Kit’s development for automation mechanical transmission of a cargo vehicle

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Abstract. The article describes the electric drive design for clutch control. A feature of the developed electric drive is the compensation mechanism use that allowed reducing the electric motor drive power. The developed electric drive controls the car clutch via a standard hydraulic system. The electric hydraulic clutch control does not have a pump and a flow control valve, but it is based on the piston movement in the main clutch cylinder. The main design steps were: determination of the diaphragm clutch spring parameters and operating cycles; choice of the compensation mechanism power characteristics; electric motor and gear ratio selection. The device operation was tested by simulation in a computer programs package. The calculation showed that the use of the compensation mechanism allowed to reduce the electric motor power in the electric drive by 5.7 times. This enabled to decrease energy consumption during the electric drive operation as well as to reduce its dimensions and cost.  

Currently, the main efforts of commercial vehicle developers are aimed at improving the car use economic efficiency, reducing the negative impact on the environment and improving the safety level, both passive and active. Reducing the operating costs and the negative impact on the environment is directly related to the fuel consumption reduction. The fuel consumption reduction is achieved in various ways, such as processes optimization in the engine, reducing aerodynamic drag, ensuring the engine operation in optimal modes. The most efficient internal combustion engine operates in a fairly narrow speed range. This circumstance caused the installation of the gearbox on the car, providing the necessary traction forces on the drive wheels in different driving modes. It allows adjusting the speed in a much larger range than the one that the engine can provide.  

Currently, it is impossible to solve one of the modern megacities problems - the formation of road congestions and traffic jams. Therefore, it is increasingly difficult for commercial vehicles constantly running in city traffic and for their drivers to withstand fast alternating acceleration and deceleration with regular gear changes. At the same time, an increase in the movement speed and the number of motor vehicles on the roads requires from the driver greater attention to the rapidly changing road conditions. Even an experienced driver is not able to provide constant monitoring of the optimal driving mode on a long road. Ensuring traffic safety and high performance in these conditions can be achieved by automating the gear shift. And if in the passenger cars segment the choice between the gearbox types is a matter of each particular consumer preference, in commercial vehicles everything is determined by economic viability (cost of ownership). Of all types of automatic transmissions, the most common in the medium and heavy duty trucks segments are automatic manual transmissions. Hydro mechanical
gears, due to lower efficiency, are mainly used on special and specialized chassis, such as vehicles for public utilities, tractors for the super-heavy goods transportation, quarry and mining equipment, etc. as well as buses.

Automated manual transmissions ensure that the engine always operates at the optimum speed range, which results in fuel savings of 7-10%. According to MAN, a truck with such a gearbox can, on average, save up to 2,250 liters of diesel fuel per year and emit up to 6 tons of CO2 less.

The emergence of microprocessors capable of operating in harsh cars operating conditions and having high speed, allows not only to improve the control accuracy, but also to increase the number of information parameters, thereby implementing more flexible control logic. The electronic control unit of the automated transmission at each moment selects the most economical gear and constantly provides the necessary torque. Due to the optimal gear shift, the load on the driveshaft is reduced, so as to reduce the shock load with sudden and incorrect gear changes, the clutch life will increase due to softer gear shift, which increases the nodes life and reduces both operating costs and costs for repairs, including downtime.

On cars with internal combustion engines and a manual gearbox, a clutch is used to break the power flow when gears shifting and smoothly pulling away. The GAZON NEXT (automobile) clutch is a mechanical single-plate dry-type clutch with a diaphragm spring. Clutch control is performed by the driver through a hydraulic system with two hydraulic cylinders. To automate the clutch control process, it was decided to apply an electric drive. All control options known at this stage of technical development [4-14] were considered. Of all the options, the most suitable for use on this vehicle were identified: the first option, the mechanical action electric drive on the diaphragm spring; the second option, the electric drive with the transmission of force through the hydraulic system. The first option was the most preferred as it had greater reliability and was easier to manufacture and maintain due to fewer parts. But due to the fact that the operating cylinder has a concentric design and acts directly on the spring, it was not possible to make an electric drive in such cramped conditions. Table 1 provides a descriptive list of the positive and negative points of each system. Taking into account all the points, it was decided to create an electric clutch with the force transmission through the hydraulic system. That is, the actuator acts on the clutch master cylinder, and through the hydraulic system and clutch slave cylinder, the force is transmitted to the diaphragm spring.

| Design simplicity | Electric drive | - | Through the hydraulic system |
|-------------------|----------------|---|-----------------------------|
| Operation         | +              | - |
| Wear-out compensation system | - | + |
| Location convenience | - | + |

Based on the analysis of common schemes, a system with combined electro hydraulic control was chosen. The general scheme of the clutch control system operation is shown in Figure 1. The diagram shows the main clutch elements, the hydraulic clutch control system and the electric drive that moves the piston in the main clutch cylinder. The main cylinder, through the hydro line, communicates with the clutch operating cylinder (concentric design), which transmits force to the clutch spring.

For the electric drive designing the information about the loads, movements and speeds of the working body is required [1-3]. This information was obtained as a result of the real car studies as well as from the clutch manufacturer design documentation.
To obtain experimental data measuring equipment consisting of a multi-function speed meter Racelogic VBOX 3i, a dynamic data acquisition system TMR-200, a telemetry set with torsion strain gauges measurement on the propeller shaft, pressure sensor, a rope displacement sensor, a speed transmission input shaft sensor was installed on the car. The measuring unit was connected to the CAN-bus of the vehicle. The measuring scheme is shown in Figure 2.
The main parameters as a research result were: the speed of switching off and switching on the clutch when changing gears, the pressure in the hydraulic clutch system, and the clutch diaphragm spring power characteristic. In the starting mode of the medium-duty truck loaded to full weight, using the above measuring equipment the following dependences were obtained. They are shown in Figure 3.

![Figure 3. Experimental curves obtained when car pulling away](image)

1. Clutch pedal pressing percentage
2. Pressure in the clutch hydraulic drive
3. Crankshaft revolutions
4. Gearbox input shaft revolutions

The peculiarity of the load on the clutch control body is the power characteristics change from the clutch discs wear-off. Due to the clutch characteristics change during operating time, the electric drive must be guaranteed to overlap the entire area of the clutch working characteristics. Figure 4 presents the graphs with the forces characteristics on the clutch control body. The working area is the space between the charts of the new and worn-off clutch.

![Figure 4. Load on the clutch release working body](image)

1. Worn-off clutch spring force;
2. New clutch spring force;
3. Average force value of the clutch spring.
The preliminary calculation of the classic electric drive mechanical power showed that the required power is 75 W. But if to compensate the clutch working characteristic on the average value, the electric drive with the capacity of only 13W is required, that is 5.7 times less. The compensation mechanism must meet several requirements: to have the most closely repeating average value characteristic of clutch performance as well as to lock the mechanism when switching off the clutch. As a result of various schemes and compensation methods analysis the most suitable – crankshaft-and-connecting-rod assembly with expansion spring was chosen. The scheme is presented in Figure 5. This scheme allowed fulfilling all requirements for load compensation.

![Figure 5. Lever mechanism with compensation spring](image.png)

The main parameters of the compensation mechanism were determined by the successive approximations method. Figure 6 presents two graphs, for visual comparison of the clutch performance average value and the compensation mechanism characteristic. The average deviation of the characteristics amounted to 7%. When the clutch is switched off, the compensation mechanism provides force locking with the force of 280 N and the electric drive is guaranteed not to cause an impact on the clutch spring.

![Figure 6. Graphs with clutch spring characteristics and compensation mechanism](image.png)

1. Average clutch spring force value;
2. Compensation mechanism force.

The main part of the electric drive consists of electric motor and gear reducer. The DC electric motor is selected among standardized products according to the power required for the electric drive operation with compensation mechanism. The choice of the reducer gear ratio is based on the joint arrangement of the compensation mechanism and the electric motor operation in the range of the most effective and recommended modes. Figure 5 shows the electric motor rotation speed from the working body moving. From the chart it can be seen that the electric motor speed from 500 to 1500 rpm is optimal for the selected electrometer. Its external characteristic is presented in Figure 7. Short-term casting of
revolutions up to 3500 rpm is connected with the compensation device transition into the power lock mode. On the real device the automatic controls will protect from the electric motor over revving.

The electric drive parameters are approved after checking the compensation mechanism efficiency with the reducer and the electric motor with the extreme force clutch characteristics (new and worn-off). The electric drive efficiency test as well as the compensation mechanism parameters definition and other research were carried out in the simulation programs package of the MSC ADAMS/View. Its model is presented in Figure 8. The model takes into account the mass-inertial characteristics of movable elements, the electric motor and the clutch spring characteristic. Figure 9 shows the externally high-speed characteristic of the electric motor obtained as a result of natural studies at the testing bench.

Based on the conceptual design and design calculations, the electrically driven clutch actuator with a wear-off compensation mechanism was made. The actuator has a main clutch cylinder and is designed to be connected to a hydraulic clutch control system instead of a standard mechanism with a clutch pedal. The electric drive weight amounted to about 5kg, and the external dimensions of 222 x 249 x 437 mm. The electric drive is controlled by a robotic gearbox unit. The feedback on the clutch position is carried out by means of the encoder installed on the electric motor. The compensation of the backlash formed as a result of clutch wear-off is provided by the hydraulic system and occurs automatically in the system operation process. In the electric drive the car standard main brake cylinder was used. It simplifies maintainability due to unification.
Figure 9. Electric motor externally high-speed characteristic

The clutch electric drive was developed as a part of the robotic automation of GAZON NEXT truck transmission. The electric clutch allows to control the truck clutch using electricity. The developed electric drive enables to change the way of clutch control from hydraulic to the combined control – electro hydraulic. The use of the compensation mechanism is made with the purpose of the electric motor application with the less power. That should contribute to less energy consumption at the device operation as well as reduction of weight-dimensional sizes.

Acknowledgments

This research is done with the financial support from the Science and Higher Education Ministry of the Russian Federation in the frame of the complex project “The high-tech manufacturing establishment of safe and export-oriented GAZ vehicles with autonomous control systems and the possibility of integration with the electric platform on the base of Russian production components” under the contract №03.G25.31.0270 from 29.05.2017 (Governmental Regulation №218 from 09.04.2010). The experimental research was carried out with the use of the NNSTU Centre of collective using “Transport Systems” measurement equipment.

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