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Fuzzy Controller of Two-mass System

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Introduction

Electromechanical system as object of investigation comprises electrical and mechanical parts. Electromechanical power converter and its control system depend on electrical part as well as all moving masses coupled between them form mechanical part. Electromechanical system includes various mechanical chains with infinite or finite elasticity and clearance. Systems with infinite stiffness and without clearance compose single-mass system and are quite well analyzed. Systems with capability to deform chains are more complex. They are described by high order nonlinear differential equations, and without essential simplifying of problem they cannot be solved in analytical way. In these cases computer models for problem solving must be developed, using specialized software, and system responses simulated.

Some problems of two-mass system were considered in [1–7].

Oscillations in the two-mass electromechanical system raise great problem therefore reduction of that becomes the main task in the system development of. Different control methods in close loop and open loop systems are applied for this purpose [8, 9].

The paper presents closed loop model of two-mass electromechanical system with speed feedback and fuzzy logic controller.

At present Fuzzy logic is applied in various control aeries. It is used in conventional consumer products for example, washing machines. Fuzzy logic is applied in systems such as elevators, traffic control and software: medical diagnosis, securities, data compression as well as for control of electric drives and electric networks [10–13].

Fuzzy logic is a powerful and excellent analytical method with numerous applications in embedded control and information processing. Fuzzy provides a straightforward and easy path to describe or illustrate specific outcomes or conclusions from vague, ambiguous or imprecise information [14].

This paper considers some of the potential benefits of fuzzy logic controller application to control induction motor drive speed of two–mass system.

The stages of the development of a fuzzy logic controller using two input Takagi-Sugeno fuzzy model are presented.

The main task of this paper is implementation and optimization Fuzzy logic control algorithms in order to reduce speed oscillations and to cut down start up time.

In this work, the two-mass system model was developed using Simulink. The performance of the proposed closed loop control system with fuzzy logic controller is compared with uncontrolled system simulation results.

Fuzzy controller

The idea of fuzzy logic was born in 1965. Lofti A.Zadeh published a seminar paper on fuzzy sets, which was the birth of fuzzy logic technology. At the beginning fuzzy logic was strongly resisted, but step by step more studies had been performed [15].

First, the general structure of a fuzzy logic controller (FLC), or fuzzy controller (FC) for short, consists of three basic portions: the fuzzification unit at the input terminal, the inference engine built on the fuzzy logic control rule base in the core, and the defuzzification unit at the output terminal, as shown in Fig. 1.

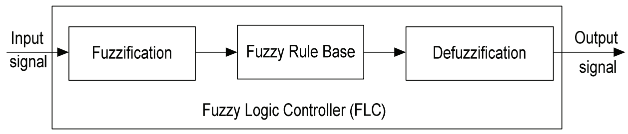

Fig. 1. General structure of a fuzzy logic controller

The fuzzification module transforms the physical values of the current process signal, the error signal which is input to the fuzzy logic controller, into a normalized fuzzy subset consisting of a subset (interval) for the range of the input values and an associate membership function describing the degrees of the confidence of the input belonging to this range.

Created Takagi-Sugeno fuzzy controller is a system with two inputs; single output, *e* and *de* are input variables, described as:

$$\begin{cases} e(t) = r - y(t), \\ de = \dot{r} - \dot{y}(t), \end{cases} \quad (1)$$

where *e(t)* is speed signal error, *r* is reference signal, *y(t)* is output signal and *de* is change of the error signal [16].

The fuzzy sets are designated by the labels: NL (negative large), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PL (positive large).

Gain coefficients k_d, k_p are used for tuning of Fuzzy controller.

Table 1. Linguistic Rule Table

de \ e	NL	NS	ZE	PS	PL
NL	ZE	PL	ZE	PL	ZE
NS	NS	ZE	ZE	PL	ZE
ZE	NS	NL	ZE	PL	PS
PS	ZE	NL	PL	ZE	PS
PL	ZE	NL	PS	NL	ZE

Simulation results

The model of electromechanical system with speed feedback signal is elaborated. Required speed value is maintained by fuzzy controller with two inputs. The first mass corresponds to the mass of motor rotor. Model of induction motor in synchronous reference frame with $q^e - d^e$ axis is considered in [17, 19]. Computer model is elaborated for a motor, whose parameters are presented in Table 2.

The second mass, attached to the motor is chosen freely. It is assumed as cylindrical shape body, fastened along mass center [20, 21].

Two-mass controlled system includes speed and torque reference signals; both those can be changed. Speed reference signal corresponds to nominal AC drive speed. In each experiment after 0.5 s, motor is loaded by 6 N·m load. Control signal is generated by Fuzzy controller. The stiffness of the second mass is 5000 N·m/rad. The model of controlled two-mass system is presented in Fig. 2.

Table 2. Parameters of the motor

Parameter	Value
Motor power, kW	2,2
Number of pole pairs	2
Phase voltage, V	230
Power factor	0,81
Rated torque, N·m	14
Rated current, A	5,14
Inertia, kg·m^2	0,0056

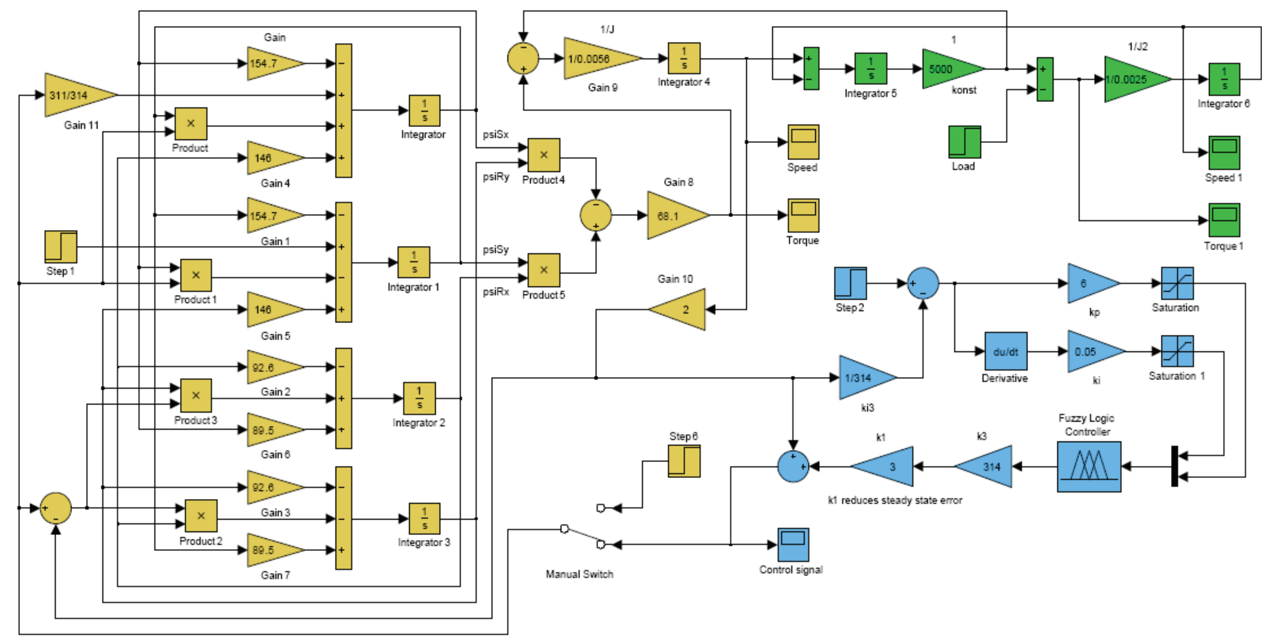

Fig. 2. Model of two-mass electromechanical system with fuzzy control

Block "step2" provides speed reference signal. Speed reference is compared with feedback signal. Error signal is fed to proportional and derivative controllers, designated respectively "k_p" and "k_i". (Fig. 2)

Fig. 3 shows simulation results of induction motor starting transients in uncontrolled system and system with fuzzy logic controller. It is seen, that at the start up time, speed of an uncontrolled system oscillates. After load is applied, motor speed reduces and reaches value smaller than rated, while in the controlled system speed settles down without oscillations and after loading its value remains almost the same with negligible oscillations of small amplitude, what can be neglected.

Fig. 4 shows the speed transients of the second mass. The speed transients are very similar to the induction motor transient process, but there are extra speed oscillations in the uncontrolled system, which occur because of the mass coupling stiffness. In this case fuzzy controller maintains a constant reference speed nevertheless, that for speed feedback signal motor speed is used.

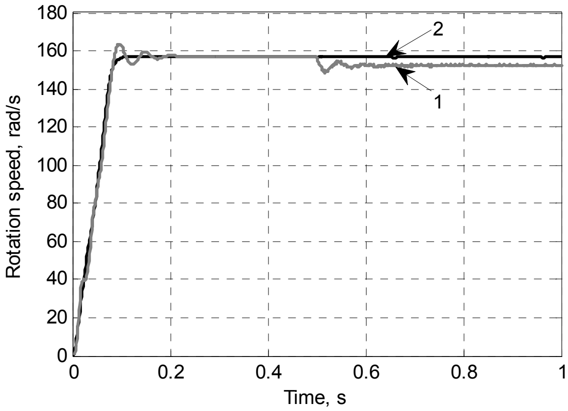

Fig. 3. Comparison of speed starting transients of induction motor in two-mass system: 1 – uncontrolled system; 2 – system with fuzzy controller

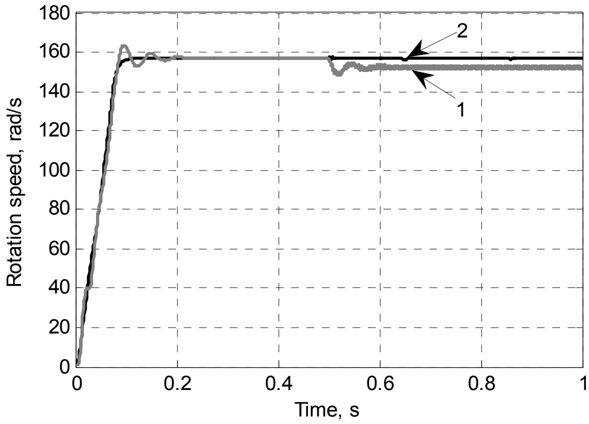

Fig. 4. Comparison of speed values of second mass in two-mass system: 1 – uncontrolled system; 2 – system with fuzzy controller

Fig. 5 shows comparison of torque developed by motor in the uncontrolled and controlled system. Simulation results show that in controlled system maximal values of torque starting transients are smaller by 30%. They also have smaller amplitude of oscillations.

Reliable operation of system with Fuzzy controller is shown in Fig. 6 where single-mass (motor) and two-mass systems speed transient are presented. Control signal of Fuzzy controller is shown in Fig. 7.

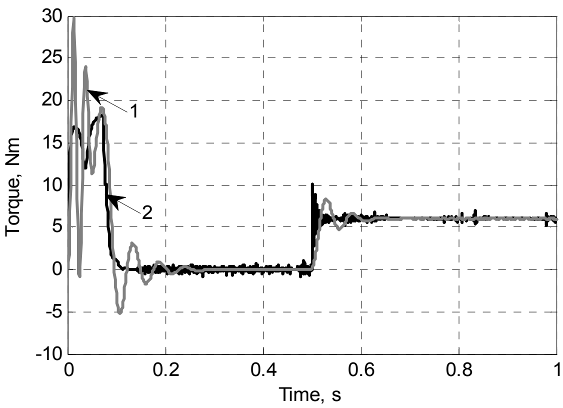

Fig. 5. Comparison of torque value of induction motor in two-mass system: 1 – uncontrolled system; 2 – system with fuzzy controller

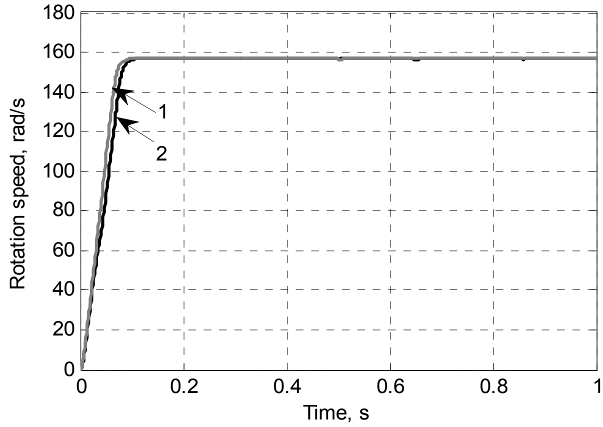

Fig. 6. Comparison of speed values of induction motor in fuzzy controlled system: 1 – single-mass system; 2 – two-mass system

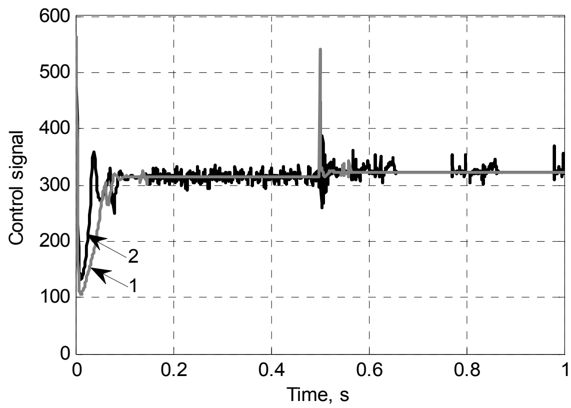

Fig. 7. Comparison of control signal of induction motor in fuzzy control system: 1 – single-mass system; 2 – two-mass system

Finally it can be concluded that for keeping very similar value of motor speed in single-mass and two-mass system Fuzzy controller generates different output signals.

Conclusions

The Simulink model of close loop system with fuzzy controller for control of electromechanical two-mass system was developed and simulation results were analyzed.

Settling time of speed of two-mass fuzzy logic controlled system is 0.1 s. Speed response has dead-beat mode without overshoot.

The speed of motor in controlled system after loading remains constant (or almost constant).

As the feedback signal is used the motor speed, nevertheless the speed of the second mass also has dead-beat mode without overshoot.

Fuzzy logic control of two-mass system specifies dead-beat speed response which almost does not depend on the load.

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The paper presents the simulation results of the close loop two-mass electromechanical system with Fuzzy controller with feedback signals proportional to speed error and its derivative. Speed of motor is controlled by signal, keeping constant voltage and frequency ratio. Simulink model of fuzzy controlled two-mass electromechanical system is elaborated. The starting transients of the system at no load and afterwards it loading are presented. Ill. 7, bibl. 21, tabl. 2 (in English; abstracts in English and Lithuanian).

S. Juraitis, R. Rinkevičienė, J. Kriaučiūnas. Dvimasės sistemos su neraiškiosios logikos reguliatoriumi tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 10(116). – P. 3–6.

Pateikiami uždarosios dvimasės elektromechaninės valdymo sistemos su neraiškiosios logikos reguliatoriumi bei greičio ir jo išvestinės grįžtamaisiais ryšiais tyrimo rezultatai. Pavaros greitis reguliuojamas valdymo signalu, palaikančiu pastovų variklio įtampos ir dažnio santykį. Sudarytas dvimasės elektromechaninės sistemos su programų paketu „Simulink“ matematinis modelis su neraiškiosios logikos reguliatoriumi sinchroniniu greičiu besisukančioje koordinačių sistemoje. Pateikiami pavaros paleidimo proceso imitacijos rezultatai paleidžiant neapkrautą variklį, o paskui jį apkraunant. Il. 7, bibl. 21, lent. 2 (anglų kalba; santraukos anglų ir lietuvių k.).