Agata NAWROCKA*, Janusz KWAŚNIEWSKI**

ADVANCED CONTROL ALGORITHM FOR STABILIZATION ROTATIONAL SPEED IN HYDROSTATIC TRANSMISSION

SUMMARY

This study focuses on the adaptive controller to control hydrostatic transmission. A hydrostatic transmission with a variable efficiency pump and a radial engine with constant working absorptivity was chosen. Pump efficiency was controlled using an electrohydraulic control system, comprising a hydraulic cylinder coupled with a pump rotor via a piston rod and a hydraulic servo-valve. As the object is nonlinear and time variant its control is very difficult. For that reason the adaptive control strategy was chosen and a follow-up control algorithm was designed. This control strategy enables the fine tuning of the fuzzy logic controller's parameters. It can be done online, in each cycle time. Besides, this algorithm is implemented on a PLC controller. This paper outlines the structure of the controller and provides the results of laboratory tests.

Keywords: *hydrostatic transmission, adaptive controller, follow-up control, laboratory tests*

ZASTOSOWANIE ZAAWANSOWANEGO STEROWANIA DO STABILIZACJI PRĘDKOŚCI OBROTOWEJ PRZEKŁADNI HYDROSTATYCZNEJ

W artykule zostanie przedstawiony algorytm sterowania obiektem nieliniowym. Obiektem sterowania jest przekładnia hydrostatyczna, pracująca w obiegu zamkniętym. Zbudowana jest z pompy o zmiennej wydajności i silnika o stałej chłonności. Do sterowania wydajnością pompy wykorzystano elektrohydrauliczny układ sterujący. Układ ten obejmuje siłownik hydrauliczny sprzężony tłoczyskiem z wychylnym wirnikiem pompy oraz elektrohydrauliczny serwozawór przepływowy. Obiekt ten jest nieliniowy i niestacjonarny Powoduje to trudności z doborem odpowiedniego regulatora do stabilizacji prędkości obrotowej silnika hydraulicznego. W artykule opisano zastosowanie zaawansowanego algorytmu sterowania do stabilizacji prędkości obrotowej. Opracowano algorytm nadążnego dostrajania regulatora rozmytego, który następnie został zaimplementowany w sterowniku PLC. Algorytm ten umożliwia dostrajanie regulatora w każdym cyklu pracy. Zaproponowany algorytm został przebadany na stanowisku laboratoryjnym.

Słowa kluczowe: *przekładnia hydrostatyczna, regulator adaptacyjny, regulacja nadążna, badania laboratoryjne*

1. INTRODUCTION

Hydrostatic transmission is one of basic hydraulic systems, very useful in many fields of engineering. In certain applications hydrostatic transmission is a part of a machine component, such as a drive. Stabilization of either rotational speed or torque on the motor shaft is a frequent control task to be handled.

A hydrostatic transmission is difficult to control because of its specific properties, which make it sensitive to disturbances. The transmission can operate in a wide speed range, but that speed must be set very precisely. When all potentials of hydraulic transmission design are utilized, the selection of a suitable control system is of major importance.

Control using the hydraulic drive is a time-variant process, and consequently, it is affected by discrepancies in the parameters of the hydraulic fluid (for example: kinematic viscosity, compressibility, thickness). Pump efficiency is controlled using a electrohydraulic servo-system, which has a non-linear characteristic. For this reasons the advanced control strategy is proposed in this study. Rotational speed control was realized via a fuzzy logic controller whose parameters were tuned using a follow-up algorithm.

Fuzzy logic controllers proved to be a success in many control problems which could not be handled with conventional PID controllers, especially when the process to be controlled is nonlinear and time-variant. Design involves three stages: selection of membership functions for inputs (number, form and value), construction of a rule base and selection of a defuzzification method. The main problem is how to determine the exact shape and number of a membership function and how it should be related to the system output. This study outlines an algorithm for selecting the membership function locations. Moreover, the algorithm computes the input value for the optimal stabilization of rotational speed of a hydraulic engine.

Such control strategy was tested on the hydrostatic transmission in laboratory conditions. All algorithms were implemented on an industrial controller CJ1M Omron.

2. CONTROL OBJECT

Hydraulic fluid in the hydrostatic transmission used in the experiments was circulated in the closed-loop system (Fig. 1). The hydrostatic transmission comprises at a multipiston axial pump of variable efficiency HP and a multipistons radial engine with constant working absorptivity HM.

* AGH University of Science and Technology in Cracow, Poland, Department of Process Control; nawrocka@agh.edu.pl; AGH
** AGH University of Science and Technology in Cracow, Poland, Department of Process Control; j_kwa@uci.agh.edu.pl

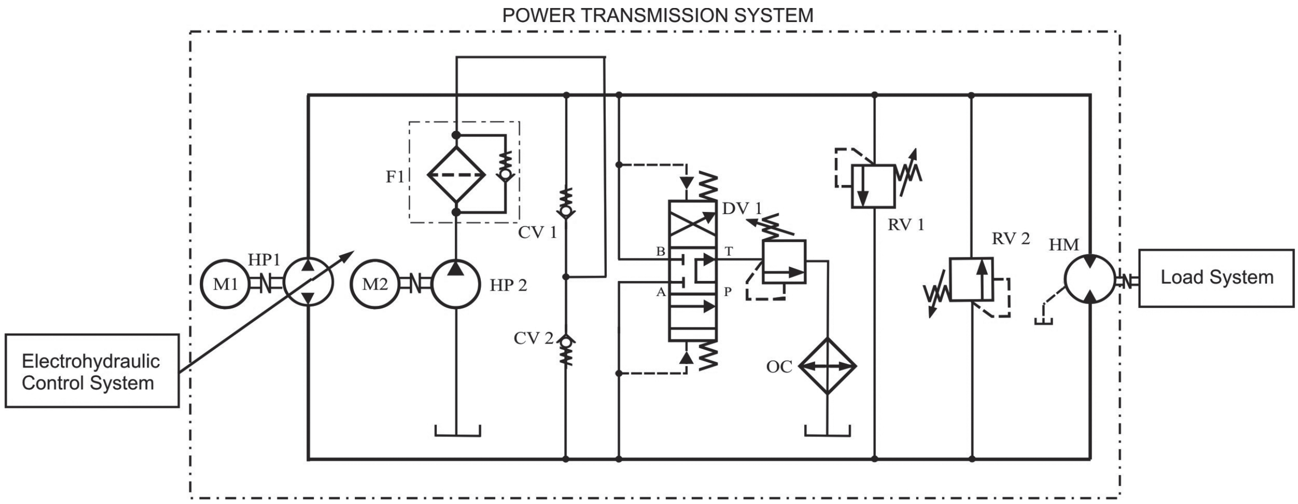

Fig. 1. Hydrostatic transmission scheme: HP – hydraulic pomp, CV – check valve, RV – pressure relief valve, DV – directional control valve, HM – hydraulic motor, OC – oil cooler, HC – hydraulic cylinder, SV – servovalve

The control of pump efficiency and of rotational speed of the motor shaft was realized via a electrohydraulic control system. This hydraulic system comprises of a servo-cylinder HC coupled with a pump rotor *via* a piston rod and an electrohydraulic servovalve SV integrated with the cylinder (Fig. 2).

Displacement of the piston rod in a cylinder is measured by a position sensor which registers angular deflection of the pump rotor. Position of the pump rotor controls pump efficiency, direction of flow of the working fluid and hence the rotational speed and the sense of rotation. The hydraulic engine loading is imposed by the pump mechanically connected with this engine.

The most important component of the system is the pump HP5 (Fig. 3) which forces hydraulic fluid *via* a circulation switch CS3 to three elements:

1) pressure relief valve RV4,
2) proportional pressure relief valve PV,
3) directional control valve DV4.

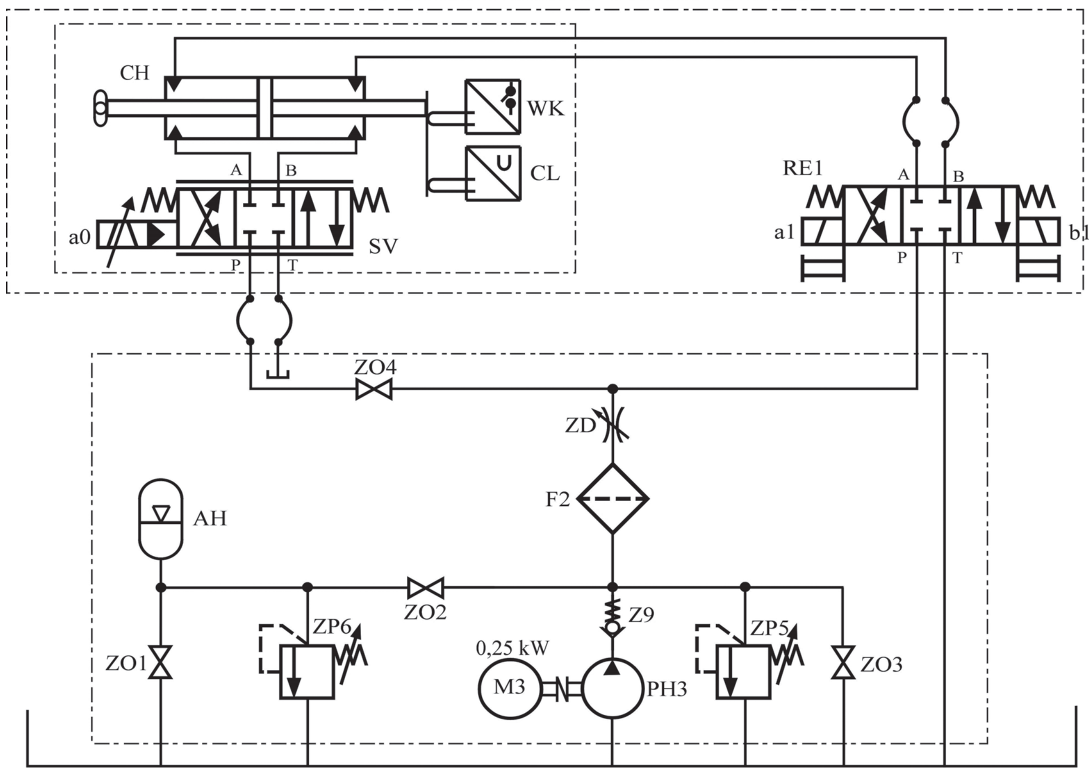

Fig. 2. Electrohydraulic control system

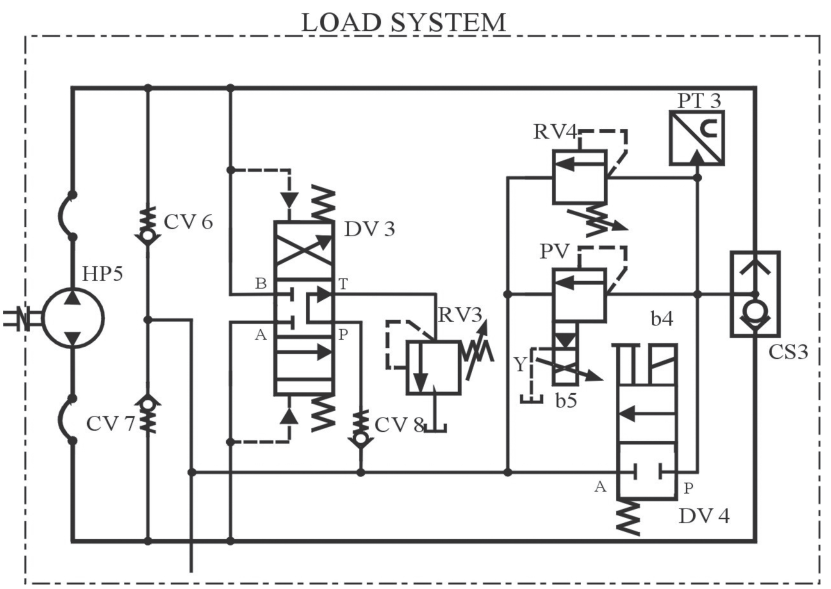

Fig. 3. Loading system

The proportional pressure relief valve PV enables the continuos control of pump pressure whilst the pressure relief valve limits the maximum pressure value. Fast loading and unloading of the hydraulic pump HP5 is achieved using a directional control valve DV4, which enables us to impose loads in the form of step functions, sinusoidal, stochastic loads etc.

The measurement and control system shown in Figure 4 was designed and engineered for the purpose of this research program. The control part comprises of:

- a torque motor,
- a servo-valve,
- a proportional electromagnet b5,
- a proportional pressure valve.

The measuring section comprises of:

- sensors,
- transducers,
- amplifiers,
- a control board,
- PCI 1711 with a terminal strip PCLD 8710 Advantech,
- elements of the computer system.

The software for hydrostatic transmission control system was developed in the MATLAB/SIMULINK environment supported by Real-Time Workshop (RTW). Simulation models are used by RTW for generating the C code and building a real-time application. Measurement signals are duly converted to give analogue input to the card. A PC with MATLAB/SIMULINK software is used for data registration only.

Control of the object was realized via an industrial controller CJ1M Omron with an analogue module CJ1W-MAD42 [1]. A specialised program used to control rotational speed of a hydraulic engine was written in CX Programmer and simulations were performed in the CX Simulator.

3. ADAPTIVE ALGORITHM FOR ROTATIONAL SPEED CONTROL

Stabilization of rotational speed in a hydrostatic transmission is a major problem and hence a fuzzy logic controller was proposed to handle the task. The Sugeno model of the controller's structure was selected. The main advantage of this model is that the number of rules can be reduced, especially for complex and high-dimensional problems [2]. This controller has two inputs and one output. Error values and error variations are taken as inputs, while the control signal to a servo-valve is an output. For input values the triangular and trapezoidal membership functions were chosen [2]. Since it is the Sugeno 0-order system, output value were singletons.

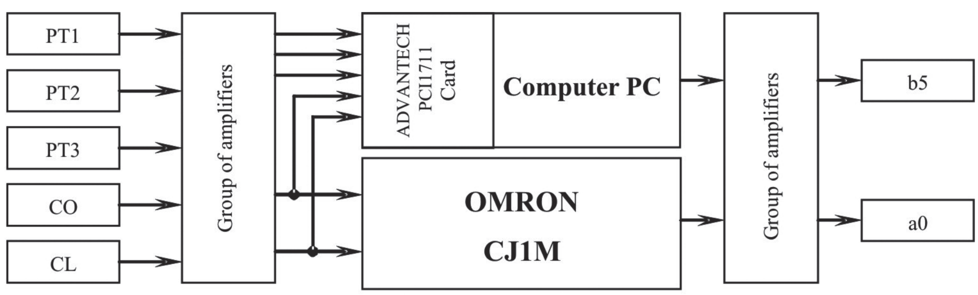

Fig. 4. Block diagram of control and measurement system

Tests run on a fuzzy logic controller have revealed that control quality depends on the controller's parameters (membership function shape, its location and singletons location). That is why a control algorithm was designed which enables the automatic tuning of controllers' parameters. The general scheme of follow-up process is shown in Figure 5.

The adaptive algorithm consists of two parts. First, the membership function location was tuned and so were the appropriate input values. Singletons started from the neutral position and their location were sought during the learning process.

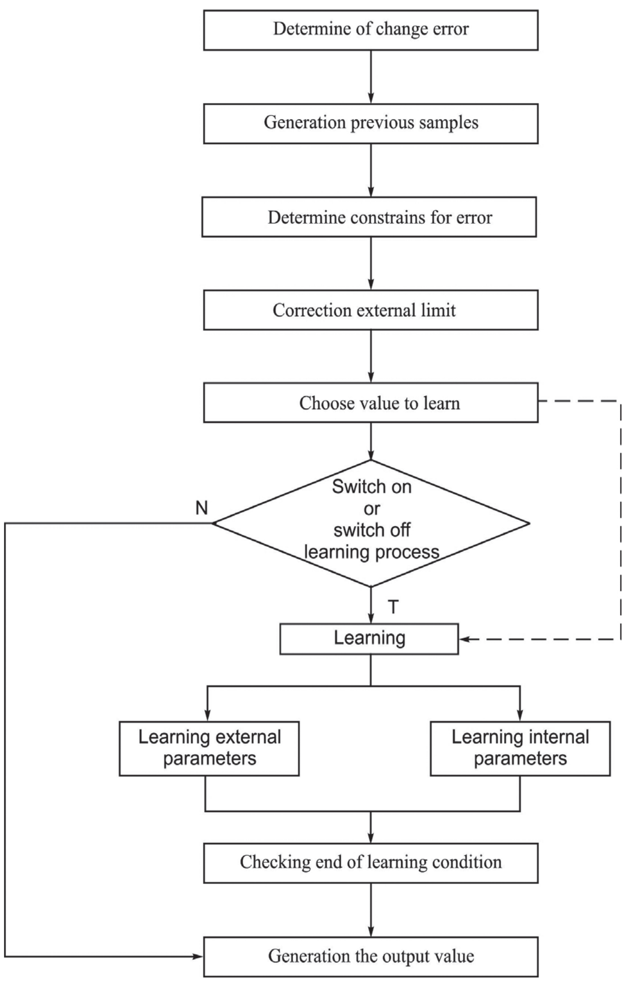

Fig. 5. The general scheme of follow-up process

In the first step the initial membership function location was established. Afterwards, the external limit (AP) correction was started. The correction process utilized the error size. The error-checking algorithm is shown in Figure 6.

During the correction process, the value of the external limit increments by one. Moreover, the sign (plus or minus) of the input value is checked. If this value is positive, the value of the first singleton is increasing but if it is negative, the first singleton value will decrease. The error checking is performed in every cycle time of the controller operation.

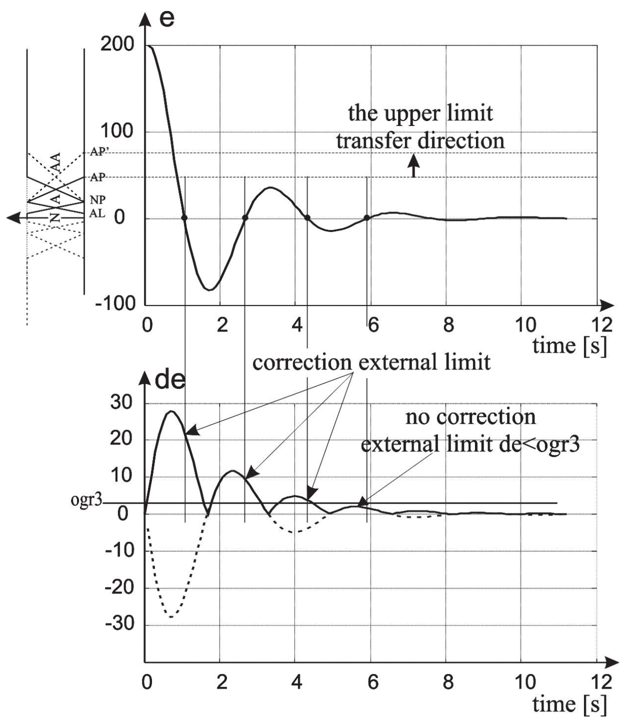

Fig. 6. The algorithm for tuning the external limit

4. LABORATORY TESTS

Laboratory tests involved two stages. At first the described algorithm was implemented using function blocks in the CX Programmer, then the algorithm was tested in the experimental set-up. The control and measurement system used in laboratory tests is shown in Figure 7. The temperature of oil during tests was fixed to be 30^{o}C.

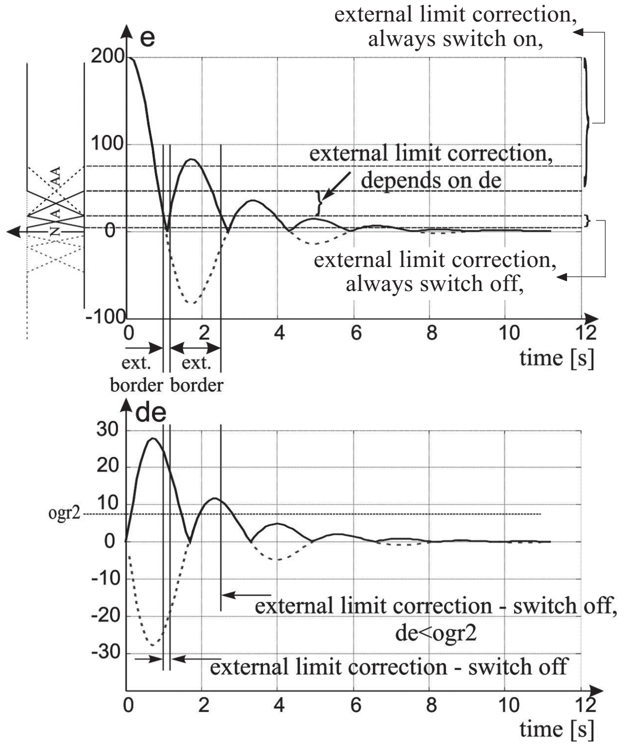

Fig. 7. Tuning of external limit activation process

The first stage consisted in controller's learning. The property of the membership function location was chosen and locations of singletons were sought using a rectangular input signal (Figs. 8 and 9). This kind of signal is adequate for learning processes because it contains a great deal of information [5].

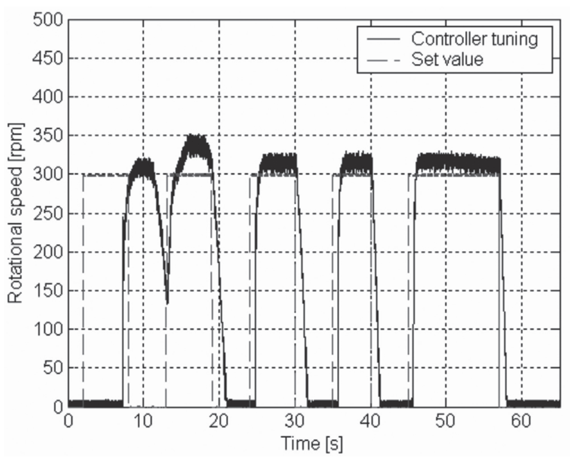

Fig. 8. Learning process for the set value 300 rpm

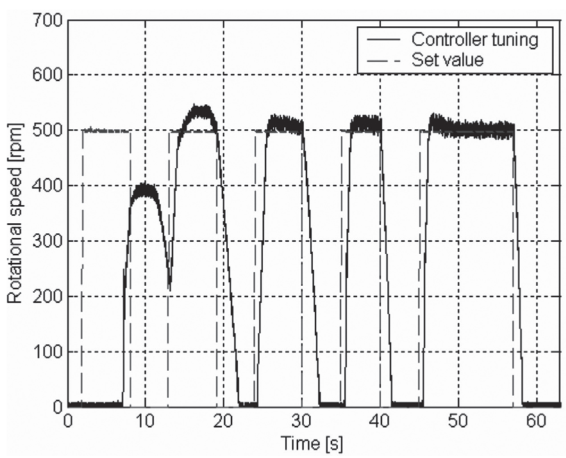

Fig. 9. Learning process for the set value 500 rpm

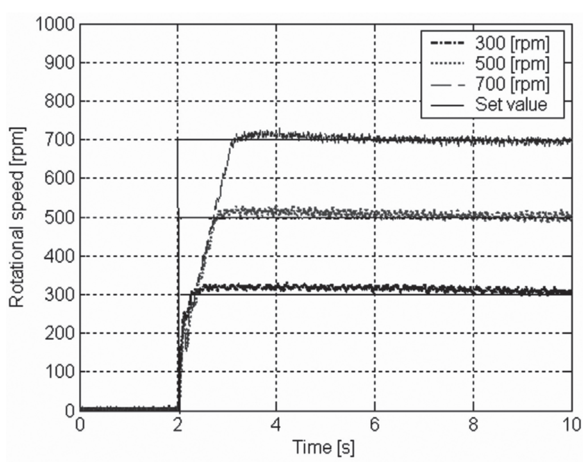

Fig. 10. Comparison of three values of rotational speed for fuzzy logic controller learning

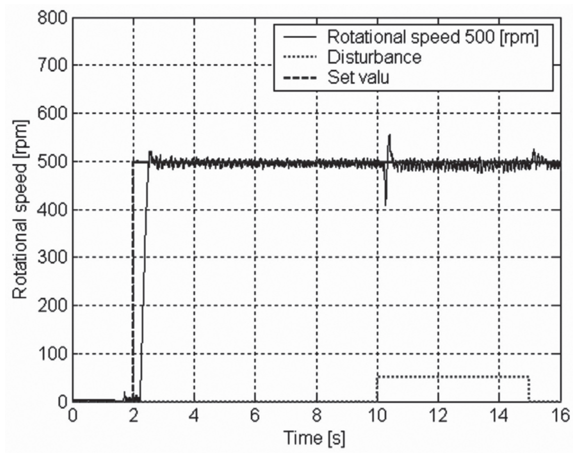

Fig. 11. Rotational speed with disturbances for a system with a learned fuzzy logic controller

In the first step the hydrostatic transmission was working without any load. The tests with a fuzzy controller were performed for three different sets of rotational speed values (Fig. 10): 300, 500, 700 rpm.

Afterwards the behaviour of a hydrostatic transmission was tested under the load applied as a step function. Rotational speed was taken to be 500 rpm and the load remained constant. Results are shown in Figure 11.

5. CONCLUSIONS

The study concerns the adaptive controller to control a hydrostatic transmission. The Sugeno model was employed to build a fuzzy logic controller. A great advantage of this model is that it uses just few rules to describes a highly nonlinear systems. Moreover, the controller designing is easy. The adaptive algorithm enables the tuning of controller's parameters. The learned fuzzy logic controller can successfully control the rotational speed of a hydraulic engine even though that system is nonlinear, which was confirmed experimental data. Application of an industrial controller with this algorithm will make it a more universal tool.

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