Design of a stepless torque converter for heavy trucks

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Abstract. The design of the stepless torque converter for heavy trucks is suggested. The stepless torque converter consists of two series-connected hydromechanical differentials. In the proposed design, automatic stepless control of kinematic and power parameters is carried out in the absence of any control system; simplicity of design options is achieved. The proposed stepless torque converter is able to cover the control range of both passenger cars and heavy trucks. The comparative analysis of designs structures in stepless transmissions produced by the modern automobile industry in different countries shows high degree of the design and technological continuity in relation to the existing production, high degree of standardization and much smaller production cost. The stepless torque converter allows the engine to operate with the equal capacity when changing the external load, which leads to an optimal capacity utilization and, accordingly, to a significant reduction in fuel consumption.

1. Introduction

One of the most important requirements for the transmissions of modern vehicles is to provide simplicity and comfort of driving. And one of the main problems of technical progress in the automotive industry is the automation of cars’ systems and units, including the development of automatic transmissions to ensure continuously variable torque control on the output shaft of the power unit. To solve these problems, the most perspective direction is the improvement of automatic transmissions and the development of new continuously variable (stepless) transmissions [2, 3 and 10].

There are various designs of continuously variable transmissions used in passenger car transmissions. However, not all of these types can be used in the transmission of heavy trucks. For example, pulse transmission and friction transmission have limitations on the magnitude of the transmitted torque. A hydrostatic transmission (hydrostatic drive) has some disadvantages:
- high specific gravity and insufficient reliability of hydraulic units operating at high liquid pressures;
- low efficiency values resulting in high fuel consumption;
- high cost;
- great influence of the ambient temperature on the drive operation, etc.

From the above, it might be assumed that the purpose of this work is development of rational models of stepless torque converter for heavy trucks and development of the design procedure for transmissions.

2. Equivalents of the suggested continuous variable transmission
The efficiency of hydraulic transmission can be increased by using differentials where power is transmitted by two streams through mechanical and hydraulic links. Such a transmission is a hydromechanical transmission with an external power separation. It is a single-circuit or two-circuit transmission, respectively, with one or two differentials and the hydraulic transmission. The power supplied to these transmissions is separated, and only part of it (usually less) is transmitted to hydraulic machines. Therefore, compared with full-flow hydraulic transmission, they have a higher efficiency at the same capacity and control ranges.

Two-flow hydromechanical transmission consists of the hydraulic transmission and the differential with mixed or external gear meshing. Depending on the location of the differential link in relation to the hydraulic transmission there is a hydro mechanical transmission with the differential link at the input or the differential link at the output.

Figure 1 shows an example of the hydromechanical transmission model with a parallel connection of differentials. A common disadvantage for all models is a limited range of control, the complexity of the design due to the use of the expensive and complex hydraulic drive and automatic control system.

3. **Design of a stepless torque converter**

The design of vehicle transmissions is a laborious process where options are multiple [1, 7, 11]. And depending on the type of transmission that is supposed to be installed on the vehicle, the design methods will be different. The design of the stepless torque converter is a complex problem, the solution procedure can be divided into several independent stages. The first stage is to determine a kinematic diagram of the transmission. The second stage is the development of the model. The third stage is the development of technological and economic indicators of the designed mechanism.

3.1. **The kinematic diagram of the stepless torque converter.**

Stepless torque converters can vary in kinematic diagrams and structure. This transmission consists of two hydromechanical differentials. At the same time, to increase the ration transformation, an additional mechanical differential with a different value of the internal gear ratio and an additional series of gears can be included in the kinematic diagram of the torque converter.
The hydromechanical differential is a converted gear-type hydraulic machine. The case of the hydraulic machine is a pinion cage of the differential and can rotate around its axis. The hydromechanical differential has the following features:
- has two degrees of freedom;
- the use of the working fluid flow as a hydraulic connection between the hydromechanical differential and one of the possible mechanisms for converting hydraulic energy into mechanical, allows to create a continuously variable hydromechanical transmission;
- the mechanical torque removed from the pinion cage of the hydromechanical differential can be summed up with another mechanical torque obtained after the conversion of the hydraulic flow power;
- when changing the angular velocities of the links of the hydromechanical differential, there is a change in the supply of the hydraulic pump, which provides internal automatism when converting the power of the hydraulic flow into mechanical.

The classification of hydromechanical differentials can be considered. The main characteristic feature of the hydromechanical differentials is the type of a gear wheel. By type of meshing hydromechanical differentials can be with external and internal gears. According to multiplicity of action or the number of planet wheels hydromechanical differentials are divided into one-, two - and multiple actions. Hydromechanical differentials of multiple actions are most desirable, as they allow to provide the minimum dimensions and the best smoothness of the mechanism for the same parameters. If an additional mechanical differential is available, hydromechanical differentials with an inlet differential and without a differential are considered. According to the type of the input link drive, hydromechanical differentials with a central drive and a separate drive are discussed. The classification of hydromechanical differentials is shown in figure 2.

After the selection of the kinematic diagram of the stepless torque converter, the calculation of the gear ratio, the selection of the main dimensions according to the condition of the rotor balancing (pinion cage) at the maximum transformation ratio are made. At the same time, it is necessary to take into account some additional conditions related to design objections.

3.2. Design of a stepless torque converter.
In case of continuously variable transmission of heavy trucks and the need to increase the ration of transformation are essential, it is advisable to apply the models of stepless high-torque transformers composed of hydromechanical differentials with internal gears capable of operating at pressures above 20 MPa. In addition, it is necessary to use hydrostatic torques on the hydraulic pump and on the hydraulic motor so that they are directed towards the rotation of the input shaft [7, 8]. The design of the stepless torque converter is considered, the scheme is shown in figure 3.

It is essential to determine the necessary transformation ratio and the gear ratio of the differential hydraulic pump. The preliminary calculation has showed that in order to ensure the maximum transformation ratio, it is important to increase the dimensions of the case of the stepless torque converter significantly, so it is more expedient to apply an additional two-stage supplementary gearbox, which would also ensure the presence of a speed-increase gear and reverse in the transmission.

The calculation of the gear ratios in the supplementary gearbox is carried out in the following sequence:
1. The required maximum transmission ratio to overcome the maximum resistance of the road is determined by:

\[ u_{tr\ max} = \frac{\psi_{\ max} G_a r_k}{M_{\ max} \eta_{tr}} \]  

where \( \psi_{\ max} \) – the maximum road resistance index; \( G_a \) – the total weight of the heavy truck, N; \( r_k \) – the kinematic rolling radius, m; \( M_{\ max} \) – the maximum engine torque, N∙m; \( \eta_{tr} \) – transmission efficiency.
2. The minimum gear ratio of the transmission to ensure the movement of the heavy truck at maximum speed is determined by:

$$U_{tr\min} = 0,105 \frac{n_V V_{max}}{V_{max}}$$

(2)

where \(n_V\) – rotational frequency of the engine when driving at maximum speed, \(min^-1\); \(V_{max}\) – maximum speed of the heavy truck, m/s.

3. The gear ratio of the speed-increase gear of the supplementary gearbox \((U_{DH})\) is set and the gear ratio of the transmission is determined by value \(U_{tr\min}\):

$$U_0 = \frac{U_{tr\min}}{U_{DH}}$$

(3)

Figure 2. Classification of hydromechanical differentials
Figure 3. The kinematic diagram of a stepless torque converter: 1 – wheel to the input shaft; 2-2’ – planet wheels; 3-3’ – driving wheel of the pump; 4 – driven wheels hydraulic pump (planet wheels); H₁ – pinion cage (body hydraulic pump); HP – hydraulic pumps; HM – hydraulic motor; 5 – crown wheel hydraulic motor; 6-6’ – planet wheels of the hydraulic motor; 7 – a gear wheel of the output shaft

4. The maximum transformation ratio \( K_{\text{max}} \) based on the maximum permissible dimensions of the gearbox case is set and the gear ratio of the lower stage of the supplementary gearbox is determined by:

\[
U_{DL} = \frac{U_{0\text{max}}}{U_0 K_{\text{max}}}.
\]

Further, having set the maximum transformation ratio, the main parameters of the kinematic links of the stepless torque converter are found.

3.3. Design of the stepless torque converter.

As a result, the model of the stepless torque converter for heavy trucks was designed (Figure 4.)
4. Conclusions
The studies have led to the following results:

1. Innovative models of hydromechanical differentials have been developed and classified. Hydromechanical differentials are characterized by a hydrodynamic connection between the links, which are differential schemes of gear hydraulic machines. This allows obtaining different values of hydraulic and mechanical power flow distribution, and provides automatic control of hydraulic flow parameters.

2. The method of design and calculation of the stepless torque converter is developed, which allows performing parametric analysis and synthesis of parameters of the continuously variable transmission of both cars and trucks.

3. The model of the stepless torque converter for heavy trucks provides a range of automatic control and continuously variable automatic change of kinematic and power parameters without external control devices and does not require a solution to the logistics management problem.

The developed design of the stepless torque converter meets the requirements for modern heavy truck transmissions in the field of ease and convenience of control, and also solves the problem of automation of car`s systems and units.

References
[1] Mavleev I R, Salakhov I I and Nuretdinov D I 2018 Modular heavy duty truck transmission IOP Conference Series: Materials Science and Engineering 386 doi:10.1088/1757-899X/386/1/012018.
[2] Hassle H 1980 Ecosplit – a new gearbox series for heavy commercial vehicles AUTOMOBILTECH. Z. 82 369-374.
[3] Blokhin A, Barakhtanov L, Fadeev E and Lubichev P 2017 Research of robotized manual transmissions for all-terrain vehicles ARPN Journal of Engineering and Applied Sciences 12 (1) 20-32
[4] Naunheimer H, Bertsche B, Ryborz J, Novak W and Fietkau P 2018 Automotive transmissions: Fundamentals, selection, design and application Springer 717
[5] Liao Y-G and Quail A M Jr. 2011 Experiment and simulation of medium-duty tactical truck for fuel economy improvement Energies 4(2) 276-293 doi: 10.3390/en4020276
[6] Blokhin A, Nedyalkov A, Barakhtanov L, Taratorkin A and Kropp A 2017 Multistage mechanical transmissions with automatic control for advanced trucks and buses Acta Mechanica et Automatica 11(4) 260-266
[7] Salakhov I I, Mavleev I R, Shamsutdinov I R, Nuretdinov D I and Salakhov N I 2016 Development of a gear box of the truck Biosciences Biotechnology Research Asia 13(2) 859-864
[8] Salakhov I I, Mavleev I R, Voloshko V V, Galimyanov I D, Takhaviev R K 2016 Analysis workflows gear hydraulic machines Biosciences Biotechnology Research Asia 13(2) 779-784
[9] Haritonov S, Lukyanov A and Nagaitsev M 2006 Design kinematic schemes of automatic gearboxes with angular velocity diagrams of planetary gear links having three degrees of freedom SAE Technical Papers 1
[10] Sharipov V M, Dmitriev M I, Zenin A S and Savkin Ya V 2010 Work of gearing in gearbox at gear shifting without breaking the power flow from the engine Engineering Journal 11 8
[11] Sharipov V and Dmitriev M 2013 Definition of slippage parameters of friction clutches for different installation versions in tractor gearboxes SAE Technical Papers 12