Developing the Hybrid Stepper Motor Model for Tracking Purpose Using New Methodology

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Abstract. Most control systems are working on the measurement coordinates and trajectories of dynamic targets in the space need to particular type of motor to meet the accuracy. It has demanding requirements for tracking the performance of the system. The currently used different soft computing techniques for step response enhancement of hybrid stepper motor are used to build up a model using MATLAB software package. The objective of the present paper is to use PSD fuzzy controller to enhance the performance of the open loop control system to control the speed and position of the hybrid stepper motor performance. It was represented by 2DOF with a fuzzy controller and received an excellent response and good result. The difficulties are great and real time implementation of control actuation the controlling of position of hybrid stepper motor and to improve motors efficiency. The fieldoriented for a PM stepper motor application is presented in order to demonstrate the effectiveness for this real time embedded controller, t the proposed control algorithm will realize better rise time and less overshoot better and detailed analysis is carried out to confirm the viability of the proposed system.

1. Introduction

Stepper motors have been found a wide range of applications in machines and devices where robustness, accuracy and small size at a low cost are needed. The stepper motor can be operated in three different stepping modes namely full-step and micro step. Micro stepping has many advantages compared with other modes of excitation. An open loop position controlled stepper motors are well suitable for more application, but they show a poor performance with respect to very precise motion control and high dynamic requirements. Micro stepping is used in applications that require accurate position.

Fuzzy logic control is used in widespread system nowadays. It's an automatic control and a self acting mechanism that controls and objects in accordions with a desired behavior. Figure 1 shows the block diagram of the controller system. The two inputs of the fuzzy controller are the error e and change of error Δe [1]. Advantages of fuzzy control such as fast input response, short transition process, flexible, easy computation.

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All modern control for optimization purpose we need to create a special type of controller to adapt the entire control system. PSD fuzzy logic controller is a new type of controller used in the model to track the reference signal, it consists of combined of 2DOF PID with fuzzy controller. It realizes: (i) improved stability, (ii) good response, (iii) simple control configuration, and (iv) accurate result.

The main objective of this paper is to develop the required linear motor model in the control systems that require high accuracy by using the focus and the feedback with a new type of controller called fuzzy PSD to solve the problem of non-linear model and get the best response and minimize the error.

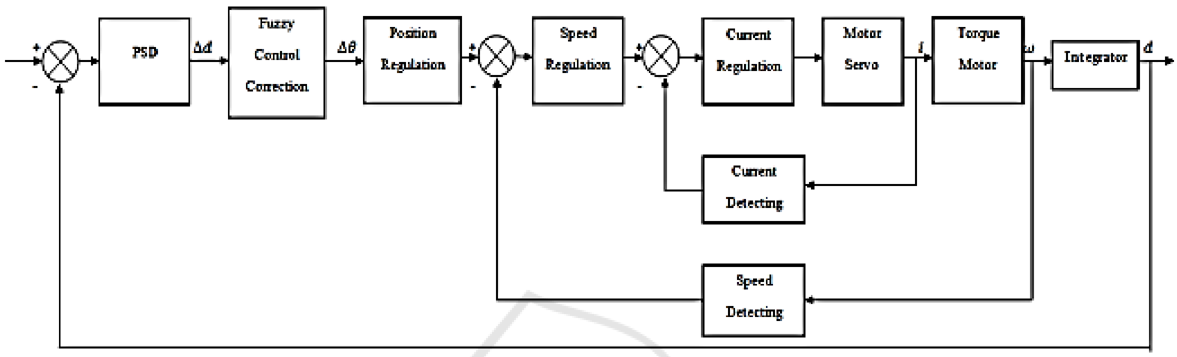


Figure 1. Block diagram of proposed model.

The application is developed as a Simulink model and consists of the controlled subsystem (stepper motor and the controller [2], presented in figure 1.

2. Methodology

In this paper, the FOC method was applied to the hybrid motor model used for tracking purposes and was connected with a new type of controller (PSD Fuzzy Controller) for the same purposes and park transformation applied with feedback loops.

2.1. Modeling of PSD fuzzy controller

The PID Controller (2DOF) block generates an output signal based on the difference between a reference signal and admeasured system output. Figure 2 illustrates PSD fuzzy controller.

The block computes a weighted difference signal for each of the proportional, integral, and derivative actions according to the setpoint weights you specify. The block output is the sum of the proportional, integral, and derivative actions on the respective difference signals, where each action is weighted according to the gain parameters. A first-order pole filters the derivative action. Controller gains are tunable either manually or automatically. Automatic tuning requires Simulink Control Design software (PID)the sum of the proportional, integral, and derivative actions on the respective difference signals, where each action is weighted according to the gain parameters. A first-order pole filters the derivative action. Controller gains are tunable either manually or automatically.

Automatic tuning requires Simulink Control Design software (PID Tuner or SISO Design Tool).

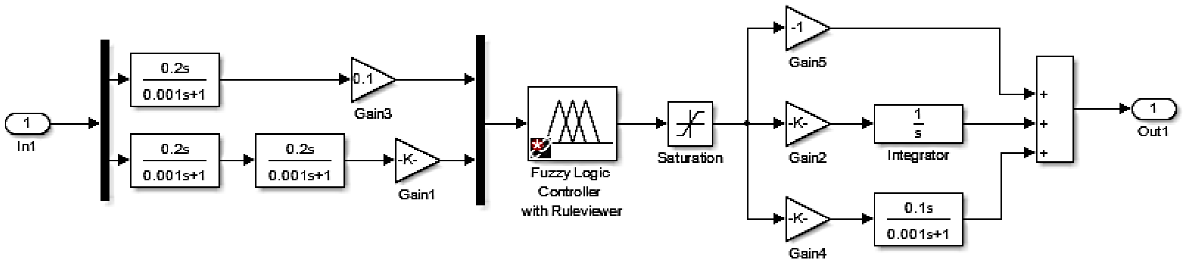


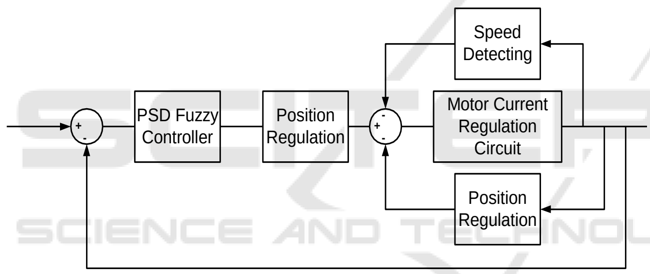
Figure 2. PSD fuzzy controller.

2.2. Apply FOC method on the model

The block represents the complete FOC. It is relatively simple and successful control strategies for closed loop system it is used to control the torque speed, and position of the motor.

The blocks (theta, omega) are respectively the controllers obtained for the position and the speed loops. Figure 3 shows the proposed system with FOC method.

Using current loop regulation can improve system rigid to speed up system response, and improve the linearity of torque control, which can achieve constant system start-stop current [3], and guarantee motor Current not to exceed the maximum allowable values.



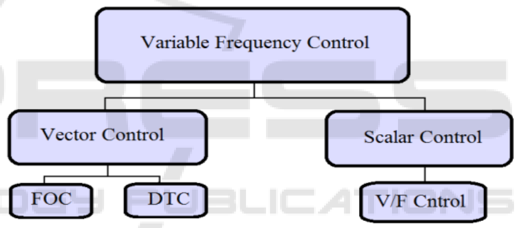


Figure 3. Proposed system with FOC Method. **Figure 4.** Variable Frequency Control.

Figure 4 shows the variable frequency control of AC synchronous motors in general [4].

2.3. Modeling of hybrid stepper motor drive

The mathematical model equations for a hybrid stepper motor are given below [5]. This is a dynamical model with differential equations. Equation (1) and (2) are the electrical equations, (3) and (4) are the mechanical equations of the hybrid stepper motor. The change in inductance, detent torque and magnetic coupling between the phases are neglected in this model [6].

$$\frac{di_a}{dt} = \frac{u_a + k_m \omega \sin(N\theta) - Ri_a}{L} \tag{1}$$

$$\frac{di_b}{dt} = \frac{u_b + k_m \omega \cos(N\theta) - Ri_b}{L} \tag{2}$$

$$\frac{d\omega}{dt} = \frac{k_m i_b \cos(N\theta) - T_i - k_m i_a \sin(N\theta) - k_v \omega}{J} \tag{3}$$

$$\frac{d\theta}{dt} = \omega \tag{4}$$

Where
i_a = the current in phase A
i_b= the current in phase B
u_a = the voltage in phase A
u_b = the voltage in phase B
Ti = the load torque (Nm)
ω = rotor speed (rad/sec)
θ = rotor position (rad)

2.4. Modeling of traditional PID and feedback loop

The conventional proportional-integral-derivative (PID) controllers are used in immense control actuation applications. The PID controller has the ability eliminate steady state error through integral action as the output changes corresponding to controller derivative action with respect to input command signal [7].In general the hybrid stepper motor controllers, but they are sensitive to parameter variation and load disturbances [8]. K_p, K_i are controlled by PI, PID controller. K_p and K_i are proportional gain and the integral gain of current loop respectively, the current and voltage commands ind-q reference frame are represented by using d-q or park transformation to simplify the signal.

Apposition loop estimates the rotor position and speed information. The motor model uses voltages and currents to estimate the position .the PMSM model is based on DC motor model.

In general control signals calculated for conventional PID gain parameters K_p, K_i, K_d.

$$u(t) = K_P e(t) + \left(\frac{1}{T_i}\right) \int e(t)dt + T(dt) \tag{5}$$

$$u(t) = K_P e(t)dt + K_i e(t)dt + K_d \frac{d}{dt} . e(t) \tag{6}$$

2.5. Modelling of reference signal and transformation

The Reference signal inputs shown in figure 5 consist of two signals. The first indication to unit step which represents (start-stop) motion, and the second is direction signal which represents the motor direction (clockwise, anti-clockwise).

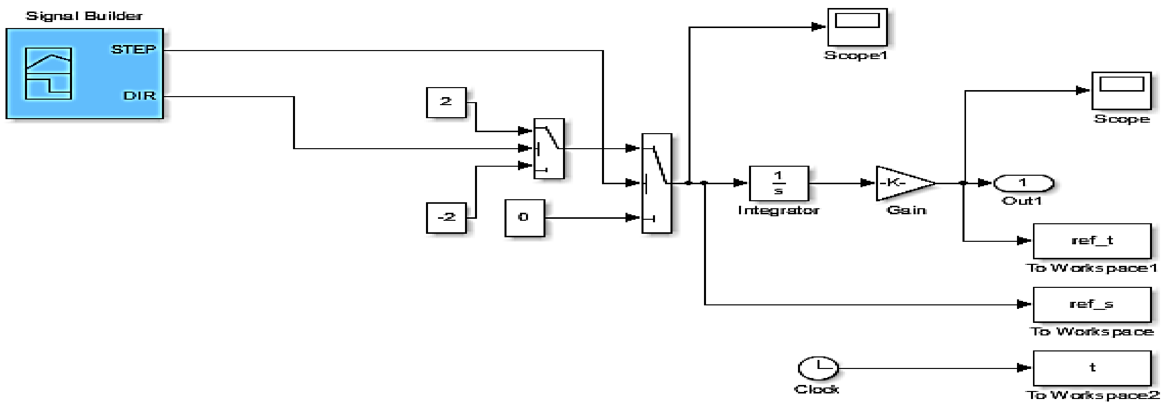


Figure 5. Reference signal block diagram.

The current and voltage commands in d-q reference frame are represented by using d-q or park transformation as shown in figure 6 to simplify the signal.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{T}{J}} \tag{7}$$

$$u_a = R.i_a + L\frac{di_a}{dt} - wk_m.\sin(N\theta) \tag{8}$$

$$u_b = R.i_b + L\frac{di_b}{dt} - wk_m.\cos(N\theta) \tag{9}$$

$$T_\theta = K_m\left[(i_b.\cos(N\theta) - (i_a.\sin N\theta)\right. \tag{10}$$

$$J.\frac{dw}{dt} = T_\theta - T_L - B_m. \tag{11}$$

$$N = \frac{360}{2.P.\theta_S} \tag{12}$$

$$\tau = K_m[-i_{a-fb}\sin(N_r\theta_{fb}) + -i_{b-fb}\cos(N_r\theta_{fb})] - K_{d4}\sin(4N_r\theta_{fb}) + K_{d2}\sin(2N_r\theta_{fb} + \emptyset_2) - K_{d1}\sin(N_r\theta_{fb}) + \emptyset_1) - F_S \tag{13}$$

$$\begin{bmatrix}\theta' \\ w'\end{bmatrix} = \begin{bmatrix}0 & 1 \\ 0 & 0\end{bmatrix}\begin{bmatrix}\theta \\ w\end{bmatrix} + \begin{bmatrix}0 \\ 1\end{bmatrix}\begin{bmatrix}-\frac{Dw}{J} & \frac{T}{J}\end{bmatrix} \tag{14}$$

$$i_{d\_cmd} = i_{q\_cmd} = \frac{1}{K_m}\left[K_{d4}\sin(4N_r\theta_{fb}) + K_{d2}\sin(2N_r\theta_{fb} + \emptyset_2) + K_{d1}\sin(N_r\theta_{fb} + \emptyset_1) + F_S\right] \tag{15}$$

$$v_d = K_P\left(i_{d\_cmd} - i_{d_{fb}}\right) + K_i\int(i_{d\_cmd} - i_{d\_fb})\,dt \tag{16}$$

$$v_q = K_P\left(i_{q\_cmd} - i_{q\_fb}\right) + K_i\int(i_{q\_cmd} - i_{q\_fb})\,dt \tag{17}$$

$$\begin{bmatrix}i_{d\_fb} \\ i_{q\_fb}\end{bmatrix} = \begin{bmatrix}\cos(N_r\theta_{fb}) & \sin(N_r\theta_{fb}) \\ -\sin(N_r\theta_{fb}) & \cos(N_r\theta_{fb})\end{bmatrix}\begin{bmatrix}i_{a\_fb} \\ i_{b\_fb}\end{bmatrix} \tag{18}$$

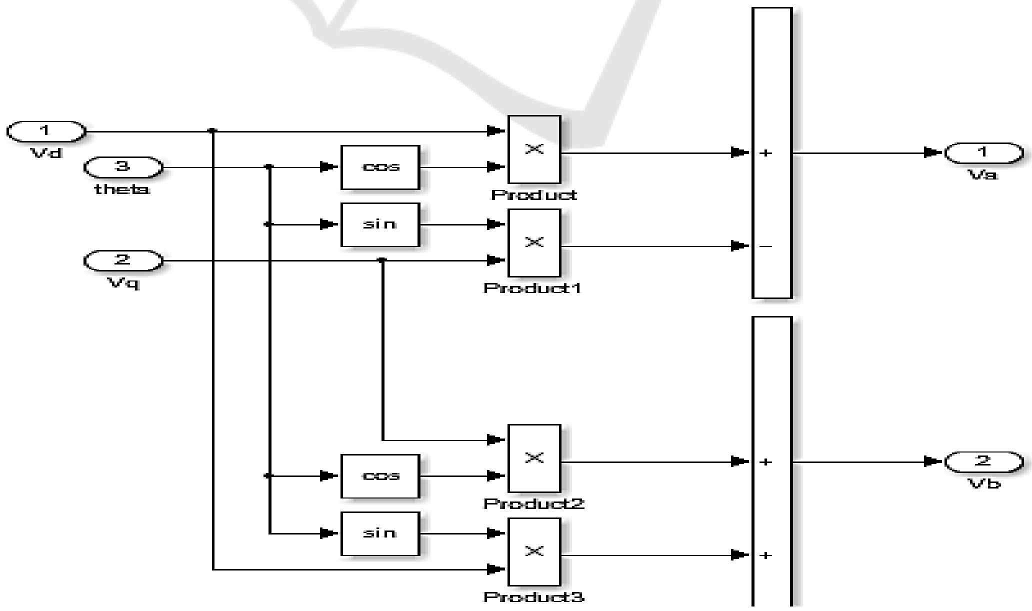


Figure 6. Park transformation.

3. Results of simulation

The data given in table 1 for hybrid stepper motor is used in the simulation. While control rules for FLC as shown in table 2. The comparisons of Experimental results have shown excellent results of proposed fuzzy-PSD controller and are well demonstrated for uncertain nonlinear conditions. Various kinds of popular control algorithm have been described for the controller design in our work have been presented to show the effectiveness of proposed model and analysis.

The hybrid stepper motor is investigated on open loop control. This investigation includes the study of the motor position, speed, and error shown in the figures.

Table 1. Hybrid stepper motor parameters.

Parameters	Values
Motor phase A resistance (Ω)	Ra = 30
Motor phase A inductance (H)	La = 0.032
Motor phase B resistance (Ω)	Rb = 30
Motor phase B inductance (H)	Lb = 32*10^-3
Machine torque constant (Nm/A)	KC = 0.5
Applied DC phase voltage (V)	Vs = 5
Friction coefficient (Nm S/rad)	B = 0.0026
Inertia constant (kgm2)	J = 4.6*10^-5
Number of rotor teeth	Nr = 50

The knowledge base defining the fuzzy rules are basic part of fuzzy controller that means make decisions based on rules and defined as conditional statement in the form (if-then) statement. Fuzzy control, which directly uses fuzzy rules is most important application in fuzzy theory. The control rules are evaluated by inference mechanism and represented as (if-then) form [9].

Table 2. Control rules of FLC.

	NB	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	PB	PB	PM	PS	PS	PS	ZO
NM	PB	PM	PM	PS	PS	ZO	NS
NS	PB	PM	PS	PS	ZO	NS	NM
ZO	PB	PM	PS	ZO	NS	NM	NB
PS	NM	NS	ZO	NS	NS	NM	NB
PM	NS	ZO	NM	NS	NS	NM	NB
PB	ZO	NS	NM	NM	NS	NM	NB

Modeling stepper motor and simulate it by MATLAB give us good results that can we see it in curves. The three types of PID controller have minimum overshoot and steady state error.

Finally, the motor performance using (PSD FUZZY) controller is tested to verify the controller capability to follow reference position. And the results are shown in figures 7 and 8. The error of the system shown in figure 9 but actually it is related to motor starting signal form.

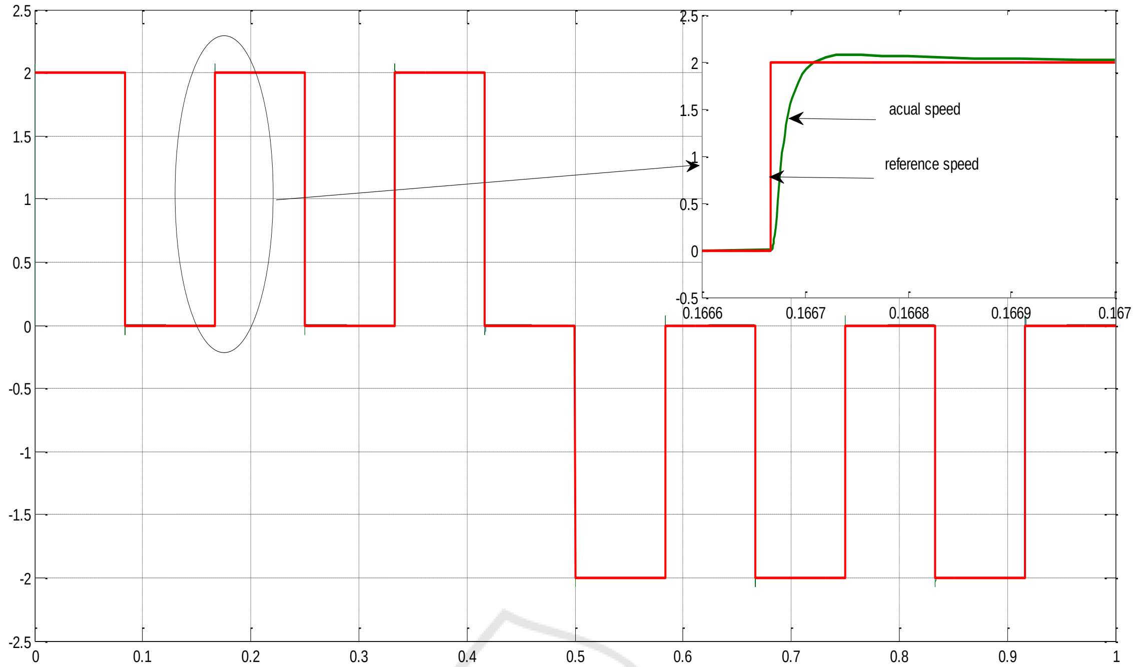


Figure 7. Speed Response Curve of Hybrid Stepper Motor.

For speed response result with inner loop current for both PSD fuzzy controller and traditional PID controller performance good rise time with minimum overshoot see figure 7.

For motor position performance is carried out for the control system (see figure 8 shows the position control equivalence with good response to track the reference signal.

For error curve see figure 9 shows the total error of the control system but it's very similar to the initial response of the motor and percentage error presented in table 3.

Table 3. Results of Position and Speed Transient Response.

Parameters	Position signal	Speed signal
Rise Time- Tr (ms)	0.0769	0.0001
Settling time- Ts (ms)	0.082	0.00025
Delay time- Td (ms)	0.04	0.00005
Transient Behavior	smooth	smooth
Maximum overshoot	2*10^-5	0.048
Peak time- Tp (ms)	0.08	0.0002
% error	0.01	0.001
Number of rotor teeth	smooth	0.0001

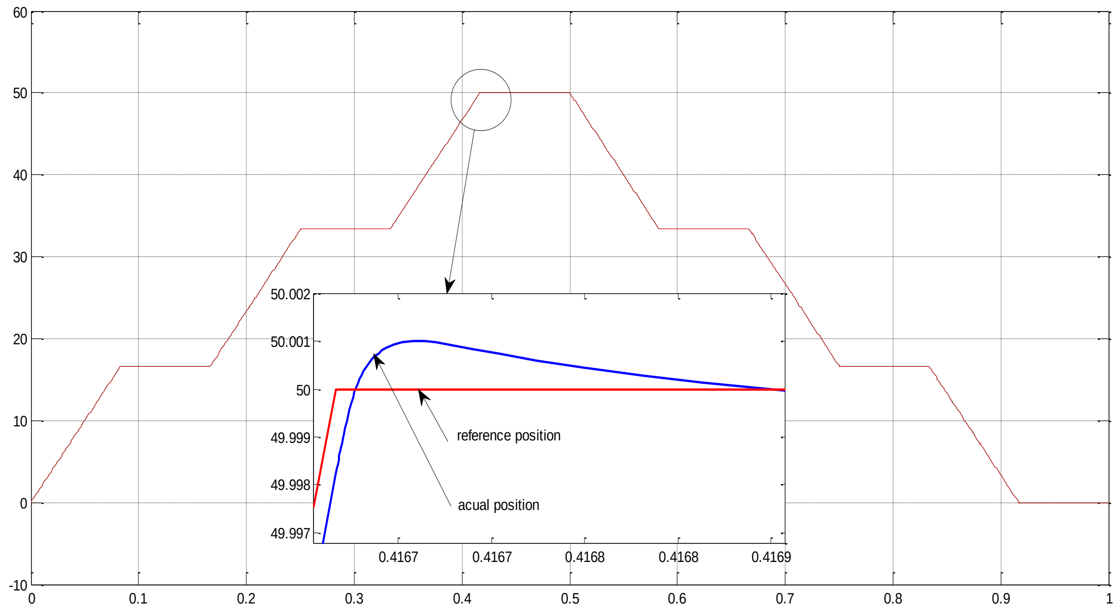


Figure 8. Motor Position Performance with Fuzzy PID Controller.

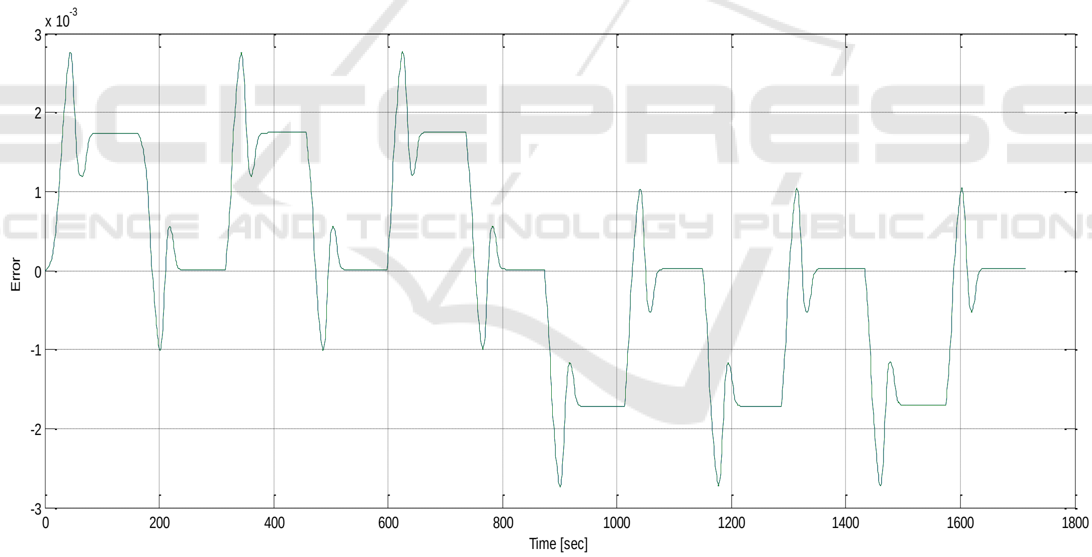


Figure 9. Overall Error of Control System.

4. Conclusions

Different computing technique including fuzzy logic and 2DOF PID (PSD fuzzy controller) applied to improve the step response of hybrid stepper motors. The linear fuzzy controller algorithm has been applied to linear fuzzy controller algorithms for closed loop controls of hybrid stepper motors have been discussed.

Also in this work, we used a new type of controller to improve the performance of the stepper motor the used to move mirror of laser. servo control structure for laser tracker as well as the control algorithms of developed fuzzy PID to fuzzy PSD, which are of current speed, displacement and position with four ring feedbacks + fuzzy correction) to perform intelligent control from model the

PSD fuzzy controller produces better performance. Speed and position waveforms also agree well with the theoretical prediction.

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