Algorithm for adapting the clutch of robotic transmissions of commercial vehicles in the light commercial vehicles and light-duty trucks class

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Abstract. In the modern world, the main efforts of developers of commercial vehicles are aimed at increasing the economic efficiency of using cars, reducing the negative impact on the environment and increasing the level of safety, both passive and active. The use of automatic transmissions allows the engine to work in the most optimal modes, and the driver to concentrate on monitoring the traffic situation and not be distracted by gear shifting. In commercial vehicles, robotic mechanical transmissions have become widespread. In such a transmission, the clutch and gear selection are controlled by actuators controlled by an electronic unit. Dry clutches are common in commercial vehicle transmissions. For adequate control of the clutch, it is necessary to have its high-quality model, which takes into account the coefficient of friction, touch point, the effect of temperature and many other factors. Therefore, the actual problem in the control of such transmissions is to determine the touch point of the clutch, which can serve as the main source of uncertainty in the clutch model along with the coefficient of friction. This article proposes an adaptation method for assessing the clutch touch point in real time. This approach has been applied to dry clutch control in transmissions of LCV and LDT vehicles, and the results are experimentally validated on robotic transmissions in production vehicles.

1. Introduction
With the growth of traffic intensity and the ever-increasing requirements for efficiency and comfort, as well as the tightening of environmental requirements, there is a tendency to use automatic hydromechanical transmissions or automated manual transmissions in modern commercial vehicles. The latter, in turn, are economically feasible, since they are based on a classic manual transmission and a dry friction clutch, which are controlled by electromechanical or electro-hydraulic actuators.

However, the disadvantage of this solution is the need to break the flow of power transmitted from the engine to the driving wheels of the vehicle during gear changes, which in turn requires increased attention to the clutch control process.

Also, a certain difficulty is the process of a car moving in a traffic jam, in which there is a need for a repeated cyclic process of starting the car from a place, followed by a stop, which leads to jerks and buildup, up to a complete stop of the engine.

Thus, the control of the clutch of the car plays a decisive role in the desire to meet the requirements of comfortable and durable operation of the car [1, 2].
To ensure smooth starting from the vehicle and synchronize the engine and gearbox speed when shifting gears, the robotic transmission controller must position the clutch release bearing in such a way as to achieve the calculated value of the transmitted torque at the required time depending on the slip speed between the clutch discs, determined by the formula:

$$\Delta \omega c(t) = \omega e(t) - \omega i(t),$$  \hspace{1cm} (1)

where: $\omega e$ – angular speed of the engine shaft; $\omega i$ – angular speed of the input shaft of the gearbox.

The clutch torque at the current time will be calculated as a function of the slip in the clutch:

$$Tc(t) = Tc_{max} \ast f(\Delta \omega c(t)), \hspace{1cm} (2)$$

where: $Tc_{max}$ – maximum torque transmitted by the clutch.

Thus, the target position of the clutch $Stcp$ will be determined by formula (3), based on the data of the dependence of the compression force of the clutch spring on its deformation, obtained from the calculated clutch model:

$$Stcp(t) = f(Tc(t)) \hspace{1cm} (3)$$

Accurate positioning of the clutch release bearing can be achieved by receiving a signal from the clutch actuator position sensor.

There are many analytical methods for determining the frictional torque in the clutch [3], corresponding to the position of the release bearing, but they all rely on the so-called clutch geometry embedded in the transmission controller.

Thus, in order to provide accurate control of the clutch slip and the transmitted clutch torque, it is necessary to use the slip speed of the clutch as a control variable [4]. Therefore, it is worth applying the algorithm for tracking the transmitted friction torque with a feedforward as in the clutch friction model used in [4, 5]. Figure 1 shows the design of the hydraulic clutch actuator. The clutch friction model can represent the relationship between the hydraulic line pressure and the transmitted torque of the clutch in the drive system, or the relationship between the position of the master cylinder piston and the clutch torque. In this study, since the position of the piston could be measured by the presence of a sensor on the actuator, the clutch friction model was considered as the relationship between the position of the master cylinder piston and torque.

The clutch friction model has parameters that change during transmission operation, such as the clutch friction coefficient and the touch point. Therefore, the clutch friction pattern must be corrected. Many studies have been mainly devoted to the adaptation of the coefficient of friction of the clutch, which changes with changes in temperature and surface roughness of the clutch discs [4, 5, 6].

It is known that in the manufacture of clutch parts, inaccuracies are allowed, and also in the case of using a clutch with a diaphragm spring, the clamp load of the spring, and, consequently, the torque transmitted by the clutch, nonlinearly depends on the value of the preload, which, in turn, is determined the degree of wear of the friction linings. Slight fluid leaks from the clutch drive are also possible, which is especially important in the case of a hydraulic drive. All of the above factors affect the redefinition of the touch point, which is essentially the starting point for plotting the characteristic of the dependence of the transmitted torque in the clutch on the position of the piston of the master cylinder.

Figure 2 shows two curves of the dependence of the clamp load of the clutch on the displacement of the master cylinder piston (the solid curve corresponds to the new clutch, the dotted curve to the worn one). It is easy to see that the release stroke of the new clutch differs from the worn one to a lesser extent, since when the friction linings are worn, the clutch compression force increases, and, consequently, the transmitted torque. In this case, the full travel of clutch release (defined as the difference between the values of the mechanical disengage clutch position (MDCP) and the engaged positions (MECP) remains unchanged. However, the position of the clutch touch point will change and with wear will tend to the depressed clutch position.
Figure 1. Diagram of the clutch drive

Figure 2. Clutch force characteristic
For these reasons, adapting the clutch touch point can be just as important as adapting the coefficient of friction of the clutch [7, 8].

This article presents a method for adapting a clutch friction model where the indeterminate parameter is the clutch touch point. The adaptation of the touch point is controlled by feedback on the readings of the master cylinder piston position sensor located on the clutch actuator and the gearbox input speed sensor.

The algorithm proposed in this article was tested through experiments using serial vehicles equipped with a robotic transmission. The main contribution of this study is to propose a method for adapting the clutch touch point in real time using engine and gearbox input shaft speeds.

2. Description of the robotic transmission control system

In commercial vehicles for general use, robotic mechanical transmissions have become widespread. A robotic mechanical transmission is a manual transmission that has automated clutch and gear selection functions. In such a transmission, the clutch and gear selection are controlled by servos (actuators), consisting of an electric motor with a gearbox and actuators controlled by an electronic system. Figure 3 shows a schematic diagram of the transmission control system and the peripheral devices of the vehicle with which it interacts.

The robotic transmission control system includes:
- Transmission control module (TCM);
- Clutch actuator;
- Gearbox actuator;
- Gear selector (Lever);
- Transmission input shaft speed sensor (ISSS);
- Electrical and hydraulic connections.

Figure 3. Diagram of the vehicle transmission control system

Automation of vehicle transmission control is achieved due to the coordinated work of the clutch and gearbox actuators, driven by the TCM, which, in turn, makes decisions based on information from
the surrounding systems, and also monitors the revolutions of the engine crankshaft and, if necessary, can control the revolutions engine, by means of a torque request.

Thus, the principle of controlling actuators is reduced to controlling the position of the actuators in accordance with the values specified by the software algorithm (Figure 4). During the operation of the TCM in the active mode, the microcontroller receives information about the position of the actuators from the position sensors in the form of a voltage supplied to the ADC of the microcontroller, thereby changing the feedback signal of the PID controller of the actuator. In this case, a regulating effect on the electric motor of the actuator in the form of a PWM arises, depending on the value of the adjuster at the input to the PID controller, determined by the proportional, integral and differential coefficients.

For bumpless gear shifting, the TCM monitors the parameters of the synchronization of the speeds of rotation of the primary and secondary shafts of the gearbox and, if necessary, aligns them by controlling the speed of the internal combustion engine shaft. The engine speed control is carried out according to the diagram shown in Figure 5.

![Figure 4. The principle of positioning the actuator](image1)

![Figure 5. The principle of control of the rotational speed of the engine shaft](image2)
In order to equalize the speed of rotation of the input shaft of the gearbox and the crankshaft, the TCM sets the effect on the internal combustion engine in the form of the requested torque, by transmitting the corresponding signals through the on-board CAN bus to the engine control module (ECM). In this case, the feedback of the crankshaft speed control loop is carried out by receiving the corresponding CAN signals with the crankshaft speed from the ECM. The value of the requested torque is determined by the internal logic of the PID regulators of the TCM, using the speed of the input shaft of the gearbox as the adjuster of the target setting of engine speed.

Most of the signals listed above are transmitted and received by the TCU and vehicle control units by coordinated data transmission via the CAN bus. The distribution and conversion of the relevant information between the vehicle control units and the TCM is carried out using a CAN gateway that combines three CAN buses with each other (CAN-I, CAN-D, CAN-T).

3. Adaptation of the clutch touch point

In this study, the clutch friction model represents the relationship between the position of the master cylinder piston in the clutch drive system and the torque transmitted by the clutch. The relationship curve between master cylinder piston position and clutch torque was obtained experimentally and used in this study to simulate the transmission. The clutch discussed in this article is permanently closed, can transmit torque up to 450 N*m, while the master cylinder piston can move from 0 to 23 mm.

The adhesion friction model is usually expressed as follows:

\[ T_{cl} = \mu \cdot R_{cl} \cdot F(S, S_{touch}) \]

where:
- \( T_{cl} \) – clutch torque;
- \( \mu \) – clutch friction coefficient;
- \( R_{cl} \) – clutch effective radius;
- \( F \) – normal compression force of the clutch;
- \( S \) – position of the piston of the main cylinder of the drive;
- \( S_{touch} \) – clutch touch point.

In the clutch model, the touch point is the position of the master cylinder piston when the clutch begins to transmit torque. In addition, the normal compression force of the clutch is a function of the piston position of the master cylinder, which is characteristic of the diaphragm spring of the clutch. It is worth noting that the shape of the relationship curve between the position of the master cylinder piston and the clutch torque is the same as that of the normal clutch clamp load curve, since they are related by the value of the clutch friction coefficient. Thus, based on formula (4), and assuming that the shape of the clutch characteristics and the effective radius of the clutch do not change, a change in the touch point of the clutch can affect the smoothness of the process of transferring torque from the engine to the transmission when shifting gears and when starting off. Thus, this article poses the problem of assessing the current clutch touch point during vehicle operation.

This study proposes an adaptive method for detecting clutch touch point using feedback on the revolutions of the input shaft of a robotic transmission. The nominal curve of the relationship between the position of the piston of the master cylinder and the clutch torque can be displaced along the axis of the piston stroke of the master cylinder by the amount of change in the touch point:

\[ S_{touch,O} = S_{touch,N} + \Delta S \]

where:
- \( S_{touch,O} \) – old (primary) clutch touch point;
- \( S_{touch,N} \) – new (actual) clutch touch point;
- \( \Delta S \) – clutch touch point displacement.

Therefore, knowing the amount of displacement of the touch point, it is possible to perform reliable clutch engagement control when starting the vehicle and shifting gears while driving. A graphic interpretation of the adaptation process of the clutch touch point is shown in Figure 6.
To estimate the displacement of the touch point, it is proposed to calculate the primary value of the position of the piston of the master cylinder (touch point of the first step, point 2 in Figure 6), where the corresponding acceleration of the gearbox input shaft exceeds a certain threshold value. It is worth noting that this primary touch point is calculated when the clutch transitions from fully open to fully closed. Here, the criterion for determining the moment of contact of the clutch is introduced; it is the acceleration threshold of the transmission input shaft. In this article, the acceleration threshold for the transmission input shaft was established during road tests of the car and is 360 units. This parameter is expressed as the ratio of the increase in the speed in revolutions per minute to the rise time of this frequency in seconds:

Figure 6. The process of adapting the clutch touch point
Then the actual touch point of the clutch (called the touch point of the second step, point 5 in Figure 6) is adapted using the same acceleration threshold of the input shaft of the gearbox, but this process occurs when the clutch is partially opened and the direction of movement of the master cylinder piston is changed in the direction of the second closing the clutch.

The amount of displacement of the clutch touch point along with the actual value of the touch point allows not only to ensure the comfort of movement when operating a robotic transmission. The rapidly changing value of the first step touch point can be used to diagnose hydraulic line failure. Considering the one-sided dynamics of changes in the values of the clutch touch points during long-term operation of the vehicle, one can assess the degree of clutch wear and warn of timely maintenance.

4. Results of experimental studies of the effectiveness of adaptation of the clutch touch point

In this subsection, the efficiency of the robotic transmission clutch touch point adaptation algorithm proposed in this article was verified by field tests using production vehicles of the LCV and LDT class. The longitudinal speed and rotational speed of the engine shaft and the input shaft of the gearbox were taken as the parameters under study when assessing the comfort of the car when starting off and shifting gears in motion. The recording of the values of the rotational speed of the shafts of the engine and gearbox was carried out using signals from the electronic control unit of the robotic transmission. The value of the current longitudinal vehicle speed was recorded using the RaceLogic VBOX data collection system.

The value of the standard deviation of the longitudinal speed of the vehicle in the time interval of the clutch operation during its closure was selected as the main indicator of the comfort of the vehicle movement during the operation of the robotic transmission.

As a result of a series of races on two types of cars with different intensities of acceleration while driving, it was found that the greatest values of the standard deviation of the vehicle's longitudinal speed for the transmissions under study are observed in the lowest gears (switching from the first to the second and from the second to the third gear). One of the graphs, including the parameters under study when starting and accelerating the car, is shown in Figure 7.

After analyzing all the data on fluctuations in the longitudinal speed of the vehicle during the operation of the clutch from a series of vehicle tests, it was found that the maximum value of the standard deviation of the longitudinal speed of the vehicle is 1.32 km/h when switching from second gear to third, with the average steady speed of the vehicle 36.4 km/h. This result makes it possible to assert about the provision of good driving comfort with high-quality operation of the clutch of the robotic transmission. Thus, the algorithm proposed in this article makes it possible to ensure adequate determination of the actual clutch touch point.
Figure 7. The main characteristics of the transmission and movement of the car when starting off and accelerating in lower gears

5. Conclusion
This article proposes a method for adapting the clutch touch point when engaging with a sliding dry clutch in transmission of vehicles of the class LCV and LDT. The proposed method was applied to the adaptation of dry clutch on production vehicles equipped with a robotic transmission, and was tested using experimental races. The touch point of the clutch was evaluated in two stages: the point of the first step was obtained with the full travel of the clutch from fully open to full closure; the point of the second step (the actual touch point) is obtained when the clutch is not completely disengaged and the direction of movement of the piston of the drive cylinder is changed. With this approach, the tracking performance of the clutch touch point has been improved and its adequacy has been confirmed in field tests with production vehicles. The experiments described in this paper have shown that this clutch touch point adaptation algorithm shows good results when assessing the comfort of movement of vehicles with a robotic transmission. The prospect of this research is the development of algorithms for assessing the clutch touch point for diagnosing the failure of the hydraulic drive line, as well as assessing the degree of wear of the clutch and clutch drive mechanisms during vehicle operation.

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