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Servo-Motor Speed Control Using Fuzzy Logic Controller

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Abstract: The position control is an interesting term used in control system Engineering. Several control algorithms can be applied in that application. This paper discusses the position control of a servo-motor using fuzzy logic controller (FL). The structure and modeling of the servo motor is discussed in details. One of the main problems found when applying other control methods, is the non-accuracy issues due to nonlinear properties. The results show that fuzzy logic controller can help solve this problem. The paper presents design and implementation of the control algorithm, which is carried out by fuzzy logic controller. Application of fuzzy logic controller on the servo motor speed control is done using MATLAB simulation. The obtained results using fuzzy logic controller are compared with the results obtained by applying proportional–integral–derivative (PID) controllers, which show that the unit step response overshoot, time rise and time settling are less when using FL controller for the servo- motor speed control.

Keywords: servomotor, fuzzy logic, PID controller, fuzzy inference.

1. INTRODUCTION

Several control system algorithms have been applied in control system engineering, one of the interesting terms is control position. Control Position of servo motor exists in a great variety of automatic processes. However, the performance of servo motor is influenced by uncertainties such as nonlinear properties, mechanical parameter variation and external disturbance. From a practical point of view, complete information about uncertainties is difficult to acquire in advance. To deal with these uncertainties, much research has been carried out in recent years to apply various approaches in the position control when it occurs [C.C.kung and. H.Su, 2005]. The fuzzy logic control is an accurate method to be used for this target.

The other methods such as PID controller possesses a good performance, but not adaptive enough [Jin Z, Shuyn W and Jindbang, 2005]. This is apparent when the load is changed, where the original controller generally cannot maintain the design performance, and thus should be re-designed for the new system conditions. An FL controller can adopt expert knowledge into regulations of control system, which can be used to determine the output value by logical inference also does not need precision system model and has high robust ability. In recent years, fuzzy controllers have been widely developed, and a variety of methods have been proposed to improve the performance of fuzzy controller [Li-Xin Wang, 1999]. D.W. Novotny and T.A. Lipo, (1996) discuss the vector control and Dynamics of AC Drives. The dynamic simulation of electric machinery using Matlab/Simulink is presented by Chee-MunOng, (1998). Where, AC drives and intelligent control methods are discussed byBimal K. Bose, (2002) and Vinod Kumar, R.R Joshi, (2005).

2. THE SERVO MOTOR

The servo motor is an automatic device that uses error sensing feedback to correct the performance of a mechanism. The term when correctly applies only refers to the systems where the feedback or error correction signals help to mechanical control position or other parameters. A common type of servo provides control position. Servos are commonly electrical or partially electronic, using an electric motor as the primary means of creating mechanical force.

Other types of servos use hydraulics, pneumatics, or magnetic principles. Usually, servos operate on the principle of negative feedback, where the control input is compared to the actual position of the mechanical system as measured bya transducer at the output. Any difference between the actual and wanted values (error signal) is amplified and used to drive the system in the direction necessary to reduce or eliminate the error. Servo motors are available as AC or DC motors. Servo motors are used in automatic machine tools, satellite tracking antennas, remote control airplanes, automatic navigation systems on boats and planes, and antiaircraft gun control systems [Chechunor, Aziehailma, Bintiche and Chekumelor, 2012].

2-1 Servo Motor Mechanism:-

As the name suggests, a servomotor is a servo mechanism, more specifically, it is a closed-loop servomechanism that uses position feedback to control its motion and final position. The input to its control is through a signal, either analogue or digital, representing the position commanded for the output shaft. The motor is paired with some type of encoder to provide position and speed feedback. In the simplest case, only the position is measured. The measured position of the output is compared to the command position, the external input to the controller. If the output position differs from that required, an error signal is generated which

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then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stops. The very simplest servomotors use position-only sensing via a potentiometer and bang-bang control of their motor; the motor always rotates at full speed (or is stopped). This type of servomotor is not widely used in industrial motion control, but they form the basis of the simple and cheap servos used for radio-controlled models. More sophisticated servomotors measure both the position and also the speed of the output shaft,they may also control the speed of their motor, rather than always running at full speed [Chechunor, Aziehailma, Bintiche and Chekumelor, 2012].

2-2 Servo Motor Modeling:-

The equivalent circuit diagram of servo motor is presented in Figure (1) below. The armature is modeled as a circuit with resistance R_a connected in series with an inductance, L_a and a voltage source $V_b(t)$ representing the back emf in the armature when the rotor rotates [Chechunor, Aziehailma, Bintiche and Chekumelor, 2012].

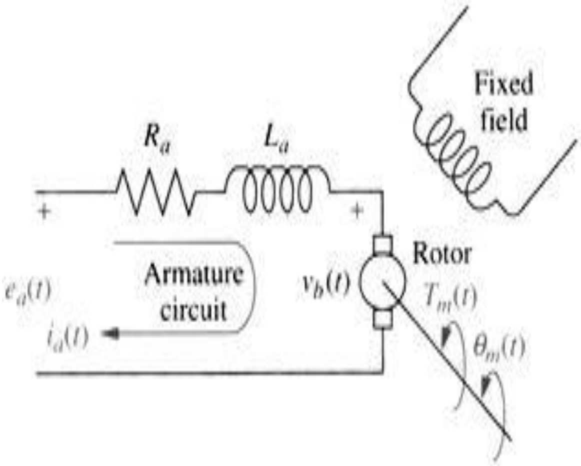

Figure (1): Servomotor system

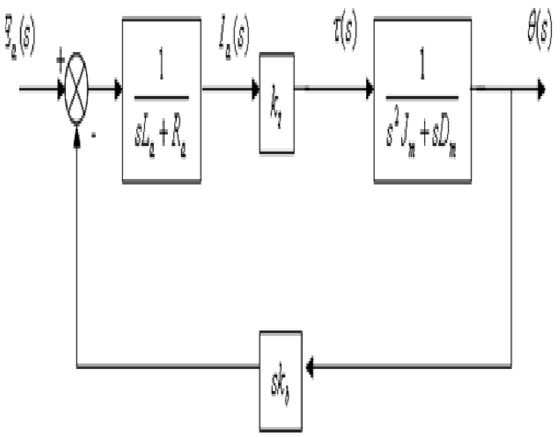

Figure (2): Schematic diagram of the servomotor

Using Kirchhoff's Voltage Law and assuming that the inductance La can be neglected, the supply voltage $E_a(t)$ can be expressed by [Chechunor, Aziehailma, Bintiche and Chekumelor, 2012]:

$$E_a(t)=I_a(t)R_a+V_b(t) \qquad (2\text{-}1)$$

Since the armature current is rotating in a magnetic field, its back electromotive force is proportional with speed. Therefore:

$$Vb(t) = K_B\, s\, \Theta_m(t) \qquad (2\text{-}2)$$

The developed torque T(t) on a motor shaft having total moment of inertia J_m and total viscous friction B is given by:

$$T(t) = J_m\, s^2\, \Theta_m(t) + B\, s\, \Theta_m(t) \qquad (2\text{-}3)$$

The developed motor output torque for this servo motor can be given by:

$$T(t) = K_T I_a(t) \qquad (2\text{-}4)$$

From equation (2-3), (2-4) it is found that:

$$K_T I_a(t) = J_m\, s^2\, \Theta_m(t) + B\, s\, \Theta_m(t) \qquad (2\text{-}5)$$

Substituting equation (2.1) into equation (2.5) it is found that:

$$K_T E_a(t) – V_b(t) = J_m\, s^2\, \Theta_m(t) + B\, s\, \Theta_m(t) \qquad (2\text{-}6)$$

By simplifying equation (2-6), the transfer function can be obtained as Follows:

$$\left(\frac{E_a(t)-V_b}{R_a}\right) = J_m s^2 \Theta m(t) + B\, s\, \Theta m(t) \qquad (2\text{-}7)$$

$$\frac{\Theta m\,(t)}{Ea(t)} = \frac{K_T}{JmR_a s^2 + s(B\,R_a + K_T K_B)} \qquad (2\text{-}8)$$

3. FUZZY LOGIC CONTROLLER

Fuzzy Logic Controller constitutes a way of converting linguistic control strategy into an automatic by generating a rule base which controls the behavior of the system. Fuzzy logic provides a remarkably simple way to draw definite conclusions from vague ambiguous or imprecise information. It is suitable for applications such as the speed control of a dc motor which has non linearities [Chechunor, Aziehailma, Bintiche and Chekumelor, 2012]. FL controllers have some advantages compared to other classical controller such as simplicity of control, low cost and the possibility to design without knowing the exact mathematical model of the process. Fuzzy logic incorporates an alternative way of thinking which allows modeling complex systems using a higher level of abstraction originating from knowledge and experience. Fuzzy logic can be described simply as "computing words rather than numbers" or "control with sentence rather than equations". The applications of fuzzy logic are usually for household appliance such as washing machine and rice cooker. Fuzzy also been used in industrial process such as

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cement kilns, underground trains and robots [S.R. Khuntia, K.B. Mohanty and S. Panda and C. Ardi, 2010].

3-1 Structure of Fuzzy Logic Controller:-

There are specific components characteristic of a fuzzy controller used to support a design procedure. Figure (3) shows the controller between the preprocessing block and post processing block.

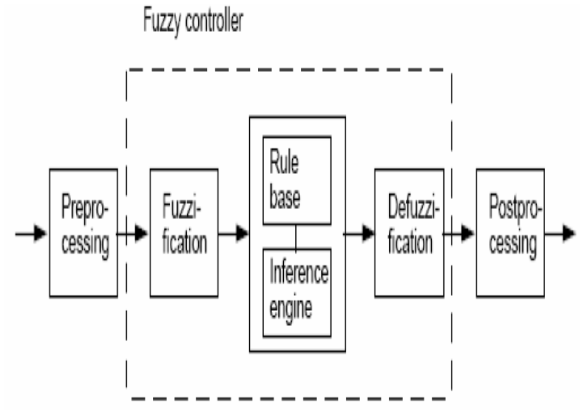

Figure (3):Fuzzy Logic Control Structure

Developing a Fuzzy logic control and applying it to a control problem involves the following steps:

1. Fuzzification
2. Fuzzy rule evaluation (fuzzy inference engine)
3. Defuzzification

The total fuzzy inference system is a mechanism that relates the inputs to a specific output, or set of outputs. First, the inputs are categorized linguistically (fuzzification), then the linguistic inputs are related to outputs (fuzzy inference), finally all the different outputs are combined to produce a single output (defuzzification) [Boumediene, Allaoua, AbdellahLaoufi, Gasbaoi, and AbdessalamAbderrahmani, 2009].

4. PID CONTROLLER

PID controller is a generic of feedback widely used in industrial control systems. It is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. It attempts to minimize the error by adjusting the process control inputs.

The PID controller calculation algorithm involves three separate constant parameters, it is accordingly called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on the current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element. The block diagram of the closed loop servo motor with PID controller is shown in figure (4) below [Mohamed Farid Bin Mohamed Faruq, 2008].

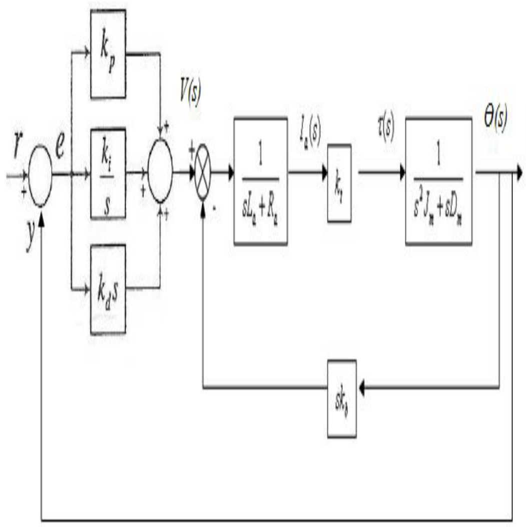

Figure (4): The block diagram of the closed loop servo motor with PID controller.

The controller output V(t), which is fed to servo motor armature is given by the following equation:

$$V(t) = K_p\, e(t) + K_i \int_0^t e(t)\, dt + K_d \frac{de(t)}{dt} \quad (4\text{-}1)$$

Using Laplace transformation, the transfer functions of PID controller is as follows [Mohamed Farid Bin Mohamed Faruq, 2008]:

$$\frac{V(s)}{E(s)} = K_p + \frac{Ki}{s} + K_d s \quad (4\text{-}2)$$

Assuming that, Kp = K, $K_i = \frac{K}{t_i}$ and $K_d = K\, t_d$ the transfer function of the PID controller can be as follows:

$$K(s) = k\, t_d\, s^2 + s + k\, s\, t_d \quad (4\text{-}3)$$

5. SIMULATION RESULTS

The speed control of a servomotor using a fuzzy logic controller and PID controller is done. The results are obtained using MATLAB with unit step response. The data of the used servomotor (case study) is presented in table (1) below.

Table (1) the parameters for servo motor:

K_T (N.m/A) = 0.121
K_B [V/(rad/s)] = 0.121
R_a (Ω) = 2.23
B [N.m/(rad/s)] = 0.0000708
J_m (kg.m2) = 0.00006286
K_p = 15
K_i = 5
K_d = 0.5

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When the parameters in table (1) are substituted in equation (2-8), the transfer function of the servomotor is found as follows:

$$\frac{\Theta_m(t)}{E_a(t)} = \frac{863.19}{s^2+105.58\,s} \qquad (5\text{-}1)$$

The step unit response of the servo motor with fuzzy logic controller and PID controller are shown in figures (5) and (6) respectively.

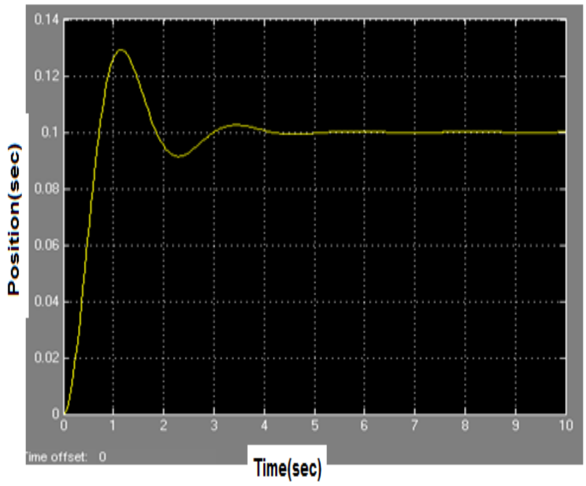

Figure (5): Unit step response of FL controller for speed control of the servo motor.

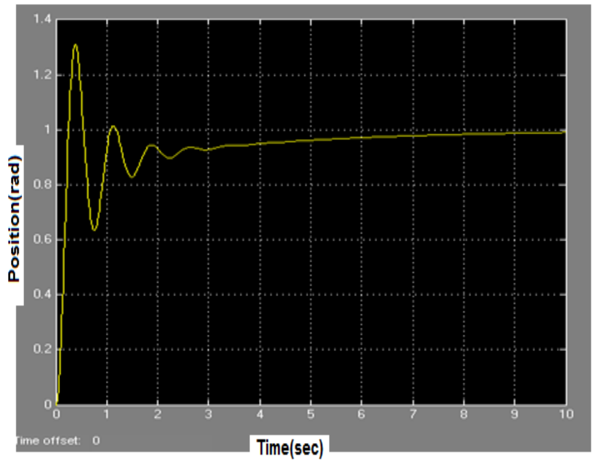

Figure (6): Unit step response of PID controller for speed control of the servo motor

6. CONCLUSION AND DISCUSSION

As mentioned above many methods are available for servo motor speed control. Here the use of FL controller is discussed with unit step response. To show the accuracy of FL controller, the obtained results are compared with PID controller ones. The overshoot, rise time and settling time, for both controllers, are determined; these are presented below in tables (2), (3) and (3) respectively.

Table (2); Overshoots of the FL and PID controllers

Controller	Overshoot MP
FL	1.24
PID	1.28

Table (3); Rise time of the FL and PID controllers

Controller	Rise time (sec)
FL	0.4
PID	1.2

Table (4); settling time of the FL and PID controllers

Controller	Settling time (sec)
FL	6.4
PID	9.8

The tables above show that the overshoot, rise time and settling time are found to be superior with the fuzzy logic controller when compared with PID controller.
Although the results show there is preference in using FL controllers in position control for the servo motor, there are however some problems in FL controller application, for example; lack of a systematic design methodology and the difficulty in predicting the stability and robustness of controlled system.
So modern techniques such as state space method, space vector method and artificial neural networks can be used for servo motor speed control, which may give better results.

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