaged from both edges with the first and the second protecting elements, it is equipped with a tool of axial fixation and protection against rotation around longitudinal axis. This device is considered as a prototype. This starter is also characterized by disadvantages, such as constrained reliability related with rubber elements and complicated pattern of lower gear, especially at low temperatures. The existing starter, comprised of electric motor with four permanent excitation magnets, traction relay, freewheel clutch with advance lever and power planetary reducer, its pinion carrier shaft is located in splined screw coupling with the driving racer of freewheel clutch, is also characterized by disadvantages. It is possible to mention that upon activation of the traction relay, the efforts, transferred by its armature for advance of freewheel clutch in order to engage its drive gear with the gear ring of engine flywheel, are carried out by means of lever and other auxiliaries which often fail during activation and deactivation of the traction relay, thus making the starter inoperable. Another disadvantage of the starter also includes increased wear of internal working surfaces of the freewheel clutch, its driving and driven racers, connecting cylindrical rollers and spiral springs of clamping devices, which is stipulated by the use of power planetary reducer. During transfer of torque from armature shaft of starter electric motor to driving sun gear of planetary reducer insufficient reserve of strength is observed in their splined coupling, which leads to twisting of rotor shaft of starter electric motor [5].

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The most close to the proposed device is the electric starter with ordinary planetary reducer between the drive shaft of electric motor and driving gear of flywheel drive [6].The electric starter is comprised of DC motor with traction relay and drive shaft, ordinary three-link planetary reducer comprised of sun gear, epicyclical wheel and pinion carrier with satellites engaged with the sun gear and epicyclical wheel; the pinion carrier and the housing of epicyclical wheel are equipped with gear rings and stopping clutch of epicyclical wheel, freewheel clutch, driving gear of flywheel drive. A disadvantage of this design is that the planetary reducer is used only as a two-stage reducer which constrains selection of optimum modes of engine startup under different climatic (temperature) conditions of operation. Analysis of published results of patent search demonstrated that the developed models of electric starters, despite obvious advantages, are characterized by certain disadvantages. Aiming at expansion of performances of land vehicles, it is proposed to start cold engine with high viscosity motor oil at low rpm, and to increase rpm of crankshaft for preliminary oil supply to friction units before engine start which takes place under optimum conditions.

II. DESIGN OF FIVE-STAGE ELECTRIC STARTER

The proposed device provides possibility to expand performances of land vehicles by starting-up and preliminary lubrication supply to friction units. The essence of the proposed device is as follows: the electric starter is comprised of DC motor with traction relay and drive shaft, ordinary three-link planetary reducer comprised of sun gear, epicyclical wheel and pinion carrier with satellites engaged with the sun gear and epicyclical wheel; the pinion carrier and the housing of epicyclical wheel are equipped with gear rings and stopping clutch of epicyclical wheel, freewheel clutch, and driving gear of flywheel drive; herewith, the sun gear shaft is installed in the supports of gear ring of driving gear and in the rear housing wall of planetary reducer with gear ring and striker clutch, the edges of this shaft are equipped with gear rings, the drive shaft is equipped with three-position gear ring where a clutch with external and internal gear rings is installed; the pinion carrier is mounted on input and output tubular shafts with gear rings; the housing of epicyclical wheel is mounted on input and output coaxial shafts with gear rings; herewith, the input shaft is staged-like and with internal gear ring; in the wall supports of reducer housing the drive tubular shaft of electric starter is installed with freewheel clutch and flywheel driving gear of flywheel drive, at the output of this shaft near gear rung of sun gear the gear ring is mounted; the two-position gear at the input of the driving tubular shaft with striker clutch is located near gear ring of the gear ring of pinion carrier [7]. Figure 1 illustrates the flowchart of electric starter with ordinary three-link planetary reducer equipped with four striker clutches, the shafts of input and output of three links of planetary reducer with gear rings. At the top the striker clutches are shown in the 1-st gear position, at the bottom – in the 2-nd gear position (clutch 33 (C) – in the 3-rd gear position).

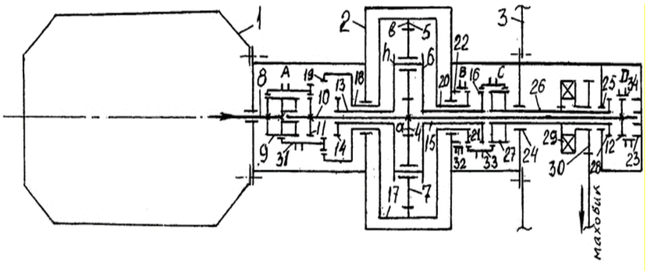

Fig. 1. Electric starter with ordinary three-link planetary mechanism

1 - DC motor; 2   planetary reducer body; 3 - flywheel crankcase of vehicle engine; 4 - sun gear; 5   epicyclical wheel; 6   pinion carrier; 7 - satellites; 8 - drive shaft of DC motor; 9 - gear ring support; 10   shaft; 11,12 - gear rings; 13 - input tubular shaft; 14 - gear ring; 15 - tubular shaft; 16 - ring gear; 17 - body side; 18 - stepped coaxial shaft; 19 - internal ring gear; 20 - output coaxial shaft; 21, 22, 23- gear ring; 24   internal body wall; 25 - external body wall; 26 - drive shaft; 27 - two-position gear ring; 28 - gear ring; 29 - freewheel clutch; 30 - drive gear of electric starter; 31 - striker clutch; 32 - stopping clutch of epicyclical wheel; 33 - two-position striker clutch; 34   clutch [7]. The DC motor 1 with traction relay is mounted on the housing 2 of planetary reducer fixed on the crankcase 3 of flywheel of land vehicle engine. In the housing 2 a three-link ordinary planetary reducer is located comprised of the sun gear 4 (a), the epicyclical wheel 5 (b), and the pinion carrier 6 (h) with the satellites 7 engaged with the sun gear 4 and the epicyclical wheel 5. At the output of the drive shaft 8 of the DC motor 1 the three-position gear ring 9 is mounted. The drive shaft 10 of the sun gear 4 (a) is located in the support of the gear ring 9 and in the support of rear wall of the housing 2. At the edges of the shaft 10 the gear rings11 and 12 are mounted. The pinion carrier 6 is engaged with the input tubular shaft 13, where the gear ring 14 is mounted, and with the output tubular shaft 15, where the gear ring 16 is mounted. The housing 17 of the epicyclical wheel 5 is engaged with the internal gear ring 19 by the staged coaxial shaft 18; the other side of the housing 17 is engaged by the coaxial shaft 20 with the gear ring 21 located near the gear ring 16. On the wall of the planetary reducer housing 2 the gear ring 22 is located near the gear ring 21. Similar gear ring 23 is located on the rear wall of the planetary reducer housing 2 near the gear ring 12 of the shaft 10. In the supports of internal 24 and external 25 walls of the housing 2 the drive tubular shaft 26 of the electric starter is installed with the two-position gear ring 27 at the output of the shaft 26 and the gear ring 28 at the output of the drive shaft 26. On the drive tubular shaft 26 the freewheel clutch 29 is located flexibly in axial direction, at output of this clutch the driving gear 30 of electric starter is installed. The three-position striker clutch 31 (A) is installed on the gear ring 9 at the input. The stopping clutch 32 (B) of the epicyclical wheel 5 is located on the gear ring 22 of the wall of the housing 2. The two-position striker clutch 33 (C) is installed at the input of the drive tubular shaft 26, and the clutch 34 (D) is located on the gear ring 12 at the output of the shaft 10.

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III. OPERATION OF FIVE-STAGE ELECTRIC STARTER

Figure 2 illustrates two ray path diagrams of operation of planetary reducer for its two internal parameters: K = 4 and K = 1.62.

K = 1.5-5 is the internal parameter of planetary reducer equaling to the ratio of teeth amount of the epicyclical wheel (b) to the teeth amount of the sun gear (a). K = 1.5 is restricted by minimum sizes of satellites. K = 5 is restricted by minimum sizes of sun gear.

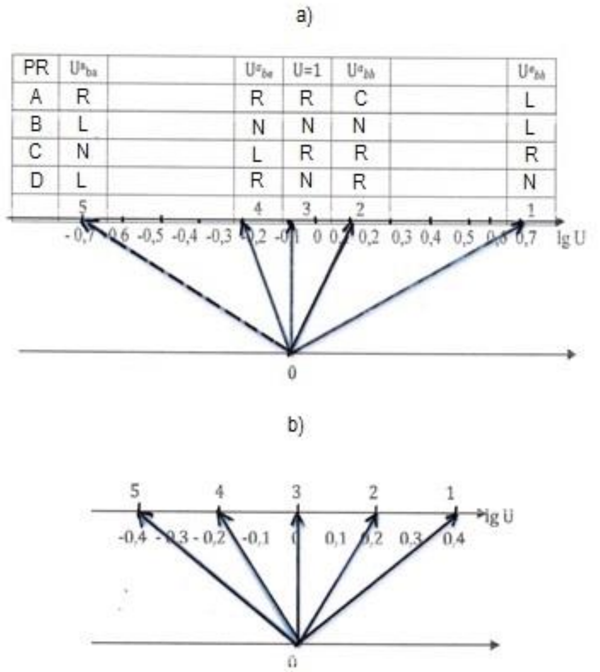

Fig. 2. Ray path diagrams for internal parameters: a) K = 4; b) K = 1.62.

Modification of the internal parameter K leads to variation of kinematic properties of electric starter with planetary reducer. The upper diagram is for four operation gears, the fifth, accelerating, gear is possible, though the probability of its use is low. At K = 1.62 there are equal segments between gears, in such variant the fifth gear is possible. On the horizontal axis, the planetary reducer gears are shown in logarithmic scale. The vertical ray indicates at direct transfer of torque from electric motor to flywheel drive gear of ICE with gear ratio U = 1.0. The ray upwards to the right characterizes decelerating mode of planetary reducer: the steeper is the ray, the higher is the ratio. The ray upwards to the left characterizes accelerating mode of planetary reducer operation: the steeper is the ray, the lower is the ratio. The ray path diagrams are useful for understanding of operation of multistage reducers, since the value of each ray is constant at all diagram segments. Above the ray path diagram, the table summarizes states of planetary reducer for each gear. The superscript indicates at the stopped link, and the subscripts – at the links of torque input and output. For instance, for the 1-st gear the planetary reducer is in the state of U_{ah}^{b} = K+1. When the epicyclical wheel (b) is stopped, the torque is transferred to the sun gear (a) and taken from the pinion carrier (h).

Ordinary three-link planetary reducer can provide five gears without reversing rotation.

The first gear. The mode with low rpm is intended for engine start-up under low temperatures at high viscosity of motor oil. Electric starter operates similarly to shaft-turning gear of gas turbine when heavy rotor should be started-up and just be rotated before starter activation. In the ray path diagram this mode is indicated by flat ray from point 0 upwards to the right to point 1. Above this point the clutch states are shown (Fig. 1, upper position of the clutches): A and B – left (L); C – right (R), and D – neutral (N). In the top of the table the planetary reducer state Ua_{h}^{b} = K+1 is shown.

The epicyclical wheel 5 (b) is stopped by the clutch 32 (B), which has engaged the gear rings 22 of the reducer housing 2 and 21 of the housing 17 of the epicyclical wheel 5. Upon activation of the electric starter, current is supplied to the traction relay and to the exciting winding of motor stator. Herewith, the traction relay moves the freewheel clutch 29 and the driving gear 30 up to the engagement with the engine flywheel. The torque from the gear ring 9 of the drive shaft 8 and DC motor 1 by the clutch 31 (A) is transferred to the gear ring 11 and by the shaft 10 to the sun gear 4. The sun gear 4 (a) rotates the satellites 7, which, rolling across the epicyclical wheel 5 (b), rotate the pinion carrier 6 (h) at decreased frequency but with increased torque. Via the tubular shaft 15, the gear ring 16, the clutch 27 (C) the torque is transferred to the tubular drive shaft 26, the freewheel clutch 29 and the driving gear 30 of the electric starter, which provides start-up of mechanisms and system of land vehicle engine, rotates engine crankshaft, actuates oil pump and starts lubrication supply to friction units.

If K = 4, then the ratio is U_{ah}^{b} = K+1=5; lq 5=0.7. The rpm of the driving gear 30 decreases by 5 times in comparison with the rpm of the drive shaft 8 of DC motor 1, but with 5-fold torque (without consideration for efficiency). At K = 1.62 the ratio is U_{ah}^{b} = K+1=2.62; lq 2.62=0.42.

The second gear. The clutch A is switched from the left to the middle position (C), the clutch B – from the left to the neutral (N) position, and the clutch D – from the neutral to the right (R) position (Fig. 1, lower position of the clutches, except for the clutch C). In the top of the table, the U_{bh}^{a} state of planetary mechanism is shown. In comparison with the 1-st gear, the links are replaced: the sun gear 4 (a) is stopped, the torque is transferred to the epicyclical wheel 5 (b).

In the ray path diagram this mode is indicated by steep ray from point 0 upwards to the right to point 2. The sun gear 4 (a) is stopped by the clutch 34 (D) which engaged the gear rings 23 of the wall in the right part of the housing of the reducer 2 and 12 of the shaft 10. The torque from the gear ring 9 of the drive shaft 8 of DC motor 1 of the external gear ring by the clutch 31 (A) is transferred to the internal gear ring 19 and by the staged tubular shaft 18 to the epicyclical wheel 5 (b) which rotates the satellites 7 which, rolling across the sun gear 4 (a), rotate the pinion carrier 6 (h), as at the 1-st gear, further to the flywheel at decreased rpm but with increased torque.

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If K = 4, then the ratio is $U_{bh}^{a} = (K + 1)/K = 5/4 = 1.25$; lq 1.25 = 0.1. At K = 1.62 the ratio is $U_{bh}^{a} = (K + 1)/K = 2.62/1.62 = 1.62$; lq 1.62 = 0.21. *The third gear – forward.* The clutch A is switched from the middle to the right (R), herewith, the internal gear ring of the clutch 31 and the external gear ring 14 of the tubular shaft 13 of the pinion carrier 6 are engaged. In the ray path diagram this gear is shown by the vertical ray from point 0 to point 3. The torque from the internal gear ring of the clutch 31 (A) is transferred to the external gear ring 14 of the tubular shaft 13 via the pinion carrier 6 and then as at the 2-nd gear. After engine start-up, the freewheel clutch 29 disengages the flywheel from the electric starter. *The fourth gear.* The clutch C is switched from the right to the left position (L), the clutch D – from the neutral to the right position (R), herewith, in comparison with the 2-nd gear, the torque input and output links are replaced. In the ray path diagram this mode is indicated by the steep ray from point 0 upwards to the left to point 4. The sun gear 4 (a) is stopped by the clutch 34 (D) which engaged the gear rings 23 of the wall in the right part of the reducer housing 2 and 12 of the shaft 10. The torque to the pinion carrier 6 (h) is transferred as at the 3-rd gear which rotates the satellites 7, they, rolling along the stopped sun gear 4 (a), rotate the epicyclical wheel 5 (b) via the housing 17 to the tubular shaft 20, the gear ring 21, the clutch 33 (C) to the gear ring 27, and then as at the previous gears, to the flywheel but with increased rpm and decreased torque. If K=4, then the ratio is $U_{hb}^{a} = K/(K + 1) = 4/5 = 0.8$; lq 0.8 = –0.1. At K = 1.62 the ratio is $U_{hb}^{a} = K/(K + 1) = 1.62/2.62=0.62$; lq 0.62=-0.21.

The fifth gear. The clutch B is switched from the neutral to the left (L) position, the clutch C – from the left to the neutral (N) position, the clutch D – from the right to the left (K) position, herewith, in comparison with the 1-st gear, the torque input and output links are replaced. In the ray path diagram this mode is indicated by the flat dashed ray from point 0 upwards to the left to point 5. If K = 4, then the ratio is $U_{ha}^{b} = 1/(K + 1) = 1/5 = 0.2$; lq 0.2 = –0.7. At K = 1.62 the ratio is $U_{ha}^{b} = 1/(K + 1) = 1/2.62 = 0.38$; lq 0.38 = –0,42. At K = 4 the use of the 5-th gear is unreasonable, since $U_{ha}^{b} = 0.2$; the rpm of the driving gear 30 will increase by 5 times in comparison with the drive shaft 8 of DC motor. For the four remaining gears the range will be $D = U_1/U_4 = 5/0.8 = 6.25$, thus providing various conditions of engine start-up. The 1-st gear with $U_1 = 5$ will provide engine start-up under severe climate conditions even with high viscous motor oil. The other gears can be used both for increase in rpm of engine crankshaft and for engine start-up. At K = 1.62 all five gears can be used. In this case the range will be $D=U_1/U_5=2.62/0.38=6.9$; but at the 5-th gear the rpm of the driving gear 30 will increase by 2.62 times in comparison with the DC motor drive shaft 8, which is undesirable. At the 1-st gear $U_1=2.62$, the torque can be insufficient to start-up engine at low temperatures.

IV. FEASIBILITY STUDY OF FIVE-STAGE ELECTRIC STARTER

Electric starter is comprised of a DC motor with traction relay and drive shaft, an ordinary three-link planetary reducer is comprised of a sun gear, an epicyclical wheel and a pinion carrier with satellites which are engaged with the sun gear and the epicyclical wheel; the pinion carrier and the epicyclical wheel housing are equipped with gear rings and stopping clutch of epicyclical wheel, the freewheel clutch, and the driving gear of flywheel drive that is characterized by the fact that the sun gear shaft is mounted on the supports of gear ring of driving gear and in the rear wall of the planetary reducer housing with gear ring and striker clutch; gear rings are mounted on the edges of this shaft, the drive shaft is equipped with three-position gear ring where a clutch with external and internal gear rings is installed; the pinion carrier is mounted on the input and output tubular shafts with the gear rings; the epicyclical wheel housing is mounted on input and output coaxial shafts with gear rings; herewith, the input shaft is staged-like with internal gear ring; in the supports of reducer housing walls the drive tubular shaft of electric starter is installed with freewheel clutch and flywheel driving gear; at the output of this shaft near the gear ring shaft of sun gear the gear ring is mounted, a two-position ring at the input of the drive tubular shaft with striker clutch is located near the pinion carrier gear ring. The invention relates to transport, it can be applied in the engine start-up systems of land vehicles: automobiles, tractors, etc. The technical result of the invention is expansion of ICE performances, improved reliability and operation lifetime due to start-up and supply of lubrication to friction units before engine operation. In the five-stage electric starter the three units (sun gear, pinion carrier and epicyclical wheel) of ordinary three-link planetary reducer are equipped with gear rings and striker clutches at input and output of planetary reducer providing operation of the planetary reducer at five-stages (gears).

V. CONCLUSION

The proposed device eliminates risks of cold engine startup, which is similar to vehicle run of hundreds of kilometers, as well as expands engine performances: increase in its reliability and lifetime due to engine startup which requires for high torque as well as prevention of engine startup before lubrication supply to friction units.

REFERENCES

1. S.V. Akimov, Yu.P. Chizhkov, "*Elektrooborudovanie avtomobilei*" Vehicle electrical system], Moscow, Guidebook: Za rulem, 2001.
2. N.N. Vishnyakov, V.K. Vakhlamov, A.N. Narbut, "*Avtomobil`: osnovy konstruktsii*" [Vehicle: basic design], Moscow, Guidebook: Mashinostroenie, 2-nd revised edition, 1986.
3. N.A. Mozharov, O.A. Korobova, V.A. Petrov et al., "*Starter for internal combustion engine*", Author's Certificate №1420231, Bulletin, №32, August 30, 1988.
4. V.I. Nekrasov, O.O. Gorshkova, "*Two-mode electric starter*", Patent RU № 2567847.
5. V.I. Nekrasov, O.O. Gorshkova, "*Five-stage electric starter*", Patent RU № 2624778.
6. V.A. Vinogradov, S.V. Solov'ev, "*Starter with planetary reducer*", Russian patent № 2092712.
7. A.M. Litvinenko, A.V. Zhilkin, "*Starter with planetary reducer*", Patent RU № 2560932.

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