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INTELLIGENT ACTIVE FORCE CONTROL APPLIED TO PRECISE MACHINE

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ABSTRACT

This paper present about the performance of vibration control via active force control (AFC) scheme is investigated through simulation study by application of MATLAB/ Simulink® software. AFC is a widely used control scheme in dynamic system control, and it is a highly robust control scheme although under unknown disturbances and operation condition. In this study, the AFC is incorporated with conventional proportional-integral-derivative (PID) controller to control active vibration isolation system which is two degree of freedom (TDOF) cutting tool of turning machine model. A harmonic force due to unbalance rotating mass and a sinusoidal response that pretended to be an internal disturbances are applied into both axes of models(X and Y) respectively. Generally, the estimated mass (EM) is the most significant parameter in the AFC scheme, thus the interest in this study is to obtain the EM via conventional crude approximation method and intelligent fuzzy logic method. A new AFC scheme proposed in this study is named AFCFLC scheme which mean AFC co-operate with PID and FLC. The main purpose of this scheme is to obtain the optimum EM value via the intelligent method and to suppress vibration. Finally, a demonstration of comparison study between each control schemes is carried out and it is clearly shows that the proposed AFCFLC scheme is the most superior control method for both axes vibration isolation cutting tool models.

***Keywords**:* AFC, Vibration, PID, AFCCA, AFCFLC,EM

INTRODUCTION

In the industrial like manufacturing, the circumstance of precise machine is very significant because the products final outline depend on the efficiency of the cutting and machine tools. Positioning of the cutting tools with respect to work piece will affected the precision of a machine [1]. Vibration is a frequent problem that affecting the result of machining and cutting tool life. Vibration can be agreeable and useful, or it can be unpleasant and unsafe. Vibration also can interfere with our comfort, damage to structures, and reduction of equipment performance and machinery noise level. Furthermore, a vibration environment can cause malfunction or failure of mechanical systems and may be injury to human beings. This phenomenon generated at a source and is transmitted through the ground or structure that forms the transmission path to a receiver. There are several steps to eliminate the unwanted vibration in vibration control. This may involve action taken at the source in order to reduce the vibration that transmitted from source to receiver or finally action taken at the receiver to reduce its response to unwanted vibration of its supported [6].

Instead of controlling vibration at source and receiver, modification of transmission path has a significant role in vibration control. Vibration along the transmission path is magnified by resonance and reduced by damping. In vibration control, it is a must to avoid resonance and to incorporate as much damping as predictable. Vibration absorber and vibration isolator are two important devices to reduce vibration at transmission path. Vibration absorber is a secondary mass spring system that tuned to absorb energy from primary system to which it is attached. The secondary mass is usually small in comparison with primary mass. The motion of the secondary mass is opposite phase to that of the primary mass and therefore imparts a reaction that opposes the motion of the primary system [6].L.Pettersonfound and used active vibration control (AVA) as a mechanism to reduce vibration on machine and cutting tools. From the study, many researchers made an improvement and introduced with the new control system. [2].

Currently, intelligent active force control (IAFC) scheme is so far become another popular control scheme and widely used in the robot control. Generally the IAFC scheme is a combination of IAFC loop and conventional PID controller in one controlscheme. The most important parameter in this scheme is the assumption of estimated mass (EM) in IAFC loop and tuning of PID gain in PID controller. Recently,the application of intelligent method in IAFC scheme for robot arm control has been presented by M.Mailah and N.Izzah [3]. These methods also applied at the suspension system [4]. But intelligent method such as iterative learning method and fuzzy logic control (FLC) are only applied to obtain the estimated mass (EM).

PROPORTIONAL –INTEGRAL – DERIVATIVE (PID) CONTROLLER

Proportional integral derivative (PID) controller is the most widely used control method. It is a simple and effective feedback control. It also provides fast response and good system stability especially for slow speed operation or during very small disturbance. However, the performance of PID controller is reduced when the system is operating at high speed and with presence of disturbance.

The input signal for the PID controller is the error signal between reference input and output response. The output signal from PID controller is then used to control the actuator in order to change the response of dynamic system. The basic equation governing the controller is expressed as follows:

$$m(t) = K_p e(t) + K_i \int e(t)\,dt + K_d \frac{d}{d_t} e(t) \tag{1}$$

According to Zhao [11], the transfer function of PID controller gain can be illustrated as follows:

$$G(s) = K_p + \frac{K_i}{s} + K_d s \tag{2}$$

where $T_i = \frac{K_p}{K_i}$, $T_d = \frac{K_d}{K_p}$, so the T_i is the integral time constant and T_d is the derivative time constant. Meanwhile, the relation between intigeral time constant and derivative time constant can be expressed as follow [7].

$T_i = \alpha T_d$, where α is a constant value

$$\frac{K_p}{K_i} = \alpha \frac{K_p}{K_p} \tag{3}$$

ACTIVE FORCE CONTROL

The active force control (AFC) first had been proposed by Hewit J.R [8] which applied this strategy to control dynamic system in the early 80s. It showed that system controlled by AFC remain stable and robust even in the presence of known and unknown disturbances. Then the intelligent method had been applied to the control scheme to make it robust. Figure 1 show that the blocks diagram of AFC with PID that applied on the system.

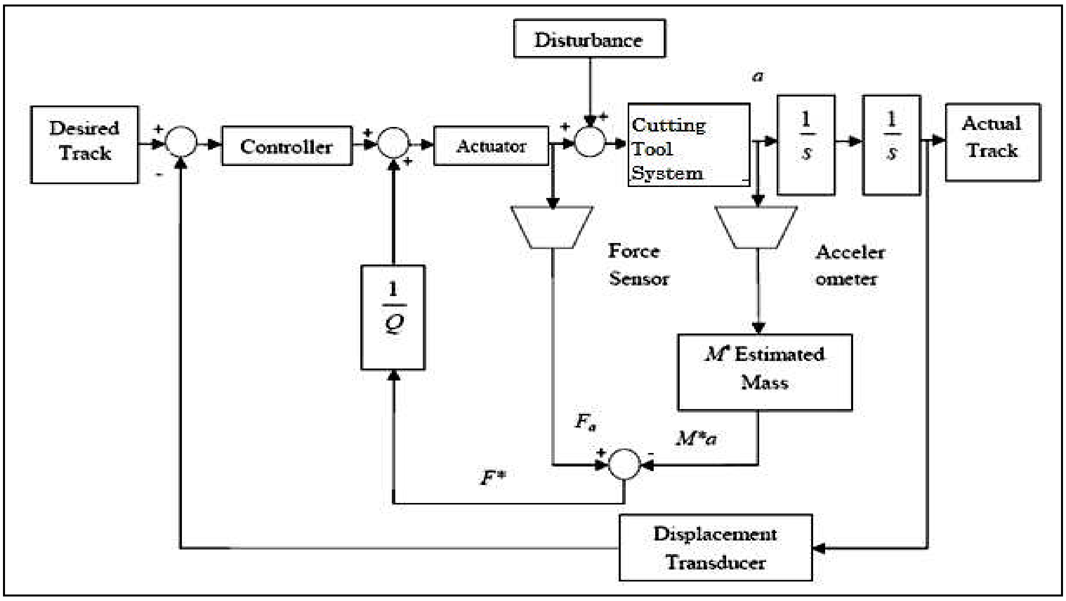

Figure 1: Basic Scheme Active Force Control for Cutting Tool System

Recently M.Mailah had applied intelligent active force control (IAFC) to robot arm control with fuzzy logic control (FLC) and neural network. It indicates that AFC has superior result compared to the conventional method in controlling a robot arm [3,9]. Figure 1 shows that a schematic diagram of IAFC strategy applied to a dynamic system. The IAFC schemes serve as a disturbance rejection scheme in which the disturbance, *Fd** can be compensated in the feedback loop if the estimated mass (EM) is well estimated. Hence, the essence of the AFC strategy is to obtain the estimated disturbances force, *Fd** via measurement of mass acceleration, *a* and actuator force *Fa** and an appropriate estimation of the estimated mass, EM* as described in equation (4):

$$F_d = F_a * -EM * a \tag{4}$$

The physical quantities that can be measured directly from the system are actuator forces and the acceleration. These quantities can be easily accomplished by using force sensor and accelerometer. The main disadvantage of IAFC is to estimate the mass that is needed in the feedback loop. Hence, in its study, crude approximation method and fuzzy logic control (FLC) or other iterative learning has been used to estimate the mass [10].

DYNAMIC MODEL LATHE CUTTING TOOL

For lathe or turning machine, the position of cutting tool is static and the work piece will move to produce shape of product. For this study, there will be used two degree of freedom (TDOF)passive system of cutting tool like shown in figure 2. There will be *x* and *y* direction of vibration for cutting tool but work piece just in one direction V_0.

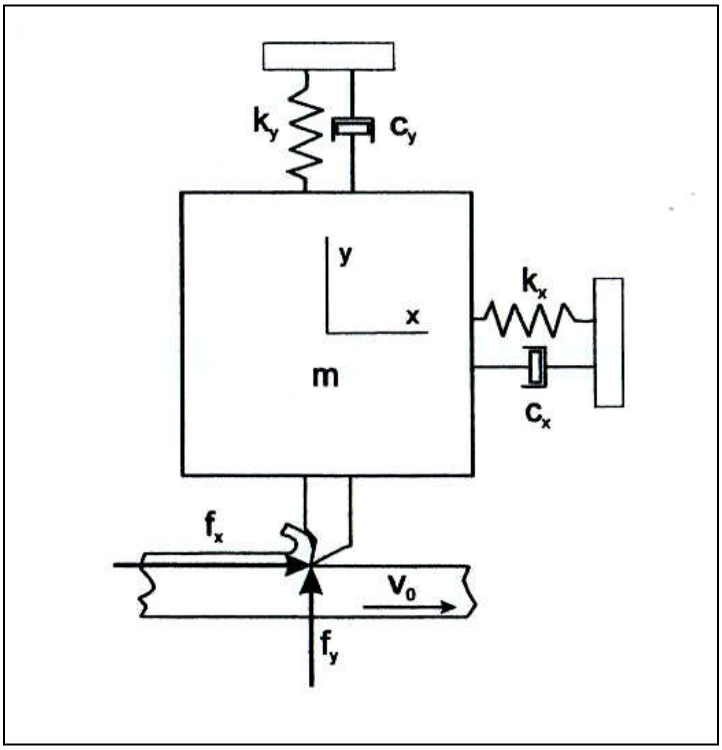

Figure 2: Two degree of freedom cutting tool model

The dynamic analysis for passive TDOF cutting tool system will be done separately for both axes. Analysis for x-axis which involved stiffness, damping, force and initial velocity in the x direction for cutting tool movement. By using Newton second law, $\sum F = ma$ the mathematical modelling can be shown like equation (5).

$$F_D + V_0 - F_s - F_d = m\ddot{x} \tag{5}$$

Where $F_D$is force and V_0 initial velocity that acting in the direction of x – axis. $F_s$is the spring force and F_d is the damping force and can simplified as shown below.

$$. F_D = F_x \cos \omega t \tag{6}$$

$$F_s = k_x x \tag{7}$$

$$F_d = C_x \dot{x} \tag{8}$$

And all above can be substituted in the Equation (5) and produced Equation (9)

$$m\ddot{x} + k_x x + C_x\dot{x} = F_x \cos\omega t + V_0 \tag{9}$$

Initial velocity units is m/s^2, so to equilibrium the equation into same unit, it will used Equation (10)

$$F_x = C_x f_0\, hH(v_0)(\alpha(v_0 - 1)^2 + 1)H(h) \tag{10}$$

$$H(x) = \frac{1}{2}[1 + sgn\ (x)] \tag{11}$$

$$sgn(v_0) = \frac{v_0}{|v_0|} \tag{12}$$

Substitute equation (11) and (12) into 10 and will get equation 13 below;

$$F_x = C_x f_0\, h\left(\frac{1}{2}\left[1 + \frac{v_0}{|v_0|}\right]\right)(\alpha(v_0 - 1)^2 + 1)\left(\frac{1}{2}\left[1 + \frac{h}{|h|}\right]\right) \tag{13}$$

Then equation 13 will be substituted in the equation 9 and then transfer into block diagram. For *Y* direction analysis, the analysis same with *X*-axis but without initial velocity. The mathematical modelling for *Y*-axis liked equation 14 below.
By using Newton second law which same as analysis for *x*-direction we get

$$-F_s - F_d = m\ddot{y} \tag{14}$$

Where F_D is force that acting in the direction of *y* – axis. F_s is the spring force and F_d is the damping force and can simplified as shown below

$$F_D = F_y \cos\omega t \tag{15}$$
$$F_s = k_y y \tag{16}$$
$$F_d = C_y\dot{y} \tag{17}$$

Then we substituted all the equation above into general equation 14 and get the Equation (18)

$$m\ddot{x} + k_y y + C_y\dot{y} = F_y \cos\omega t \tag{18}$$

The piezo actuator stiffness is an important parameter for calculating the force generation, resonant frequency, full-system behavior, etc compared to its mass and damping parameter. By taking account piezo actuator stiffness only, it becomes linear and can be represented as follows:

$$F_a = k_T x \tag{19}$$

Apiezo actuator and sensor will be embedding at cutting tool holder which control by active controller system, the resulting system is transformed to an active system and the equation becomes:

$$m\ddot{x} + k_x x + C_x \dot{x} = F_a + F_x \cos \omega t \quad (20)$$

$$m\ddot{y} + k_y y + C_y \dot{y} = F_a + F_y \cos \omega t \quad (21)$$

To complete mathematical analysis for dynamic model of cutting tool, the parameter of equation had been derived need to be substitute. The mathematical model consist two axes with nine parameter need to be consider. All the parameters were obtained from previous study about lathe machine process. There are disturbances will be introduced in the system such as vibration forces that occurred from body machine during machining process. These forces can be concluded as internal or external disturbances force. In the active system model (cutting tool), a harmonic force due to the internal vibration or external vibration, which represents a force disturbance is applied on the model.

SIMULATION RESULTS AND DISCCUSSION

When the machining occurred, the tuning process of the controller gains is an important task that needs to be done to ensure the control action gives desirable results. The results need to be focused was suppress the vibration with or without external disturbance. The tuning was done by heuristic method and intelligent artificial technique by using step input signals as a reference input signal because the results obtained are easy to evaluate step response graph and discuss in terms of overshoot, steady state error, rise and settling time etc. The tuning process for controller such as PID can be made by tuning using heuristic method for controller proportional, integration and derivatives. For this experiment, the best value of controller are T K_P =1000, K_D = 9 and K_I = 89. For AFC, a crude approximation technique was used to estimate the appropriate estimated/virtual mass (*M**) and it is a constant value.

The best estimated mass is found to be 100 kg where overshoot is very small, rise and settling time is faster while steady state error is almost zero compared to the others *M** as shown in Figure. 3. In the Figure. 4show the comparative response between the PID and AFCCA schemes. For AFCCA scheme, steady state error, rise and settling time is better than the PID control scheme. AFCCA gives the smooth response with hardly any vibration occurred. Refer to close up view in Figure. 4, the PID scheme did not reveal an overshoot compared to AFCCA but obviously, the vibration or small wave occurred could not be eliminated.

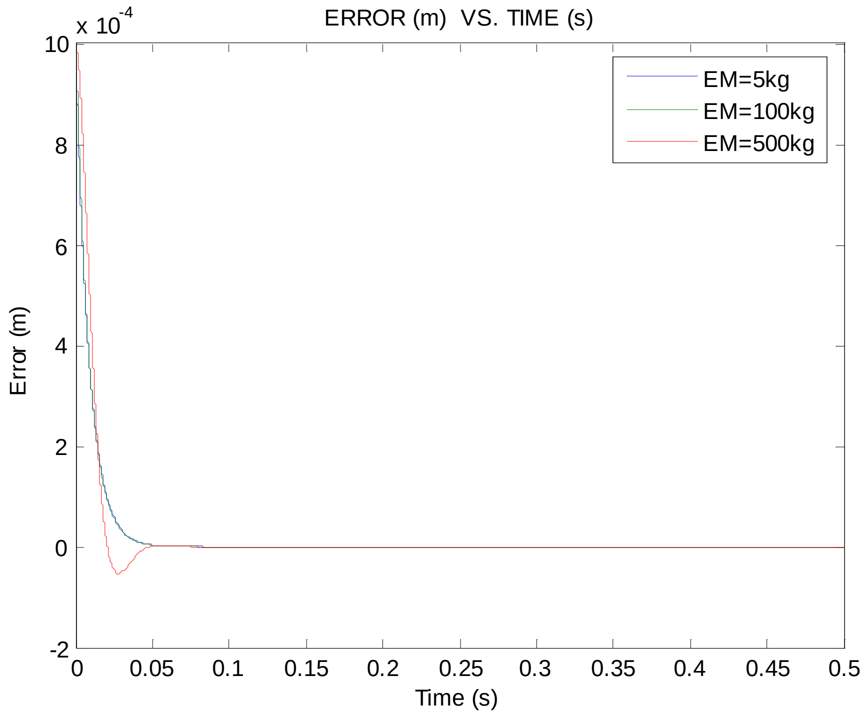

Figure 3: Plot of mass displacement with different estimated mass (EM)

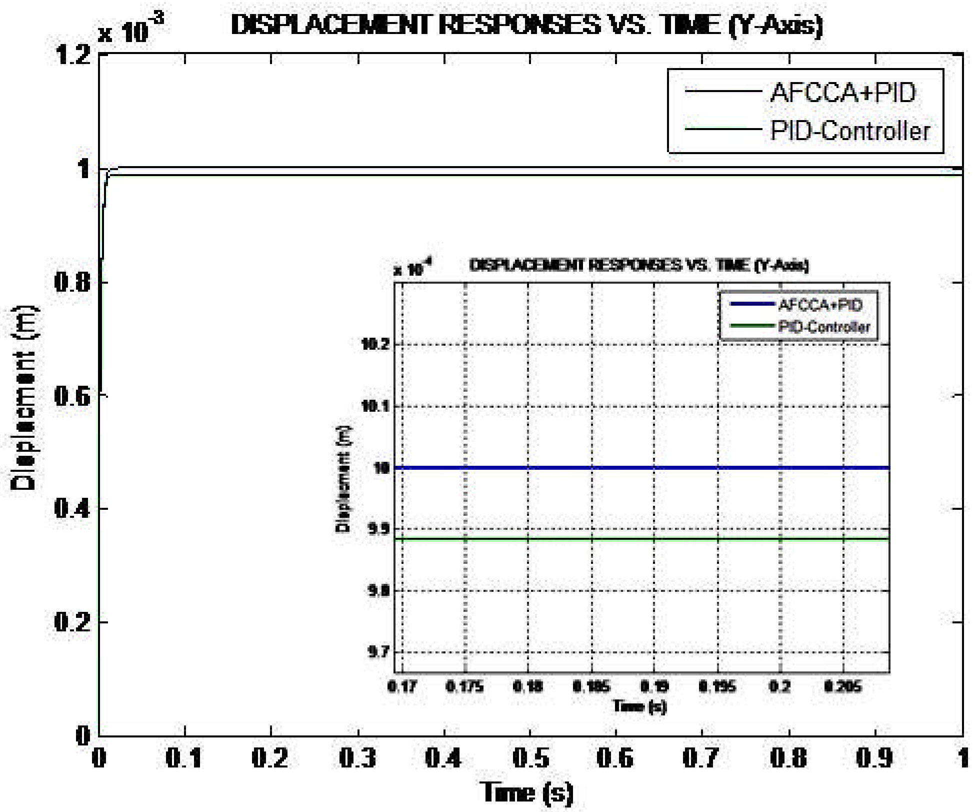

Figure 4: Plot of mass displacement AFCCA and PID for Y-axis

When machining occurred, there are external disturbance will affect the cutting tool system. This external disturbance will be introduced into the system and affect the AFCCA and PID controller, but only AFC still give the same response as shown in figure 4. AFC efficiently and robustly compensates the external disturbance but not the PID control scheme.External vibration that occurred when cutting tool of turning system operate was effectively suppressed by applying the AFC strategy. From the simulation study, AFC with crude approximation gives the best responses compared to the conventional PID control scheme, by providing a much more robust performance. The crude approximation method in computing the estimated mass is found to be sufficient in producing the desired performance if the external disturbance is constant. During machining process, there are several of external disturbance will be introduced and crude approximation method are not fully effective because of AFC need to adapt new external disturbance with several of range wave signals. To overcome this situation, artificial intelligent method will be introduced into the system as a technique of tuning the estimated mass. Artificial intelligent like fuzzy logic controller (FLC) will be introduced into AFC to tune the estimated mass. Figure 5 and figure 6 show comparative study between PID, AFCCA and AFCFLC with several of disturbance waves. PID cannot suppress the vibration unlikely AFCCA and AFCFLC. Both AFC with crude approximation and FLC suppress the vibration or external disturbance successfully, but AFCCA need to be adjusted if different external disturbance introduced.

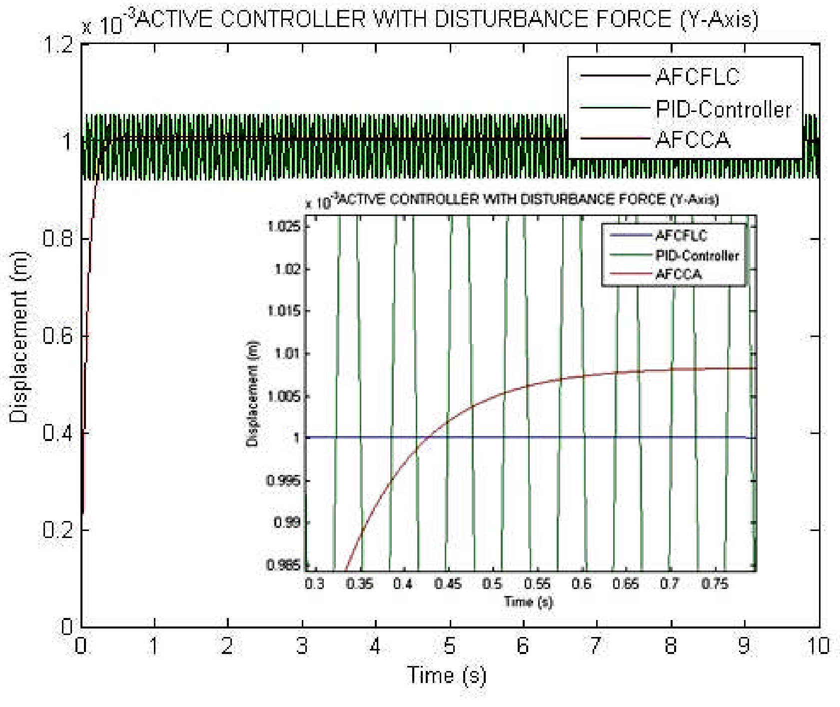

Figure 5: Plot of mass displacement for step input signals (Y-axis)

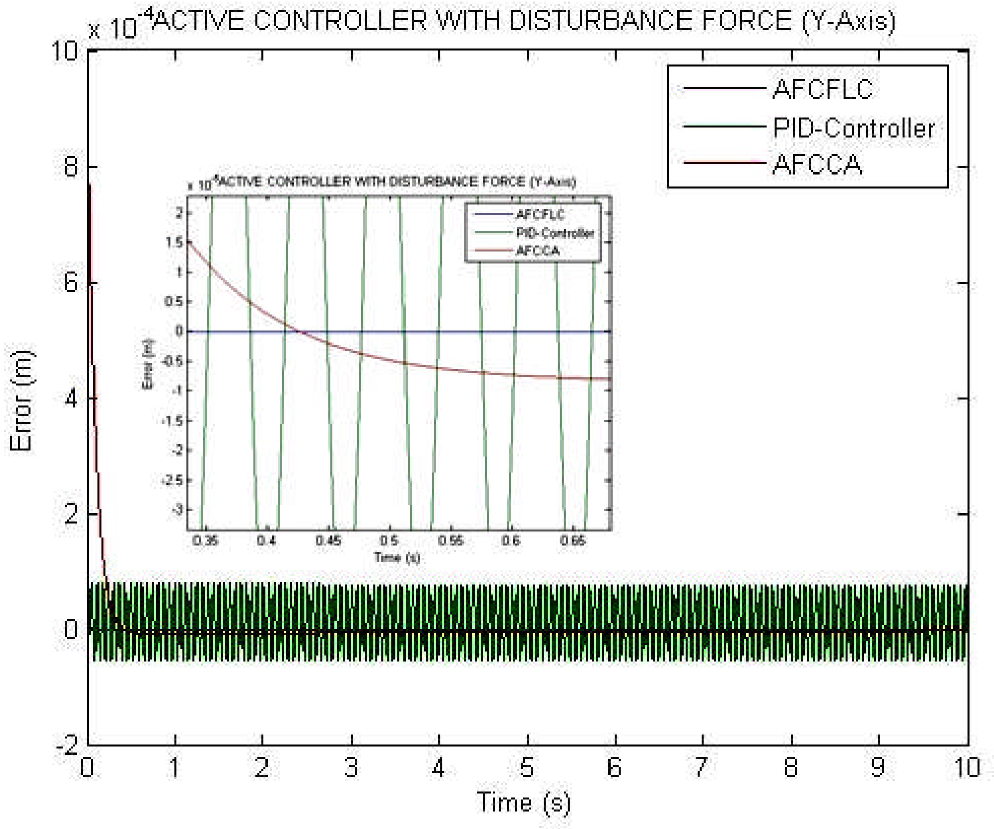

Figure 6: Plot of error versus time for step input signals (Y-axis)

CONCLUSION

From the results, it shows that the AFCFLC scheme is ~~a~~ superior,highly robust, stable and accurate control scheme compared to other control schemes. This simulation result also demonstrates that the FLC is capable to obtain the optimum estimated mass in the AFC scheme. Moreover, this scheme is able to compensate all external disturbances and ~~to~~ operate in critical condition. The AFCFLC scheme is superior to be applied in the active vibration isolation control for the force transmissibility isolation system and the displacement transmissibility isolation system.

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NOMENCLATURE

v_0	Initial Velocity
x	Displacement in x-direction
y	Displacement in y-direction
m	Mass
k_x	Spring stiffness for x-direction
k_y	Spring stiffness for y-direction
C_x	Damping coefficient for x-direction
C_y	Damping coefficient for y-direction
F_x	Force acting on x-direction
F_y	Force acting on y-direction
F_a	Actuator Force
F_D	Force acting on the direction.
F_d	Damping coefficient
F_s	Spring coefficient
a	Acceleration
ω_0	Natural Frequency
ξ	Damping Ratio Coefficient
$e(t)$	Error of active system
f_0	Forces acting on the machine tool structure
h	Depth of cut
$H(\,)$	Heaviside function
α	Stiffness ratio
EM	Estimated Mass
PID	Proportional-Integrate-Derivative
ACTD	Active Control Cutting Tool Dynamic
AFCCA	Active Force Control Crude Approximation
AFCFLC	Active Force Control Fuzzy Logic Control