A SIMPLE FUZZY CONTROLLER STRUCTURE

Pavol FEDOR, Daniela PERDUKOVÁ
Department of Electrical Drives and Mechatronics, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Letná 9, 042 00 Košice, Slovak Republic, E-mail: Pavol.Fedor@tuke.sk, Daniela.Perdukova@tuke.sk

SUMMARY

The paper deals with the development of a simple fuzzy controller structure. Compared to the common structure it does not require information on the derivation of the controlled system output variable because obtaining of information on derivation is often difficult or too costly. A possible fuzzy regulator structure only requires information about the output variable and its integrals for its operation. The properties of the proposed controller have been verified on two types of fuzzy controllers: Mandami fuzzy controller and Sugeno fuzzy controller. The presented controller shows dynamic properties suitable for all the fundamental electric drive control requirements. In view of speed control the presented controller has a PI character but from point of view of position control the presented controller has a PD charakter. Its properties are verified on the basic operational states of a drive with a separately excited DC motor by simulation with the MATLAB programming package. The methodology of its design can also be applied to other types of controlled systems.

***Keywords**: Mamdani fuzzy controller, Sugeno fuzzy controller, simple fuzzy controller structure, controlled system, separately excited DC drive, dynamic properties, fundamental electric drive, dynamic part, static part, human language description*

1. INTRODUCTION

In technical practice, the systems which analytical description is very complicated and it is very hard to build up and also to determine its parameters, can occur very often. In these cases the untraditional methods for modelling are used very often. In recent time fuzzy logic methods present the most promising areas in the modern system control theory.

The requirement for the application of a fuzzy controller arises mainly in situations where:

- the description of the technological process is available only in word form, not in analytical form
- it is not possible to identify the parameters of the process with precision
- the description of the process is too complex and it is more reasonable to express its description in plain language words
- the controlled technological process has a „fuzzy" character, i.e. its behaviour is not fully unequivocal under precisely defined conditions, or it is not possible to precisely define these conditions.

Standard fuzzy controller structures known from literature require for their input besides the proper output variable also its derivation (to be precise, the control deviation and its derivation). Concurrent obtaining of information on derivation is often difficult or too costly. For example, with electric drives the derivation physically represents electric current, or the dynamic moment (angular acceleration) of the motor. Obtaining the motor torque data is costly and technically demanding, the current in drives that are usually powered by static inverters often has a markedly cut and discontinuous character and is difficult to implement for processing in the controller without further adjustment (e.g. filtering). It is therefore necessary to select such variables for the electric drive fuzzy controller that are technically easily obtainable and that can be processed with sufficient accuracy and promptness in real time.

The presented paper shows a possible fuzzy regulator structure that only requires information about the output variable and its integrals for its operation. Compared to the common structure it does not require information on the derivation of the controlled system output variable because obtaining of information on derivation is often difficult or too costly. With electric drives this means the data on the angular velocity and position of the rotor. This data is easy to obtain and process, e.g. by means of incremental sensors.

2. DESCRIPTION OF PROPOSED CONTROLLER

The performance of a fuzzy controller is defined by the dependence between the controller intputs and outputs, this dependance being described not by analytical equations, but by rules of the following type:

IF $\boldsymbol{e_1}$ is .. AND $\boldsymbol{e_2}$ is .. AND $\boldsymbol{e_3}$ is .. THEN $\boldsymbol{u}$ (or $\boldsymbol{\Delta u}$) is (1)

In these rules, close to human language description, $\boldsymbol{e_i}$ is ith input variable and $\boldsymbol{u}$ is the output of the fuzzy controller static part (or $\boldsymbol{\Delta u}$ is the gain of the output variable).

As the operation of a fuzzy controller is based on qualitative knowledge about the system being controlled, it is first important to identify these properties. Our selection of the fuzzy controller input variables is based on Fig. 1 which represents the response of the controlled system output $\boldsymbol{y}$ to the jump of the desired value of control variable $\boldsymbol{w}$.

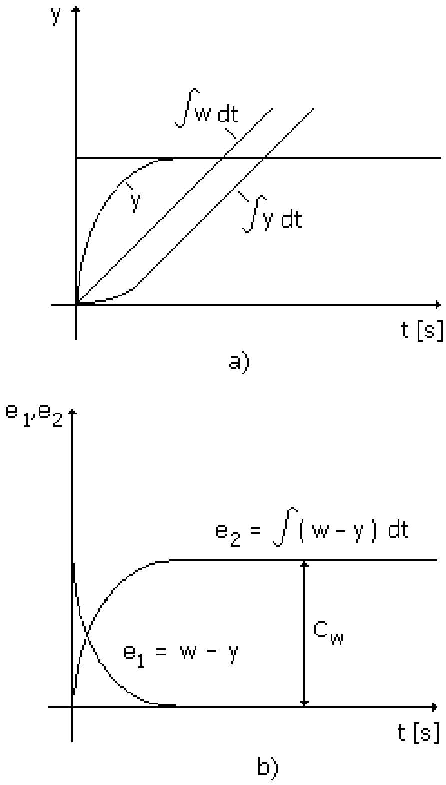


Fig. 1 Desired transient characteristics of the controlled system

In case we do not wish to use the derivation of ***e*** as one of the controller inputs, it is necessary to find some other variable that can provide us with another state information about the controlled system. It can be the integral from the control deviation. As Fig. 1 shows, this integral settles at the constant value C_w which, for the concrete case, will assumingly be dependent on the magnitude of ***w***. Let us therefore select e_1 and e_2 for the fuzzy controller input variables, according to:

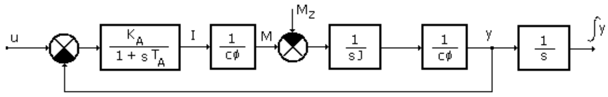
$$e_1 = (\mathrm{w} - \mathrm{y})\,.\,\mathrm{k}_1 \quad (2)$$

$$e_2 = \left(\int (\mathrm{w} - \mathrm{y})\,\mathrm{dt} - \mathrm{C}_w\right).\,\mathrm{k}_2 \quad (3)$$

We can then achieve the state of the controlled system shown in Fig. 1 for example by trying to achieve the steady state for variable $e_2 = 0$, or $e_2 =$ const. by a suitable set of rules. In this state it then applies that $e_1 = w$, which in fact means that the controlled system output variable has reached the desired value. The constants k_1 and k_2 serve for the suitable standardization of fuzzy controller inputs for the range <-1,1>.

3. CONCRETE ESTABLISHMENT OF A DC DRIVE FUZZY CONTROLLER

The verification of the performance and properties of the fuzy controller from the previous chapter is carried out on a drive with a separately excited DC motor, according to Fig. 2.



u – control voltage
y – standardized angular velocity of drive
M_z – load torque
J – moment of inertia of drive
Cϕ - excitation constant
K_A – armature amplification
T_A –armature time constant

Fig. 2 DC drive block diagram

Standard structure of DC drive fuzzy controller is shown in Fig. 3.

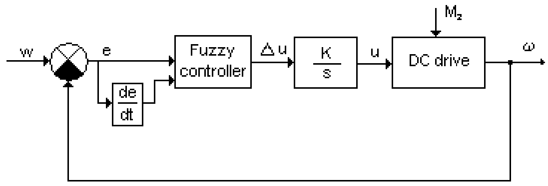


Fig. 3 Standard PI fuzzy structure of controlled DC drive

The structure of the controlled drive with fuzzy controller from Chapter 2 above is shown in Fig. 4. As constant C_w only effects a shift in e_2 that is insignificant in steady state, we can consider it to be equal to zero.

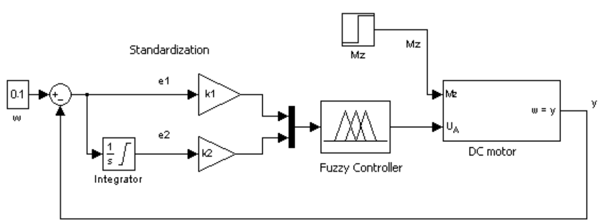


Fig. 4 Structure of controlled DC drive with fuzzy controller

The structure of the previous type of controller contained first of all a static „fuzzy“ section, the output of which was usually (with the PI type) a gain of ***Δu***. In the presented structure there is first a dynamic section in the form of a continuous PI member, and then the static non-linear fuzzy section of the controller.

3.1. Standardization of e_1 and e_2

Following establishment of the controller structure, it is necessary to determine the values of standardizing constants k_1 and k_2. One of the ways of doing this is to measure the maximum values of e_1 a e_2 at such jump ***u*** of the armature which does not yet result in exceeding the maximum allowed

ISSN 1335-8243 © 2005 Faculty of Electrical Engineering and Informatics, Technical University of Košice, Slovak Republic

armature current. Such suitable selection of constants k_1 and k_2 significantly facilitates the establishment of further fuzzy controller parameters.

3.2. Design of Sugeno Type Controller

This type of controller is suitable in case there is a database of several points available describing the relation between a certain state of inputs e_1 and e_2 and a corresponding suitable control intervention u. By means of the MATLAB programme tools it is possible to set up a relatively simple fuzzy controller from this database. Fig. 5 shows this type of controller with two rules which fuzzyficates input variables into two ranges.

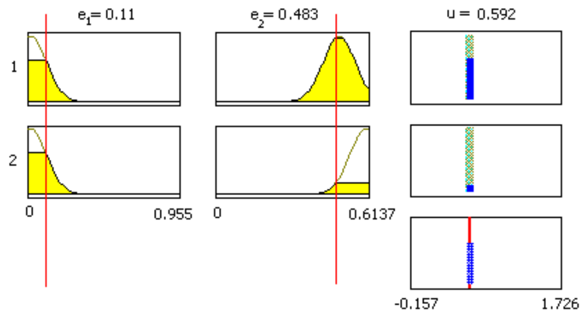


Fig. 5 Example of Sugeno type fuzzy controller structure for DC drive

Fig. 6 shows the response of this controller to various jumps of the desired value w as well as error (motor load torque) adjustment.

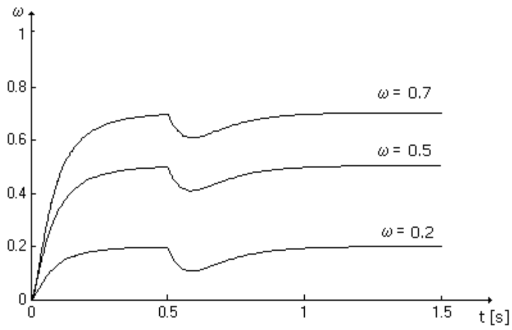


Fig. 6 Sugeno type fuzzy controller dynamics

3.3. Design of Mamdani Type Controller

Another way of setting up a fuzzy controller is the „classical“ way, i.e. transcription of the linguistic rules for its behaviour into a Mamdani form of controller. Consider the basic metarule for the design in the form „The greater the deviation of e_1 or e_2 from zero is, the greater the output u must be (i.e. active intervention into the controlled system)“. Let us further divide each of the variables e_1, e_2, u into three ranges – **P** (positive), **Z** (zero), **N** (negative). Applying the simplest triangular membership functions enables us to describe its performance by six rules, as illustrated in Fig. 7.

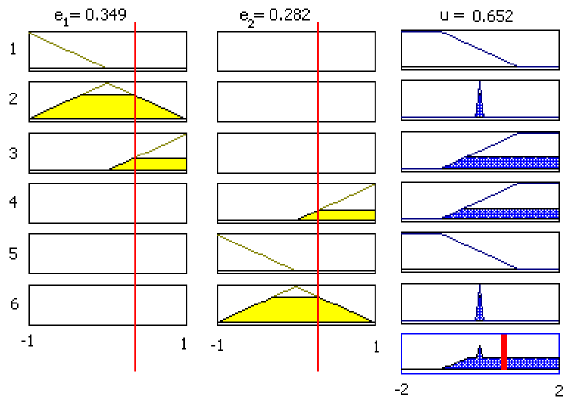


Fig. 7 Mamdani type fuzzy controller

Fig. 8 illustrates the response of this controller to various jumps of the desired value w as well as error adjustment.

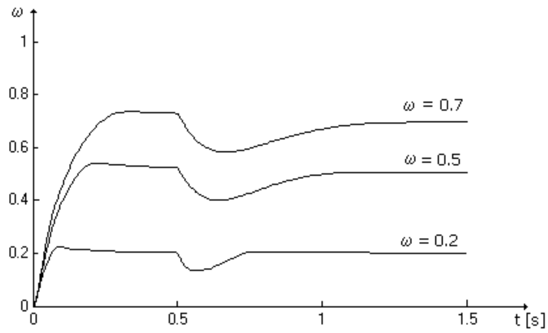


Fig. 8 Mamdani type fuzzy controller dynamics

Fig. 9 illustrates the robust properties of the designed controller which had been verified on the half-size and double-size change of the drive´s moment of inertia.

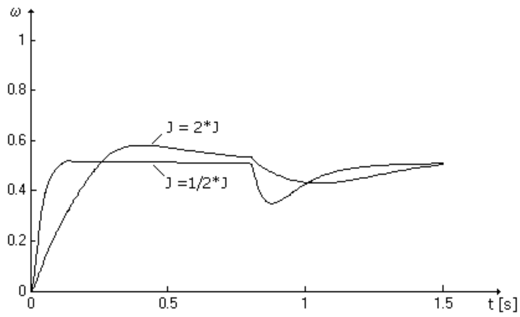


Fig. 9 Effect of moment of inertia change upon control dynamics

4. DISCUSSION AND CONCLUSION

The authors have presented a DC drive fuzzy controller structure and have verified the drive properties at jump of control or load by simulation. Comparison with the common fuzzy controller types known from literature has shown the following differences:

- The presented controller does not require obtaining data about the derivation of the drive´s angular velocity.
- In view of speed control the presented controller has a PI character, which is clear first from its structure and second from the responses to the load torque jump at which the control deviation in steady state is equal to zero.
- The structure of the previous type of controller contained first of all a static „fuzzy“ section, the output of which was usually (with the PI type) a gain of Δu. In the presented structure there is first a dynamic section in the form of a continuous PI member, and then the static non-linear fuzzy section of the controller.
- From point of view of e_2 control (which physically corresponds to position control) the presented controller has a PD character, which is clear from the responses to the jump in load torque, at which the control deviation in steady state has non-zero value.

The presented controller shows dynamic properties suitable for all the fundamental electric drive control requirements, as confirmed by the presented simulation results. The methodology of its design can also be applied to other types of controlled systems.

Parameters for simulation

$K_A = 0.625$ Ω-1 $T_A = 0.01$ s
$c\phi = 0.7$ Vs J = 0.03 kgm2
$k_1 = 1$ $k_2 = 10$

REFERENCES

[1] Novák, V.: Fuzzy sets and their applications. Prague, SNTL 1990.

[2] Vysoký, V.: Fuzzy control. Prague: ČVUT Publishing House, 1996.

[3] Fedor, P. - Perduková, D.: A DC Drive Fuzzy Model. IJECE – Iranian Journal of Electrical and Computer Engineering, Vol.2, No.1, Winter-Spring 2003, pp.11-16, ISSN 1682 - 0053

[4] Wang, L.X.: Fuzzy systems are universal aproximators. In: Proc IEEE Int. Conf. on Fuzzy Systems. USA: San Diego, 1992, pp. 1163-1170.

[5] Wang, L.X. – Mendel, J.M.: Generating fuzzy rules by learning from examples. IEEE Trans. Systems, Man and Cybernetics, 22, pp. 1414-1427, 1992.

[6] Takagi, T. – Sugeno, M.: Fuzzy identification of systems and its application to modeling and control. IEEE Trans. Systems, Man and Cybernetics, 15, 1985, pp. 116-132.

[7] Zadeh, L.A.: Outline of a new approach to the analysis of complex systems and decision processes. IEEE Trans. Systems, Man and Cybernetics, 1, pp. 28-44, 1973.

[8] P. Brandštetter: AC control drives. Modern control methods. Ostrava: VŠB TU, 1999.

[9] S. J. Dodds, J. Vittek: Robust Position Control with induction Motor. In: Proc. of PEMC´2000 Conference, Košice, pp. 6.36-6.40

[10] M. Setnes, R. Babuška, H. B. Verbruggen: Complexity reduction in fuzzy modeling, IMACS Journal Mathematics and Computers in Simulation, 46, pp 507-516, 1998.

[11] Tanaka, K. - Sugeno,M.: Stability analysis and design of fuzzy control systems, in: Fuzzy Sets and Systems, 45, pp. 135-156, 1992.

BIOGRAPHY

Daniela Perduková was born in 1960.. She graduated from the Faculty of Electrical Engineering, Technical University Kosice, in 1984. She received her Ph.D degree in Electrical Drives and Electric Traction from the same university in 1995. She works at the Department of Electrotechnics, Mechatronics and Industrial Engineering of the Faculty of Electrical engineering and Informatics at Technical University of Kosice as Associate Professor. She has extensive experience in installing of control and visualization systems in industry. In theoretical area her reseach interest includes new control structure development for continuous line control, loading of logic programmable automation in control system, modelling of technological processes, their monitoring and technological process visualization.

Pavol Fedor was born in Kosice in 1956. He received the M.Sc degree in Technical Cybernetics from Technical University of Košice in 1980 and Ph.D degree in 1986 at the same University. During 1980 – 1988 he served as an Assistant Professor of Electrical Drives at the Technical University of Košice at the Department of Electrotechnics, Mechatronics and Industrial Engineering. He currently works as an Associate Professor of Power Electronics at the same university, During 1996 – 1998 he was involved in research for continuous line control in USS firm, Kosice. He has extensivel experience in installing of control systems in industry. In theoretical area his current research activities are focused on the development of control structures by means of Lyapunov´s second method for electrical drives and multi-input multi-output systems.