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3. Electronics (EL)

EL-03. Design and Simulation of Fuzzy Logic Based Temperature Controller for Machine Tool Spindle

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Abstract:

Fuzzy logic controller has been extensively used for control applications in the industrial and commercial world. The recent tendency in manufacturing industry is demanding high spindle speeds and precision machining to improve productivity and product quality. In this paper a fuzzy logic temperature controller has been designed to control temperature of machine tool Spindle. The temperature of spindle has been controlled with the use of thermoelectric cooler. Mathematical model of a system has been obtained in the form of transfer function. The fuzzy logic controller model has been simulated in Matlab Software.

Keywords: Fuzzy Logic Controller (FLC), spindle, Thermoelectric cooler.

1. Introduction:

With the escalating industrial requirement of higher productivity and increased accuracy, machine tools with high precision machining capability are required. The spindle dominates the machining precision and productivity. Spindle is the major internal heat source in machining operations. The spindle would generate large amount of heat when it is running at high speed. The heat flow generated due to internal heat source results in thermal deformation of each component. The complex thermal behavior is the predominant factor for determining the performance of machine tool. The accuracy can be increased by reducing or compensating the machining error [1-4].

Kuo et al. implemented analytical modeling for temperature control in surface grinding [5]. Analytical modeling offers high precision in the estimation of thermal deformation, but this model takes large time in the development [6]. Finite Element Method and Finite Difference Method can be used for modelling thermal error. It provides accuracy in results but boundary conditions are not considered in heat transfer characteristics. It takes large time in development [7].P. Ramanathanet al. has been developed Fuzzy Logic Controller for temperature regulation process. He has studied the performance of fuzzy controller and PID controller. It was observed that the Fuzzy Logic Controller is faster than the conventional PID Controller [8].

Since the temperature activity of spindle is nonlinear phenomenon, handling the spindle thermal deformation becomes relatively a complex. Fuzzy logic controller (FLC) can deal with this kind of complex problem exactly. Fuzzy systems are signifying good assurance in consumer products, industrial, commercial and decision support systems. Fuzzy Logic can be customized and attuned effortlessly to get better or significantly alter system performance, because the FLC processes user-defined rules ruling the target control system. The control strategies implemented using classical controllers are expressed in mathematical functions and are fundamentally different from human control. FLC easily handles ambiguity and fuzziness present in the database, and process imprecise information with reasoning [9].

The present paper portrays design and simulation of two inputs–single output (DISO) Fuzzy Logic Based Temperature Controller to maintain the spindle temperature within deformation limit.

2. Mathematical Modelling of System:

Transfer Function (TF) has been employed for mathematical modeling of thermal Error. TF includes the excellence of the heat transport ethics. Hence the experimental parameters can be calibrated easily and it is reliable with untested inputs. The mathematical form similar to real time response can be acquired by extrapolating data [10]. Mathematical model contains heating effect of spindle, cooling effect of thermoelectric cooler and thermal deformation of spindle.The thermal deformation error [11] is specified by Eq. (1)

$$G_{Error} = \frac{E_{zheat}}{\Delta T} \quad (1)$$

Similarly the first order transfer function for a spindle temperature is represented as Eq. (2).

$$G(t) = \frac{Spindle\ Temperature}{Time} \quad (2)$$

The transfer function of spindle at 1000 rpm [12] is given by Eq. (3)

$$G(t) = \frac{4.88}{523s+1} \quad (3)$$

Thermal step response of spindle at a 1000 rpm is displayed in Figure.1.

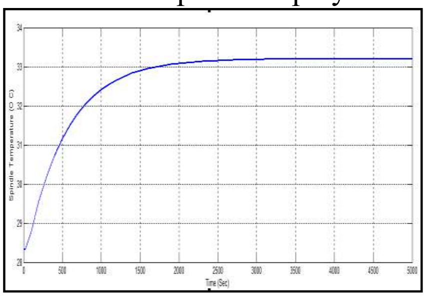

Figure 1. Thermal step response of spindle at 1000 rpm

The cooling system will increase the machining precision with heat confiscation. For cooling jacket cooling or chiller system can be used but it involves complex expensive equipment, chillers required water treatment plant.Thermal errors can be abridged by driving away the heat in the machine tool. Thermoelectric cooling has fewer moving parts, more flexibility and reliability and hence more suitable in high speed machine tool cooling. The thermoelectric air to air cooling method has been projected for the temperature control of machine tool spindle unit [13].

Transfer function for cooling effect of thermoelectric cooler is estimated in Eq. (4).

$$G(S)=\frac{Temperature}{Current}=\frac{-2.6}{50s+1}e^{0s} \quad (4)$$

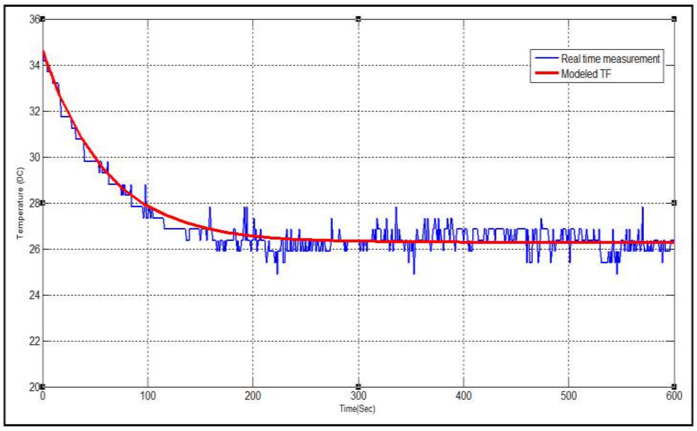

Figure 2. Thermoelectric cooler response

Figure 2 reveals that thermoelectric cooler able to reduce the temperature about by 9ºC .The transfer function of spindle system prototype is given in Eq. (5).This equation has been used for simulation.

$$G(t)=\frac{-0.815}{573.1s+1} \quad (5)$$

1. Fuzzy Logic Based Temperature Controller

The Fuzzy Logic based temperature control system for spindle is as in Figure 3. The present control system has a process i.e spindle, Fuzzy Inference System (FIS) with sensor feedback and thermoelectric cooler.

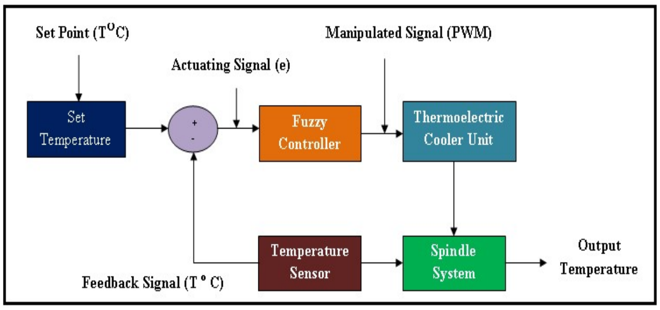

Figure 3. Fuzzy Logic based Temperature Controller

The set point is the reference temperature of the process. The error signal is the variation between the present temperature and standard reference temperature of the process. The Fuzzy controller generates the requisite control signal to control actuators to handle the process. The FIS make a use of fuzzy set for mapping input to the output. FIS includes fuzzy membership functions, operators, and fuzzy rules.

3. Design and Matlab simulation of Fuzzy Logic Based Temperature control System:

The Fuzzy Temperature Controller has been designed and simulated using Fuzzy Logic Tool Box and Simulink framework of Matlab [Ver.2015b]. It has two inputs "Error" and "Change-in-Error (CE)" these inputs are processed by Fuzzy Logic Temperature controller and provide the control signal to the thermoelectric cooler to control the temperature of machine tool. Error is the difrrence between present temperature and set temperature. The change in error is the difrrence between the present error and previous error. The block diagram of two input and one output Fuzzy Mamdani system has been displayed in 4.

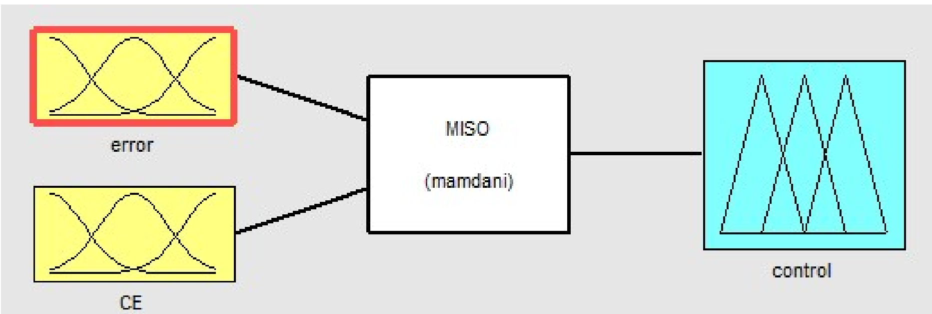

Figure 4. Block diagram of DISO Fuzzy Mamdani System

The input variable "Error" is consisting of five membership functions (MF's) contains two trapezoidal and three triangular MF's (Figure 5).

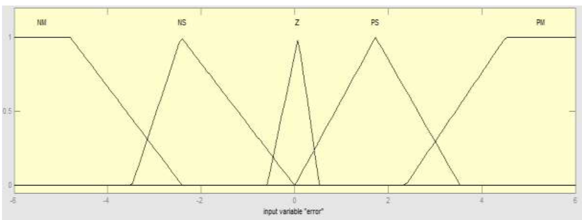

Figure 5. MF for Input Variable "Error"

The second input "Change-in –Error" variable has five triangular membership functions (Figure6).

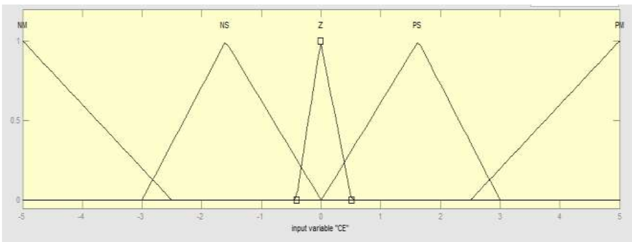

Figure 6. MF for Input Variable "Change-in-Error (CE)"

output variable "Control" consist of two trapezoidal and three triangular MF's (Figure 7).

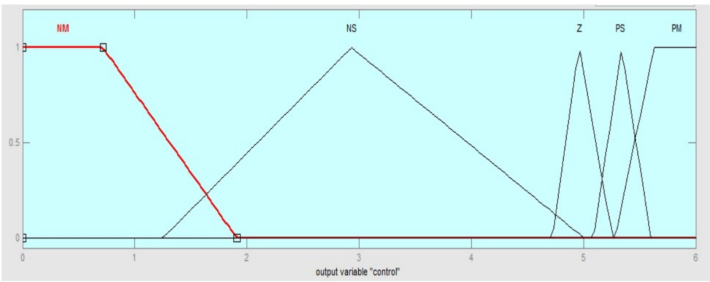

Figure 7. MF for Output Variable "Control"

Input and output linguistic variable range has been displayed in Table 1. The five linguistic variables are NM=Negative Medium, NS= Negative Medium, Z=Zero, PS=Positive Small, PM= Positive Medium.

Table 1. All Input and Output Range of Linguistic Variable

Sr. No	Input Variable Name	Crisp Input Range of "Error"	Crisp Input Range of "Change-in-Error (CE)"	Crisp Output Range of "Control"
01	NM	[-6 -6 -4.6 -2.4]	[-5 -5 -2.5]	[0 0 0.7 1.9]
02	NS	[-3.5 -2.024 0]	[-3 -1.6 0]	[1.25 3 5]
03	Z	[-0.489 0 0.437]	[-0.5 0 0.5]	[4.7 5 5.26]
04	PS	[0 1.45 2.95]	[0 1.6 3]	[5 5.34 5.6]
05	PM	[1.9 3.76 6 6]	[2.5 5 5]	[5.28 5.63 6 6]

In fuzzy logic decision relies on the rules. The rule base is constructed to control the output variable. A fuzzy rule is a IF-THEN rule with condition and conclusion. Fuzzy rules are presented in Table 2. It consists of 25 rules. The all 25 rules are executed. For example if the error is Negative Small (NS) and Change-in-Error (CE) is Negative Medium (NM) then control output is Positive Medium (PM).

Table 2. Control Rules

Control		Change-in-Error (CE)				
		NM	NS	Z	PS	PM
Error (E)	NM	PM	PM	PM	PS	Z
	NS	PM	PM	PS	Z	NS
	Z	PM	PS	Z	NS	NM
	PS	PS	Z	NS	NM	NM
	PM	Z	NS	NM	NM	NM

The Simulink model for Two Input Single Output system (DISO) is given in Figure 8. The Simulink model simulates and analyzes the mathematical modeling of DISO system in the Matlab framework. The FLC has two inputs “Error” and “Change-in-Error”. This Simulink model consists of spindle transfer function, TEC cooler prototype and fuzzy logic controller (FLC). The set temperature is 27°C. The FLC generates control output that drives the TEC used for compensation of spindle temperature.

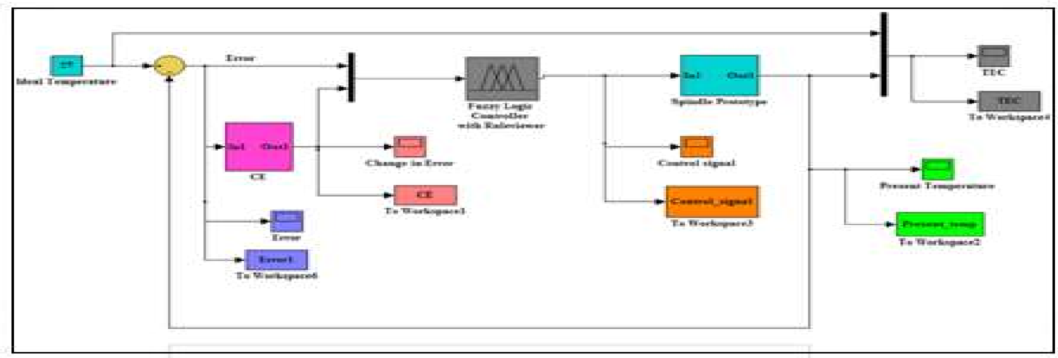

Figure 8. Simulink Model for DISO fuzzy logic controller

4. Simulation Results:

The Matlab simulation of two input-single output (DISO) fuzzy logic system has been carried out to maintain spindle temperature at 27^0 C. the machining operations are generally executed at ambient temperature. Therefore for the demonstration purpose 27^0C is chosen as an Ideal temperature for a spindle system prototype. The result of simulation has been displayed in Figure 9.

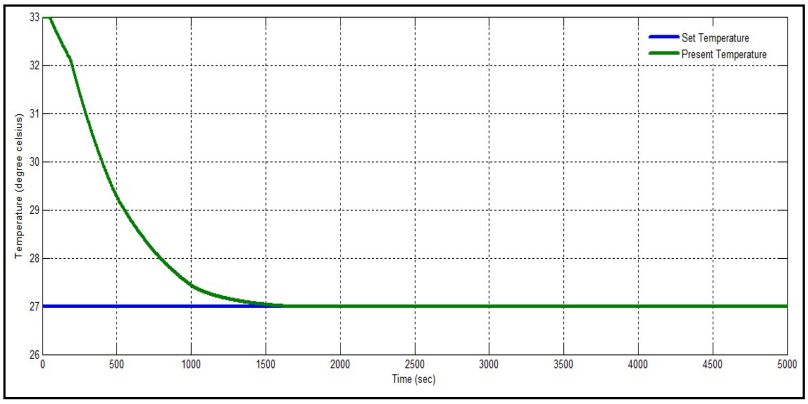

Figure 9.Set point achieved

From the Figure 9, it is observedthat the spindle temperature reaches up to 33^0 C at 1000 rpm. In the present research thermoelectric cooler reduces the temperature by 6^0 C.

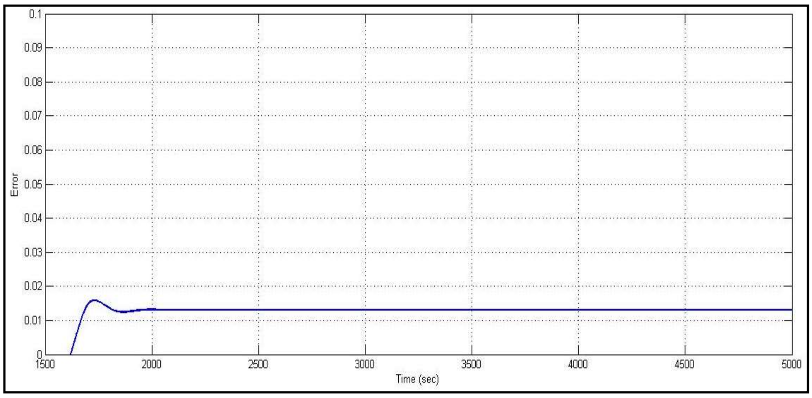

Figure 10. Error Obtained

Figure.10 shows the result of simulation of spindle system prototype. The simulation was performed from 0 to 5000 sec. The "Error" in simulation is 0.015^0 C that is $\pm$ 0.25%. The settling time for the simulation is 2000 sec.

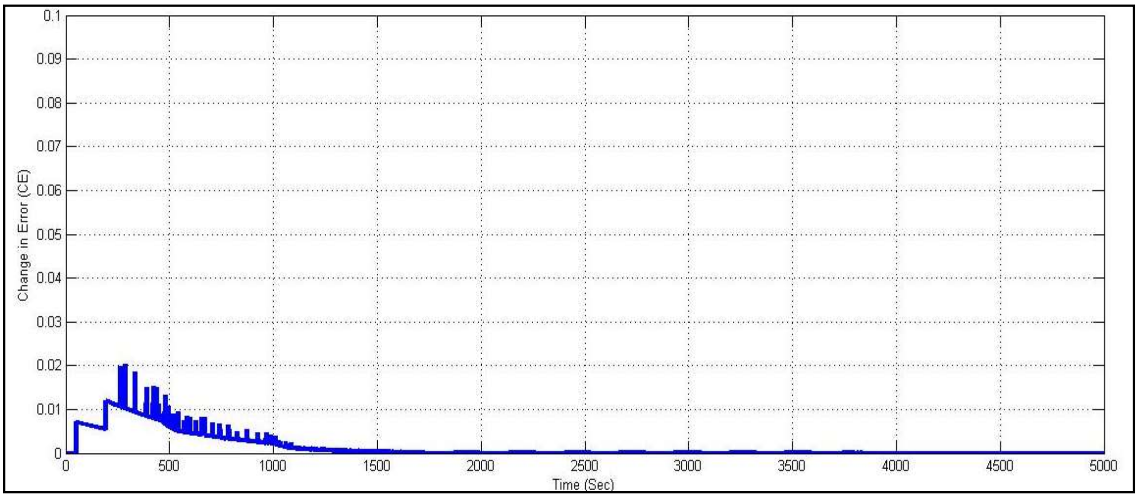

Figure 11. Change in Error (CE)

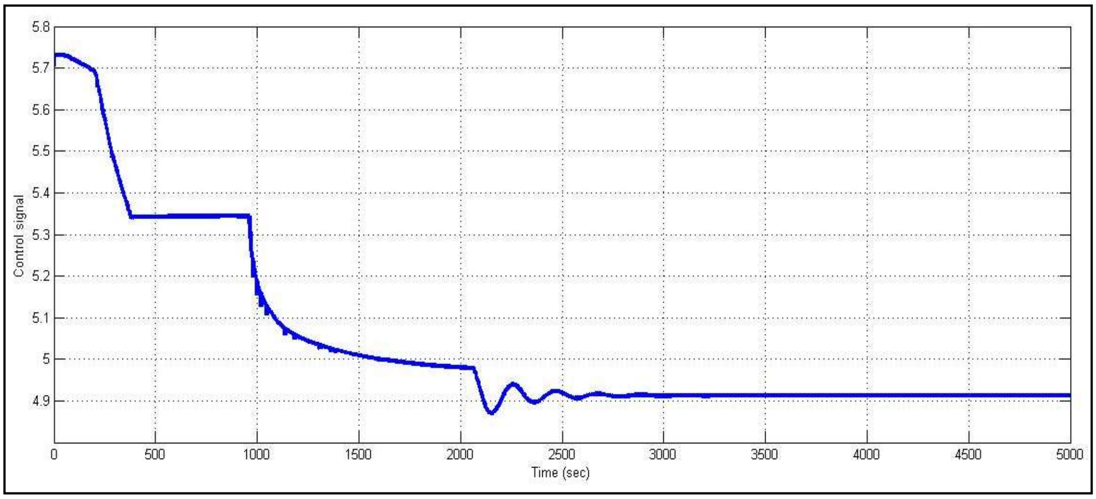

Figure 12. Control Signal

The “change-in-error” (Figure 11) varies continuously between the 0 and 0.02 range. Gradually it settles down to 0 at about 1200 sec. Figure.12 gives an idea about the output control signal generated by FLTC that supplied to the Thermoelectric Cooler to compensate spindle temperature. According to thermal error produced control signal varies to reduce the “Error” and “Change-in-Error” and to settle down the system at the requisite temperature.

5. Conclusion:

The Fuzzy Logic based Temperature Controller for spindle of a machine tool has been designed and simulated using Matlab Software successfully. In the simulation result it is found that the system maintains spindle temperature at ambient temperature (27^0C). This reduces thermal error and increases accuracy in spindle machining operation.

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