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Designing error resistant controller by using of bond-graph theory on electromagnetic loading system

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ABSTRACT

Developing methods to design controller which at least under the situation that error exists, could continue its control procedure by decreasing operation till system attains secure situation to eliminate error, is a necessary need in a lot of industrial systems. Therefore designing error tolerable controller for industrial systems by using of bond graph theory to avoid physical and financial damages is one of the most important discussing issues in control engineering and related sciences. Based on this, in this paper we would model the system and error by using of bond graph theory and designing error tolerable controller.

Keywords

Modeling the System; Designing Appropriate Controller; Error Tolerable Controller; Bond Graph Theory; Detecting and Identifying Error.

Academic Discipline And Sub-Disciplines

Designing error resistant controller

SUBJECT CLASSIFICATION

68T40, 68T45, 68N20, 68N30, 68N99, 68U07, 68U35

TYPE (METHOD/APPROACH)

Designing error resistant controller by using of bond-graph theory

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1. INTRODUCTION

For physical systems, the data which are based on model can be widely represented qualitatively or quantitatively. In quantitative models, this perception is expressed by mathematical relations form between system inputs and outputs. When an error is detected, the next step is to do some operations to correct this error. The errors will be modified by re-configuration which includes exchanging hardware with sound and faultless one or changing control laws. Bond graph is a graphical way for modeling in which energy gates are related to each other by some bonds that determine energy conduction between system components. Bond graphs are a good instrument to represent information based on the model.

In this paper [3], ultrasonic linear engines bond graph has been presented. In this survey only vibration of stature and piso-electric seramics will be studied. Therefore briefly we would proceed with variant and invariant wave issue. Because the major part of engines at first uses another kind of waves to produce stature trembles and following that elliptical trajectory of points on stature surface, therefore, the equivalent electrical orbit will be presented to introduce and explain one general idea about graphical simulation of vibrator. The simulation analyzes a linear engine in an electrical system. Analysis of the problem which includes ultrasonic situation defects FDI will be presented. The most important part of this work which has been presented in this paper is defining bond graph simulation of oscillating wave ultrasonic engine and the simulation properties which is an important part for comprehending its practical principles and dynamic behavior. In this paper [4], the procedure based on bond graph modeling and FDI .detecting and isolating) resistant in the presence of uncertainty of parameters in a steam generator have been offered. Interactions of different phenomenon have been considered by using of magnetic properties of bond graph. The LFT form (linear part by part transforms) will be used for separating ARP nominal part from undetermined part. Adaptive threshold with recognizable error value for assessing reminder and improving method of supervising will be calculated. A controller for dc motor have been designed in [5] by algebraic technics, the errors are estimated and not-acceptation of their effect on the system has been represented and also situation based on bond graph is distinguished. In paper [6], methods of detecting error (fault) for non-military engineering structures are developed by using of bond graph theory. Models of sensors by using of bond graph theory are studied and defects are determined and then they reveal error. The goals of this paper are as follow: modeling of system and error by using of bond graph, simulation of system under error for analyzing system behavior in the presence of error, designing error tolerable controller, analyzing system behavior with error tolerable controller and effect of error on system efficiency, optimization of designing error tolerable controller for having the minimum level of decreasing efficiency in the presence of error.

2. Electrical loading operators

Electro-mechanical loading system includes one situation serve and a torque serve. When an under-load operator starts to move according to a command, the loading system follows the movement of under-load operator. The movement of under-load operator creates a massive time variant disturbance on the loading system and this is the most important reason of producing Afzune torque. In each of electric or hydraulic technologies which used in producing force (torque), a force control design with high accuracy and without problem could be attained when the mechanical parts on which the force has to be induct, be static or move with a low speed. In this situation a PID controller is suitable too. In this case, we need three factors to get high accuracy [2]: high severity of the system which produces force, optimizing of PID controller gains and high accuracy of energy measuring instruments.

In simulation of electro-mechanical load one uses of an electrical motor to create torque. Direct flow motors and permanent magnetic synchronized motors (PMSM) have the most applications in electro-mechanical dynamic load simulators. The simulators of electrical load have a simple structure, their maintenance and reparation are simple and also they excrete disturbance torque effectively. Todays, by developing DC torque motors, torque motors with low inertia and by developed technology of drives, the research on simulators of dynamic load with electrical operator has been developed. Also, the simulator of electrical load has been built and is used on universities and other research institutes. For moderate and low torque, according to proportion of power and high weight and better dynamical operation, one uses permanent magnetic synchronized motors for uploading operator. Of course, PMSM has non-linear dynamic, friction, dead time and other undetermined parameters. Therefore, classical methods of controller design are not suitable for it [8-11].

In comparison with electro-hydrolic load simulator, the use of electro load simulators is in its first steps and needs more studies to recognize its properties and problems. The main issue in load simulator is to control with eliminating external torque which has been created by the movement of under-test operator, by designing appropriate structure for loading system and suitable strategy of control. The swirl of under-load operator creates a large torque on uploading operator (external torque). The external torque is a massive disturbance for torque control system and has bad effects on tracing of arbitrary load. Sometimes, this torque is bigger than external torque (figure 1).

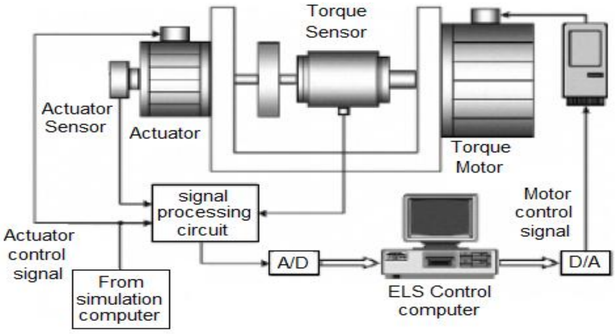

Figure 1: General view of load simulator system

3. Modeling and mathematical expression of problem

For modeling the load simulator system, which includes a DC electrical motor, a transmission and a torque-meter, we use ordinary relations of DC motor model. Also, the under-load operation is a servo system DC motor which is used in angle control mode. In figure 3, the general view of load simulator along with under-load (under-test) operator, has been shown. In the modeling of electrical motors (under-load or loading) we use classical model of DC motor with constant excitation voltage or permanent magnetic. Also, the motor drive is modeled as a constant gain. This system includes an input control voltage of motor drive (u_c) an one other input load disturbance, T_ℓ. Also, K_{pwm} , is the gain of motor drive. (We neglect the dynamic of drive). In transmission operation, for increasing torque of loading motor, the relations are as below:

$$\frac{T_{Ln}}{T_{out}} = \frac{۱}{N}, \frac{\theta_{in}}{\theta_{out}} = \frac{N}{۱} \quad , \frac{\omega_{in}}{\omega_{out}} = \frac{N}{۱} \qquad (1)$$

Practically, elastic status of the spring leads to filter the tensions which have been created because of high frequency noises and on the other hand, the under-test operator be transferred lesser toward up-loading operator [3]. Bouncy status creates an operation as a low-pass filter and also somedeal, it smooths the transferring torque toward up-loading operator. Larger amount of spring constant K_s increases the disturbance effect on up-loading operator as we show later. In some cases, one locates a torsion shaft between under-load operator and torque-meter [6]. This leads to the fact that the spring constant K_s be adjustable.

From mechanical relations of rotation, we know that if two torsion springs with spring-constant $K_{s۱}$ (equivalent with the spring status of torque-meter) and $K_{s۲}$ (equivalent with spring status of torsion shaft) become series with each other, the equivalent spring constant is obtained from:

$$\frac{۱}{K_s} = \frac{۱}{K_{s۱}} + \frac{۱}{K_{s۲}}$$

Surely, $K_s \le K_{s۱}, K_{s۲}$ and for torque-meters with above spring constant one can uses of torsion spring and decreases spring constant of the trajectory between up-loading operator and under-load operator. The relations between input and output variables of the spring are as below:

$$T'_{Ln} = K_s(\theta'_{Ln} - \theta'_{out}) \quad , T'_{out} = -T'_{in} = K_s(\theta'_{out} - \theta'_{in}) \qquad (2)$$

According to electrical motors, spring and transmission equations, the dynamic equations of load simulator along with under-test operator are as follow and also the equations of under-test and loading motors will be:

$$u_{m_j} = L_j \frac{di_{m_j}}{dt} + R_j i_{m_j} + e_{m_j} \quad , e_{m_j} = K_{ej}\omega_j \quad , T_{m_j} = K_{tj} i_{m_j}$$

$$T_{m_j} = J_j \frac{d^{۲}\theta_j}{dt^{۲}} + B_j \frac{d\theta_j}{dt} + T_{\ell_j} \qquad (3)$$

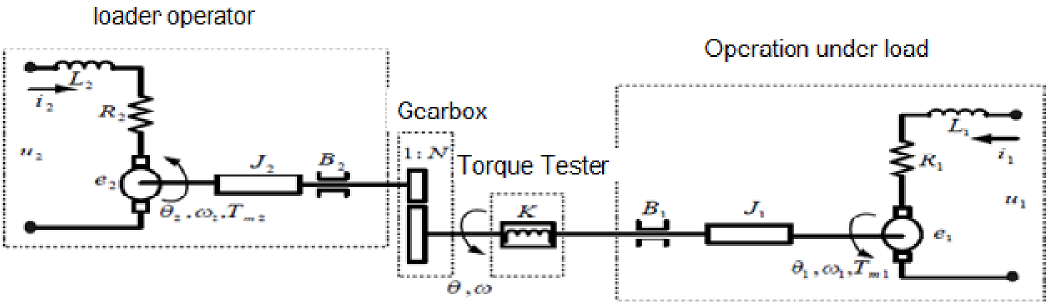

Figure 2: General view of simulator of electrical load

According to the manner of connection between torque-meter (with torsion shaft) and transmission with up-load and under-test operator, we have the relations below:

$$\theta'_{in}(\text{Spring}) = \theta_{out}(\text{Gear}$$

$$\theta'_{out}(\text{Spring}) = \theta_1 \qquad (4)$$

$$\theta'_{in}(\text{Gear}) = \theta_2$$

$$\theta_{out}(\text{Gear}) = \frac{1}{N}\theta_{in}(\text{Gear}) = \frac{1}{N}\theta_2$$

$$T_{out}(\text{Gear}) = -T'_{in}(\text{spring})$$

Now, by using of (1), (2) and (3) and the manner of elements’ connection, we specify load of each of two motors (under-test and up-load motor) as below:

$$T_{\ell_1} = T'_{out}(\text{Spr.}) = K_s\big(\theta'_{out}(\text{Spr.}) - \theta'_{in}(\text{Spr.})\big) = K_s(\theta_1 - \frac{1}{N}\theta_2)$$

$$(5)$$

$$T_{\ell_2} = -T_{in}(\text{Gear}) = -\frac{1}{N}T_{out}(\text{Gear}) = \frac{1}{N}T'_{in}(\text{Spr.}) = -\frac{1}{N}T'_{out}(\text{Spr.}) = -\frac{K_s}{N}(\theta_1 - \frac{1}{N}\theta_2)$$

Finally, by using of relations 3 and 5, the dynamic equations of under-test and up-load motors will be as follow:

$$T_{tm} = K_s\big(\theta'_{in}(\text{Spr.}) - \theta'_{out}(\text{Spr.})\big) = K_s(\frac{1}{N}\theta_2 - \theta_1) \qquad (6)$$

$$T_{m1} = J_1\frac{d^2\theta_1}{dt^2} + B_1\frac{d\theta_1}{dt} - T_{tm}$$

$$T_{m2} = J_2\frac{d^2\theta_2}{dt^2} + B_2\frac{d\theta_2}{dt} + \frac{1}{N}T_{tm}$$

4. Designing error-tolerable controller

4-1. Designing error-tolerable controller by the method of $\mathbf{H}_\infty$

To design a closed-loop system, we would look for a controller K which could comply with the properties of a closed-loop system. The designed controller has to create internal stability in closed-loop system and satisfy in condition below:

$$\left\| \begin{bmatrix} W_p S(G_{mds}) \\ W_u K S(G_{mds}) \end{bmatrix} \right\|_\infty < 1 \qquad S(G_{mds}) = (I + G_{mds}K)^{-1} \qquad (9)$$

In which Wp and Wu are not the matrix below. If the above condition satisfies, it could decrease the amount of disturbance to an acceptable level. The diagram block of closed-loop system with considering uncertainty, has been shown in figure (4).

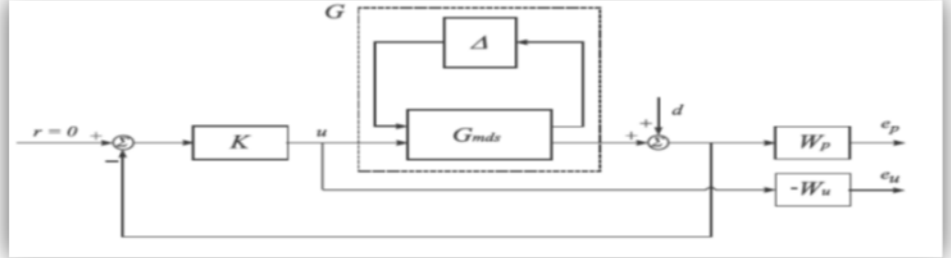

Figure 3: The structure of closed-loop system

Noticing that the indelible error of the system is too much and also to avoid indeterminations of the system, we can propose a better method to control the system.

In first step we try to obtain the system transform function by using of bond graph model of electro-mechanical upload system. To obtain system transform function without indetermination, one can use this command:

G=linearize(mdl)

4-2. The design of loopshaping control

The favorite transform function which it is better to have a good transition response and speed, for a favorite and resistant efficiency, has to satisfy the conditions below:

$$\left\| T_{y1u1} \right\|_\infty \le 1 \qquad T_{y1u1} \overset{def}{=} \begin{bmatrix} W_1 S \\ W_3 S \end{bmatrix} \tag{10}$$

Then, by using of the command below, in Matlab an obtaining weight functions W_1 and W_3, we would design error tolerable controller by the H_∞ method.

5. Simulation

5-1. Analyzing closed-loop system without the presence of controller

We apply two sinus waves into system inputs:

The applied input to the first system:

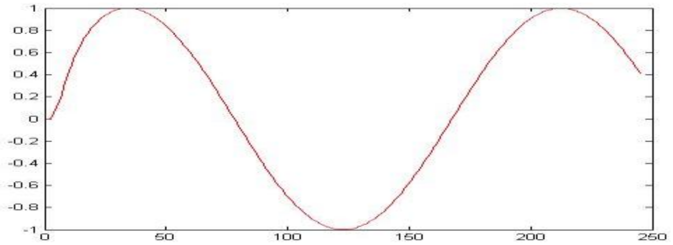

Figure 4: The reference input for angle control sub-system

The applied input to the second system:

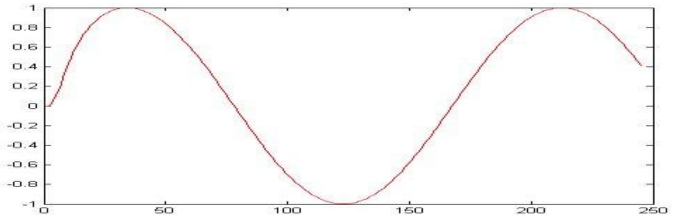

Figure 5: The reference input for the torque control sub-system

The output of under-test operator:

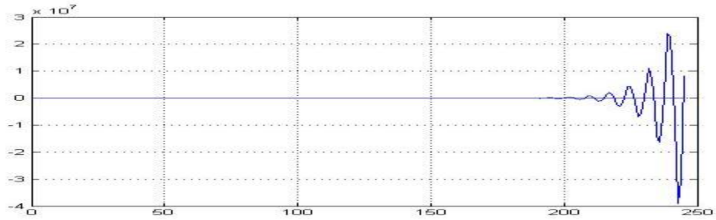

Figure 6: The reference input for the sub-system of angle control

The output of up-load operator:

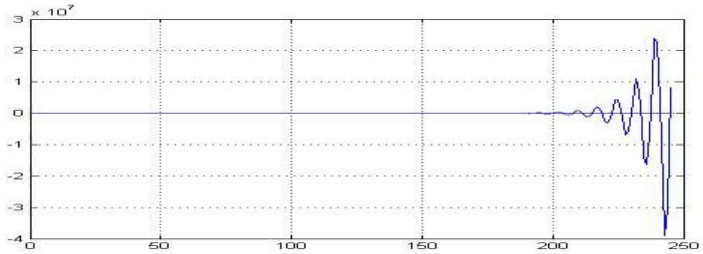

Figure 7: The reference input for the sub-system of torque control

5-2. The use of resistant controller for electro-mechanical up-load system

To avoid indeterminations of the system, one has to propose a better method to control the system. In first step, we try to obtain the transfer function of the system. To get the transfer function of the system without indeterminations, one can use the command below and observe the response of the system:

G=linearize(mdl)

The step response of the system after linearization is as follows:

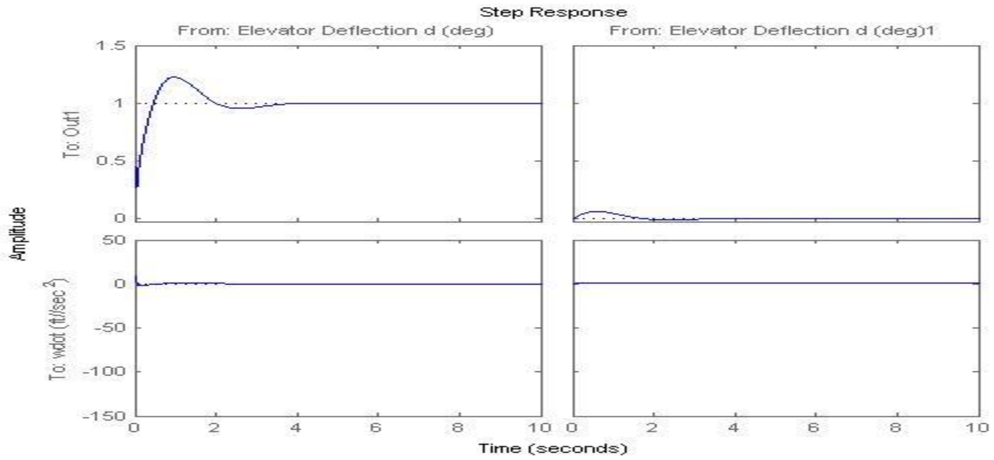

Figure 8: The step response of iroload system after linearization

After running the Simulink file a, indetermination will be appeared in variables ke1 and ke2, which each of parameters have 80 percent of indetermination.

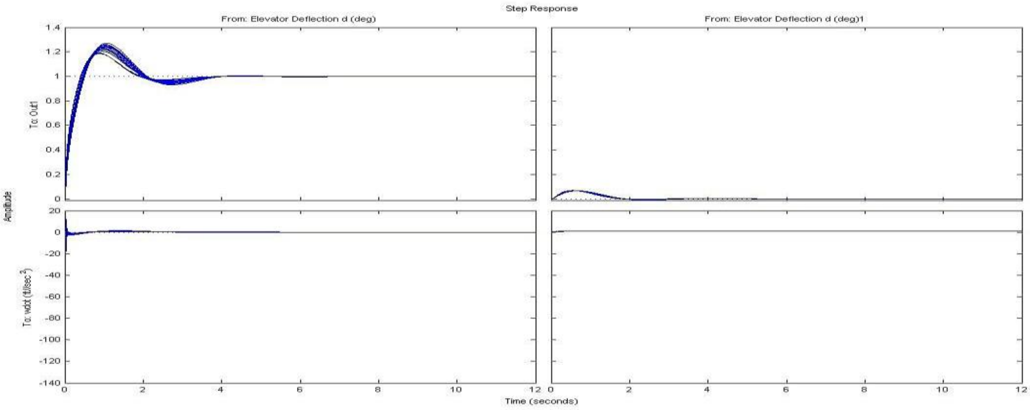

Figure 9: Step response after applying indetermination

In figure 10, singular value in frequency domain and step response of the system with resistant controller have been calculated and drown.

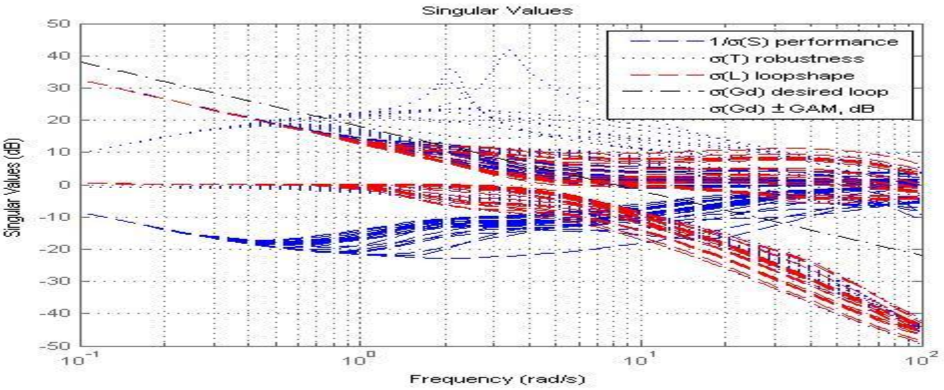

Figure 10: The perspective of singular values in frequency domain

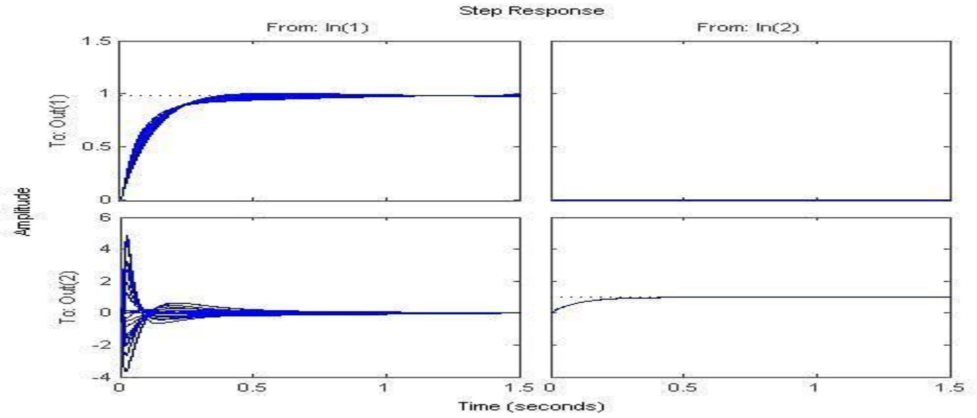

Figure 11: The step response of the system with resistant controller

The step response of system, with resistant controller, has been evaluated and drown.

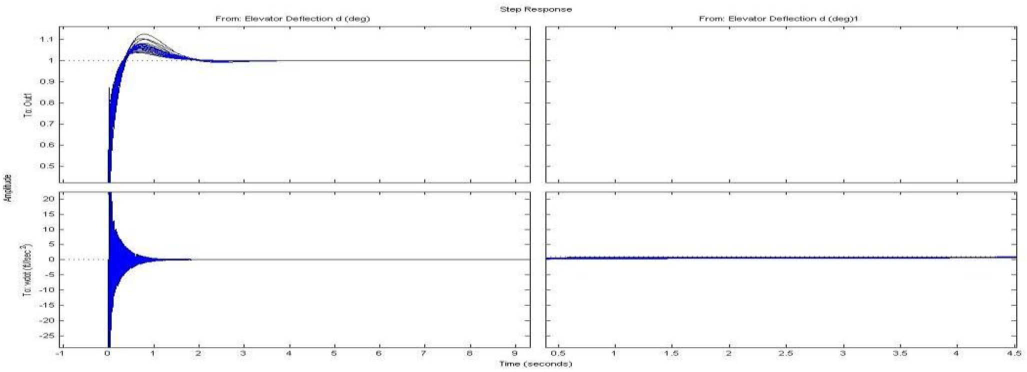

Figure 12: The step response of the system after applying indetermination in variables N, ke2 and ke1

Again, with previous resistant method, we can observe the results of control:

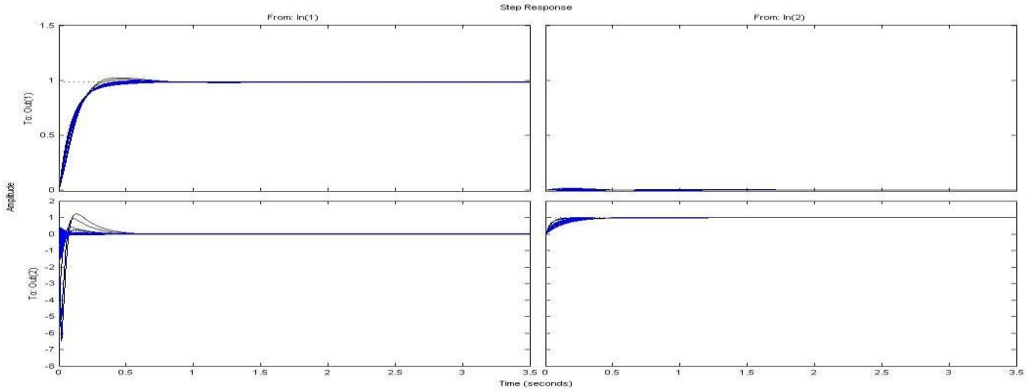

Figure 13: Step response after applying indetermination in quantities N, ke2 and ke1 with resistant controller

We can observe that the resistant controller has improved the step response of the system well. The speed of the system has increased and also the amount of system over-shout has had suitable decrease for almost all of the intervals of indeterminations.

The uncertainty in torque sensor:

We assume that parameter k has uncertainty:

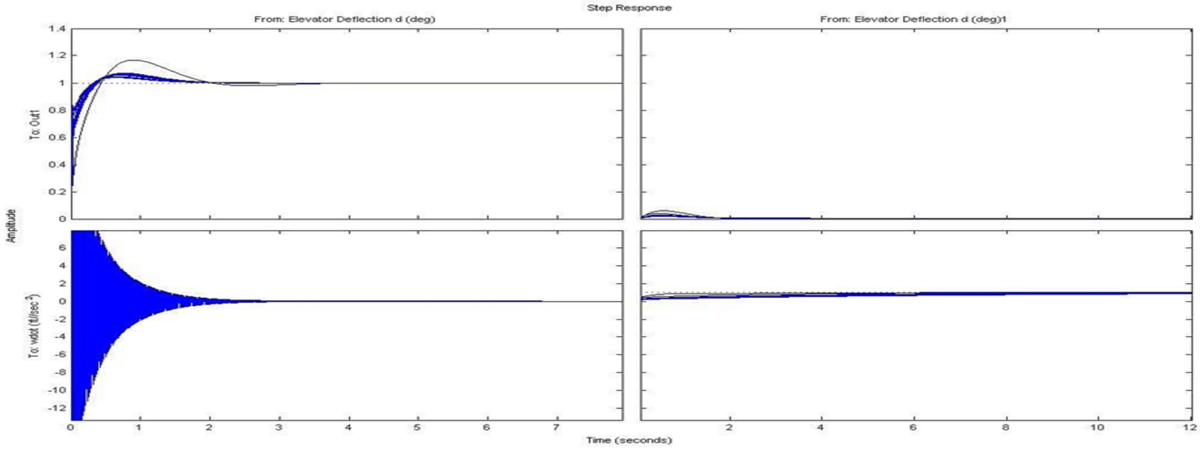

Figure 14: The system step response after applying uncertainty in quantities N,ke2,ke1 and K

We observe that the resistant controller has improved the system transient response as well, the speed of the system has increased and the amount of over-shout of the system response has decreased for almost all intervals of uncertainties.

5-3. The study of time-variant uncertainty on electro-mechanical up-load system

In this project, we neglected of FDD part because of using inactive methods of error tolerable control and also no effort has made to recognize time, location and kind of error. Therefore the closed-loop system will be resistant to some kinds of pre-determined errors (if they occur) and by decreasing operation, it continues its act of controlling in a stable manner. We draw the error of parameters k, ke1 and ke2 as a function of time and study the three concurrent errors.

The input, output, error to sinus wave as input and parameter errors for angle control servo system:

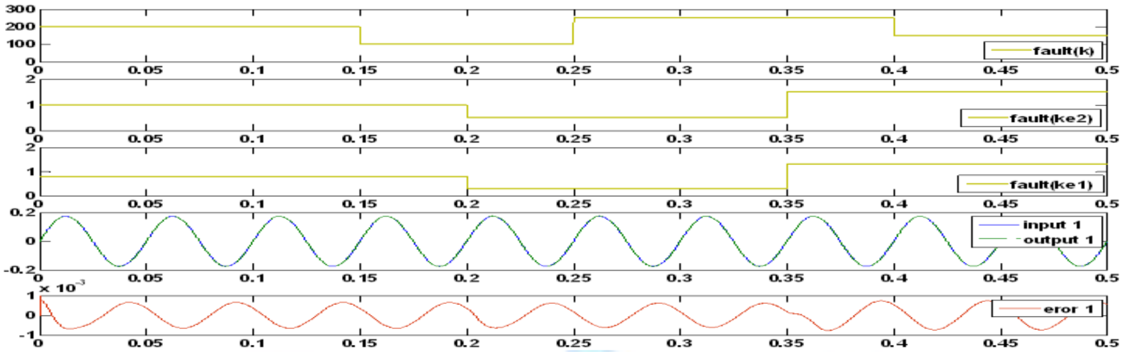

Figure 15: The error of parameters ke2, ke1, k, first input and first output and error to reference input in angle control servo system

The input, output, error to sinus wave as input and parameter errors for angle control servo system:

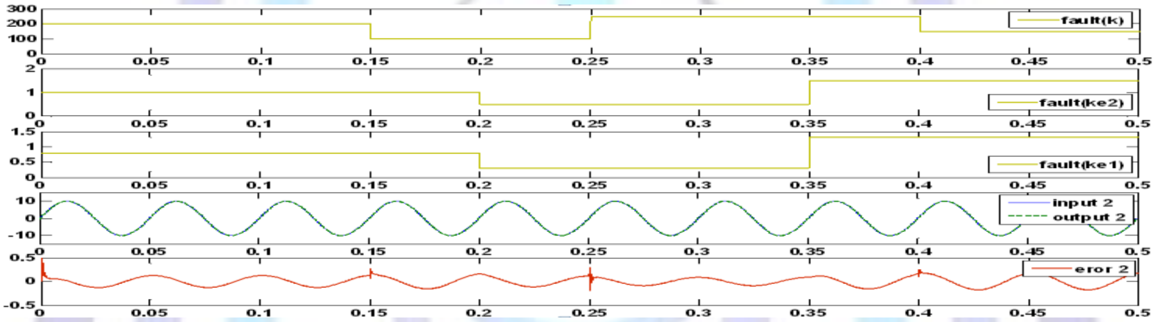

Figure 16: The error of parameters ke2, ke1, k, second input and second output and error to reference input

The diagrams of chasing situation and chasing error and diagrams of chasing torque and torque error have been shown in figures 5-45 and 5-46. The notable point is that the situation real output follows situation command and also the real output of torque follows the torque command, precisely. By applying time-variant indetermination, the time of tracing system has increased in second input ant it shows that the effect of error has increased in servo system of torque control.

5-4. the effect of noise on electro-mechanical up-load system

In last simulation, we want to study the noise effect in closed-loop control system. To evaluate the effects of measured signal, in continuing simulation, we add a white noise signal with power 0.05 and sampling time 0.0s sec to output signal of torque-meter.

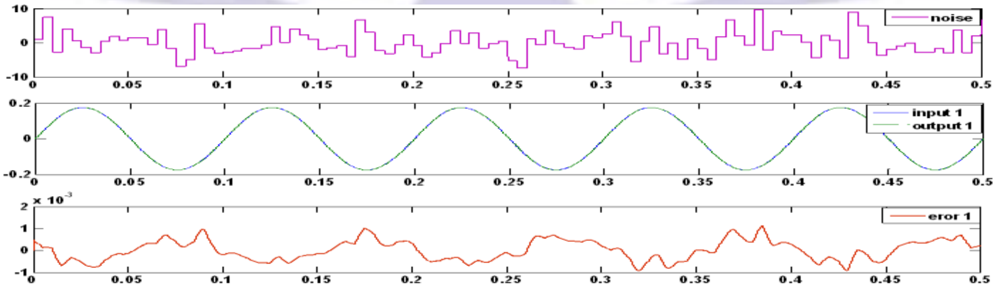

Figure 17: The measured noise in control servo system of the torque of chasing situation and in servo system of situation control and error of chasing in presence of noise in torque control servo system

In figure 17, chasing situation and its error in situation control servo system in presence of noise in torque control servo system have been shown. As we see, noise has effect just on error of chasing. The set of diagrams related to situation control servo system shows that the existence of noise in second sub-system does not have significant effect on first sub-system and it is because of good separation of two sub-systems in control designing.

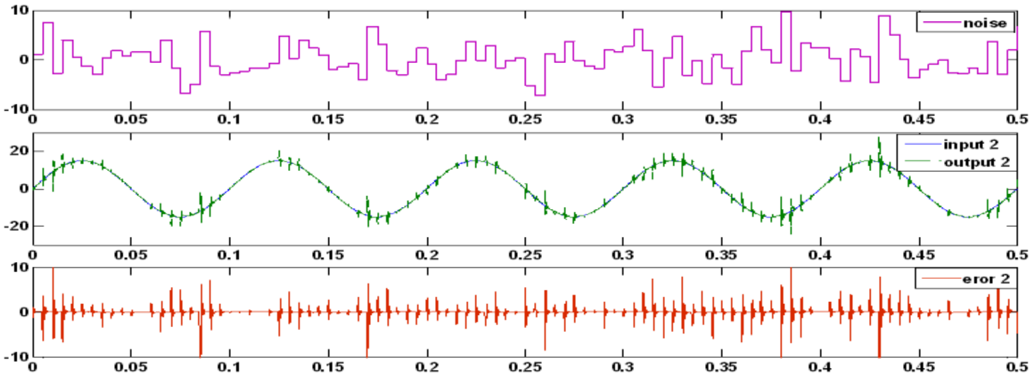

Figure 18: The measured noise in torque control servo system, chasing torque in torque control servo system and error of chasing in presence of noise in torque control servo system

6. Concluding

The offered solution method was based on designing error tolerable controller by using of bond graph modeling theory, which is so effective on electro-mechanical up-load system. In this method, the time of solving problem is so short and the accuracy of the result is so high. Also, one can apply the offered method in calculations of real time in which the time of problem solving is important. Therefore, in this paper, we proceeded to the modeling of system and error by using of bond graph theory and designing error tolerable controller and we simulated and studied the modeled and controlled situation in presence of unknown parameters and noise.

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