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DEVELOPMENT OF CONTROL ALGORITHMS FRICTION CLUTCHES AUTOMATIC TRANSMISSIONS

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Abstract The article features the general scheme (diagram) of the control system of mobile machines transmission. It also covers the results of the simulation of various types of control algorithms with the friction clutches of automatic transmissions, as well as the options for the application of the heuristic approach and fuzzy inference for the use of fuzzy logic principles. There marked the problems, associated with the development of adaptive control systems, and presented their solution with the employment of the simulation modeling system.

Key words: automatic transmission, control algorithm, fuzzy controller

AMS Mathematics Subject Classification: 70Q05

1 Introduction. Statement of the Problem

The contemporary technical level of auto- and tractor industry is characterized by rapid growth in the field of electric power plants, including the one accounted for escalating competition in the context of globalization and economic recession. The competitiveness of such equipment and technologies is based on the perfection of its power units, containing internal combustion engine (ICE) and automated transmission, operating under control of their electronic systems, united in common information and control network. When applied to stepped ratio gear transmission, prevailing in such units, the use of automated control and interaction with ICE allowed to enhance the designation and reliability figures of the power unit and reach the level never attained earlier. According to the analysis [1], the recent years have been witnessing a rapid growth in the field of kinematic diagrams, design and control systems of automatic transmissions. Among domestic scientists, these issues were repeatedly brought up in their research papers by such eminent scientists, well known in the field of 'Machine - building', such as: I.S. Tsitovich, L.G.Krasnevsky, K.Y. Lvovsky, V.B.Algin, V.P.Tarasik, V.A. Petrov, I.P.Ksenevich, V.N.Ksendzov, V.V.Gritskevich and others.

The task of controlling a stage automatic transmission with friction clutch engagement can be divided into two independent subtasks: the selection of the transmission, optimal in terms of the current traffic conditions, and management of friction clutches in transient operating modes. With the latter, constituting the focus of interest of the present research, the purpose of the study is not only the control algorithm selection of friction clutches for the given model of transmission, but also the testing of methodology of development and debugging of control algorithms at the stage of the system engineering and design.

The control theory and technology of both the friction clutch and its operation as part of the dynamic system of machine assembly constitute a field of research with colossal scope of information, including thousands of patents. The developments of such systems are known as business secrets of manufacturers and most often are carried out as inventions [2,3,4,5,6,7,8,9,10]. The leading position in this domain belongs to the company 'General Motors', which in the 30s was the first to create the passenger planetary hydromechanical transmission 'Hydromatic' with friction clutches and band brakes, with the company 'Allison' to have become the world's largest manufacturer of high-power hydromechanical transmissions [2]. In domestic literature sources, despite a considerably large number of research works on hydromechanical transmissions, employing a friction clutch (coupling) as the key control element, very little emphasis was placed on the issues related to the smoothness and fluency of gear changing. Until recently the smoothness was provided only with the help of mechanical hydraulic control system due to the smoothness of control pressure build-up in the activated friction clutch. However, there is no possibility to adjust it depending on changing environment. The evolution of hydraulics, pneumatics, mechanics and electronics gave birth to the development of game changing domain of technical engineering, termed as mechatronics, comprising the calculating capacity of microprocessor based systems with the power characteristics of machine units and mechanisms. The task of the present paper lies in the development of control algorithms for the friction clutches of home-made automatic transmissions with their wide variety and relatively low production rates. The consideration of all the above-mentioned factors requires the developers to work out uniform approaches to the development of algorithms and soft hardware for their realization.

Considering the uniformity of impact factors (such as the nature and magnitude of the load, the friction coefficient unstability, and the parameters of the hydraulic system, etc.) as well as the requirements for the quality of the system performance, the algorithms controlled by the friction clutches of the automated transmissions of different sizes and by different manufacturers should differ in parameters only, while maintaining the overall behavior and logic. To test this logic, the following simplifications should be accepted:

- the load is inertial-dissipative by nature;
- the development of switch algorithms is carried out with one pair of friction clutch;
- the information parameters of the management system shall be the rotational rates of the input and output shafts of transmission;
- the signals of pressure sensors have a relay nature (Yes / No);
- the feedback of the internal combustion engine (ICE) control is not available (missing);
- the upward gear change occurs at the point of maximum power of the external characteristic of ICE;

- the downward gear change occurs at the point of the maximum external characteristic of the ICE.

The function block diagram of the object under control (the pairs of friction clutches of automated transmission), comprising the systemPIP‚в„ўs informational and control signals, has the form, shown in Figure 1.

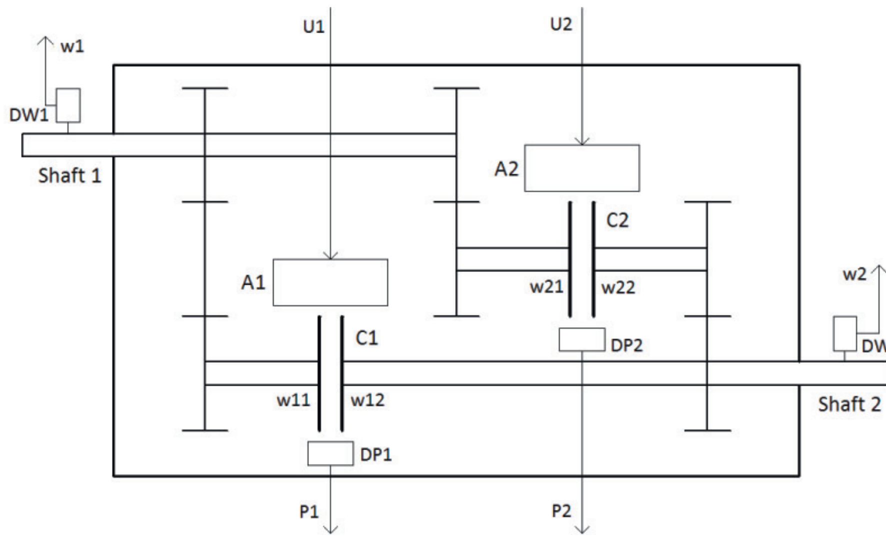

Figure 1: Function block diagram of automated transmission where: w1, w2 - angular rates of rotation of transmission input and output shafts; DW1, DW2 - rotation rates sensors; P1, P2 - logic signals for reaching the threshold pressure in friction clutches; DP1, DP2 - relay-type pressure sensors; U1, U2 - control signals for the actuators of pressure control in friction clutches, C1, C2 - upshift and downshift friction clutches, A1, A2 - clutch control actuators.

For the mathematical simulation of dynamic processes of clutch switching, requisite for the evaluation of the quality of algorithms performance, we present the functional diagram of the automated transmission as a six- mass dynamic model with two friction elements, two transformer elements and one elastic-dissipative element. The obtained dynamic model is shown in Figure 2.

Mathematical description of the dynamic model, shown in Figure 2, is performed with the use of the well-known method of internal moments [1]. The solution of differential equations of the model mathematical description is also performed with the help of standard methods of numerical integration and presents no interest within the scope of the given article.

2 Software Model for Control Algorithms Debugging

To perform the debugging of control algorithms with the friction clutches of automatic transmission, there was devised a simulation program model, with its configuration (structure) shown in Figure 3. As a control object (object's actuator model), implemented within the scope of the simulation software model, there was adopted a dynamic

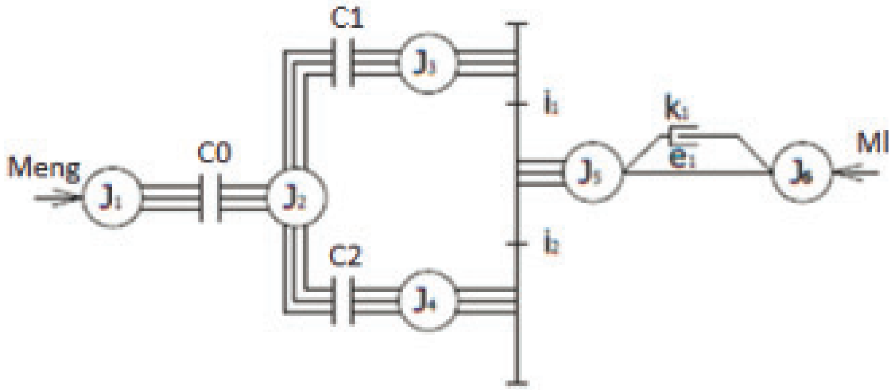

Figure 2: Dynamic model of controlled object

model (see Fig. 2). The parameters of this model correspond to those of the propulsion system of the tractor 'Belarus 1525'.

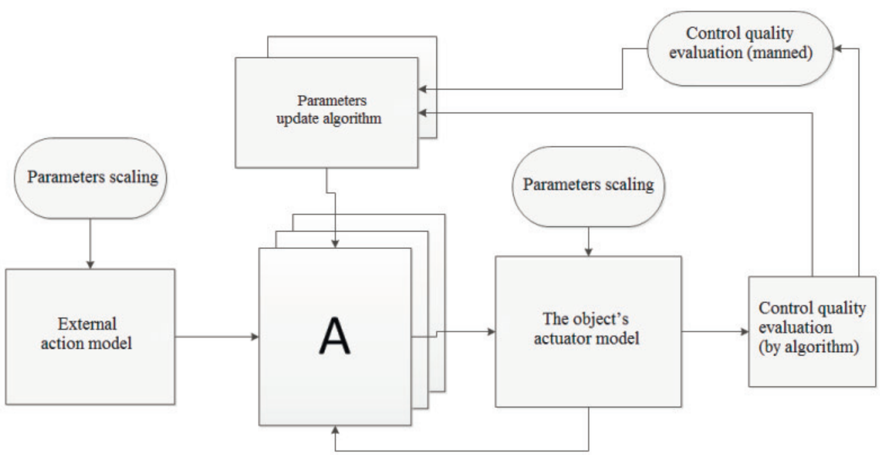

Figure 3: Structure of software model for control algorithms analysis and testing

The program model was implemented in the language C# (platform .NET). The choice of the language and platform may be accounted for the development simplicity and speed, capabilities to elaborate in detail on the simulation of processes of any level, as well as the availability of convenient tools for working with graphics and files.

The input data of the program model are presented by the function of the control algorithm (A), and the output data are presented in the form of the torque characteristics and the rotational rates of the dynamic model components (including their graphic expression), allowing to evaluate the effectiveness of the control algorithms performance by friction clutches .

The structure of the program model is represented by the following functional blocks:

- the block with initial data, characterizing the parameters of the system dynamic model;

- the block of the mechatronic control system simulation, including the setpoint of the control signal, described analytically. It is in this block where control signals get generated by the actuators of friction clutches, based on control algorithms , whose effectiveness is under test;
- the block for electrohydraulic system simulation, containing analytical dependencies, featuring the pressure function in the friction, depending on the applied control signal. The relations (dependencies) were obtained from experimental data by means of averaging data of several tests for each of the gears;
- the block for friction clutches simulation, describing the characteristics of frictional moment, transmitted in the process of switching , as well as their thermal characteristics;
- the block for simulating the transmission dynamic model, implementing numerical methods for solving the system of differential equations.

The validation of software model was performed by comparing the dependencies of the torque on the transmission output shaft, obtained upon the simulation results as well as during its bench tests. The interval of received deviations made up $\pm$ 15%.

Thus, the received software model makes it possible to set the parameters of external influences on-line and select characteristics of control algorithms in such a way in order to maximize control quality.

3 Research Findings on Testing of Control Algorithms by Friction Clutches

Nowadays, as alternative methods for controlling the units of mobile platforms (vehicles), including transmissions, they employ:

- the classical methods of adaptive control by means of P, PI , PID controllers (which provide the necessary non-linearity of the management function);
- the classical multilayer neural networks (which provide the approximation of the requisite nonlinear control function);
- fuzzy controllers (which allow the use of a priori information about the object under control, experts' experience, while providing the non-linearity of control characteristics).

We shall linger on the last, mentioned on the list. The general structure of the transmission control system, based on a fuzzy controller, is shown in Figure 4.

The mathematical basis of fuzzy controllers is constituted by fuzzy inference methods, which in turn are based on the theory of fuzzy sets. Depending on technical requirements and design limitations, fuzzy controllers can be implemented both as software, and hardware. The global leaders in the production and use of such controllers are FujiElectric, Klockner-Moeller, Rockwell-Automation, Allen-Bradley, Siemens and Yokogawa [1-4]. The wide spreading of fuzzy controllers in transmission control systems shall be attributed to the following peculiarities of this system type:

- a wide range of operating loads of the control object;
- a wide range of operating temperatures, causing the change in the parameters of the system's electrical and hydraulic components;
- the change of the design parameters of transmission during its wear, as well as variations, caused by manufacturing peculiarities;
- different working styles of the operator;
- inability to anticipate the road (traffic scenario).

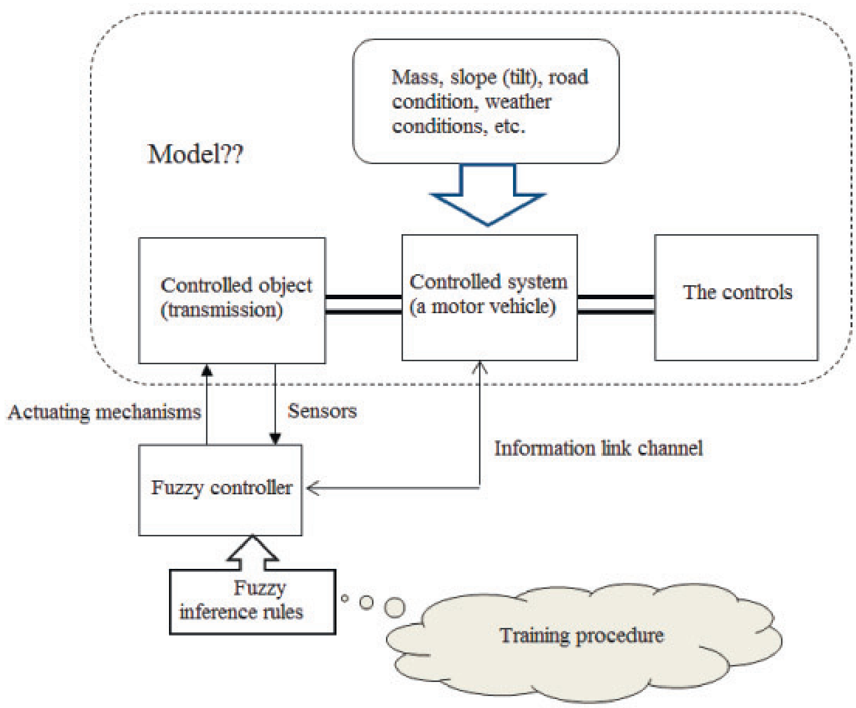

Figure 4: General structure of transmission control system based on fuzzy controller

The rigorous analytical description of the specified features is highly time consuming, therefore when in practice, in the control algorithms of mechatronic systems or design models of the current state of the object they only consider the most significant aspects, understood as such by the developers of the system. Together with that the use of fuzzy controllers make it possible to obtain the fitness of the control model not only analytically, but also heuristically utilizing fuzzy inference methods and relative magnitudes (linguistic variables, membership functions) [6].

The main advantage of fuzzy control lies in the simplicity of recording (and use) of man's informal knowledge and experience associated with the controlled object, control (operation) modes, risk minimization, etc., obtained by trial and error. On the other hand, a significant disadvantage is that there are currently no formal design procedures (and most importantly, setup) for fuzzy systems, whereas the evaluation of the effectiveness of the fuzzy controller may only be possible after its introduction and implementation into the system. In this regard, the software model, considered in paragraph 1, can be applicable with no limitations for debugging of fuzzy control algorithms.

The fuzzy controller training procedure shall implement:

- the choice of inference method (as alternatives to fuzzy inference methods there are considered the fuzzy inference method of Mamdani, Takagi - Sugeno and others);
- the selection (the definition of 'specification') of linguistic variables;
- the setup (selection) of parameters of membership functions;
- the formation (task) of inference rules (number and wording of rules).

There exist no formal methods of teaching fuzzy classifiers, however it is possible to suggest a number of intuitive and user-friendly approaches to the development of teaching methods, though they will always be based on some degree of heuristic knowledge, formulated by an expert, etc.

4 Conclusion

When designing the algorithms for transmission control, one should consider a number of objective problems.

1. It is difficult to formulate the criterion of 'optimal control'. For example, if for the control of one clutch of PTO it is relatively simple to do so, then regarding a multistage gearbox, it presents a certain problem. At the heart of 'optimality' there is always a parameter or functional, which gets 'optimized' by the system, maintained within the set limits, maximized, minimized, etc.

2. It is hard to imagine the actuator with the control object presented in the form of an adequate mathematical model, fit for debugging control algorithms. For that reason, the debugging of algorithms is commonly carried out on a real system by 'model' control function. (The model control function is understood to mean the function, meeting the criteria of optimal control, which, according to paragraph 1 also faces the problem of definition.)

3. Fuzzy controllers constitute a promising basis for the development of adaptive systems of controlling the units of vehicles, they hold a number of useful properties, although they should not be considered panacea for all problems. Though being very famous in domestic machine-building, there has been no precedent of their practical application.

4. Mathematical apparatus of fuzzy controllers holds application restrictions in cases where there is no a priori (expert) information about control function. The scope of computations as compared to the tabular method increases several-fold. In

some cases, in a regular microcontroller it will be problematic to provide the required performance for real-time control with the set scope of calculations.

There exist no fundamental obstacles to the practical application of fuzzy controllers. The above mentioned theoretical problems are inherent in any control methods and not limited to fuzzy controllers only, therefore their solution can be carried out if not in a strictly formal manner, then at least keeping in mind existing practical standards.

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