AEROSPACE ENGINEERING AEE 383- SYSTEM DYNAMICS 2023 – 2024 FALL SEMESTER MINI – PROJECT

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***Abstract*—This report is about behavior of PID controllers for a mechanical system. Report has a content of studies done for designing PID controllers and providing a suitable environment for a test such as design of physical system, DC motor and applications on proper software.**

Keywords: control; PID; torque; overshoot; settling time; rise time.

Introduction (Heading 1)

This report includes the design of a rudder with given dimensions and the analysis of simulation studies for a control system. The purpose of this project is to design a rudder control system including a PID controller, DC Motor, gearbox, and rudder. Modeling of the DC motor and gearbox was carried out using MATLAB Simulink, and Simmechanics was used to model the rudder. Before simmechanics modeling, the rudder was designed using SolidWorks according to the specified rules. After the material was assigned to Solidworks, it was exported to the MATLAB environment. Thus, the moment of inertia values of the rudder calculated automatically by the software. PID gain values founded by Ziegler–Nichols method.

Methodology (Heading 2)

This project requires four main steps and these are creatingthe physical environment , selection proper elements, designing the elements and contruct the elements. Every step explained briefly below:

A. Solidworks

In scope of project we have some dimensional information about the physical parts. To obtain a simulation, Physical modeling done with modeling software Solidworks.

Given dimensions of pars given as:

Shaft diameter: 17(*mm*)
Shaft height: 202(*mm*)
Rudder joint diameter: 34(*mm*)
Rudder tip diameter: 8.5(*mm*)
Rudder height: 162(*mm*)
Rudder length:94.5(*mm*)
Rudder mass:1.7(*kg*)

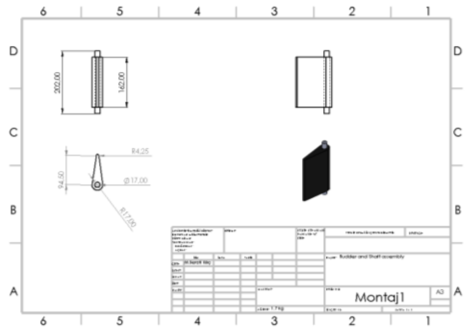

Figure 1: Technical drawing of rudder and shaft model

Technical drawing of designed rudder and shaft model given in *Figure1*.

Thanks to the software used, properties such as volume,location of center of mass and moment of inertia can be easily accessed.

B. Selection of DC motor

One of the requirements of the project is engine selection. and this selection was requested to be made based on physical structure. After calculating the required features, a suitable DC motor was selected from MAXON.

The feature taken into consideration when selecting the motor is to be able to provide the torque required by the specified movement. The method used to calculate the required torque has been simplified and modeled considering the physical environment. This simplification includes the following: acceleration of the rudder to reach the desired position occurs at half the angle between the initial position and the desired position. It is assumed that the remaining distance will be traveled with constant angular velocity. Since our maximum angle is 35°, as stated in the requirements of the project, the necessary torque must be provided to reach the maximum value. To make this assumption, we also need to choose the rise time. In this context, considering the physical conditions, the rise time is assumed to be 0.5 seconds, and 0.4 seconds of this time belongs to acceleration and 0.1 second belongs to constant speed motion. Please note that this assumption is made only to simplify modelling. It is expected that more effective results will be obtained from such an assumption in simulations. To calculate required torque the limiting conditions considered and equations (1-3) used.

$$\omega = d\theta/dt \quad (1)$$
$$\alpha = d\omega/dt \quad (2)$$
$$T = I\alpha \quad (3)$$

Since rudder has moment of inertia about the shaft approximately 3.46 (gm^2) torque required for movement is at least 26.5 (*mNm*). Considering the non-ideal conditions and safety factors, it was decided that the motor would be *"ECX SPEED 13M Ø13 mm ceramic bearings, brushless "*

Figure 2:ECX SPEED 13M Ø13mm

C. Design of motor

DC motor that used in simulations firstly designed in Simulink. Diagram[1] is used in design given in *Figure 3.* This diagram gives the modelled transfer function in the context of Simulink.

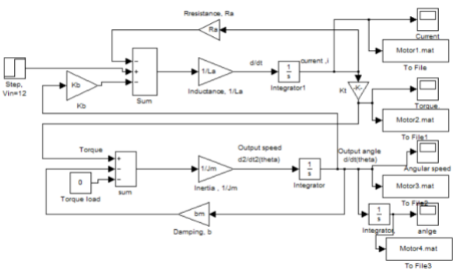

Figure 3: Simulink diagram of DC motor.

With the characteristic values of DC motor decided and Simplified version of this diagram formed in Simulink as *Figure 4.*

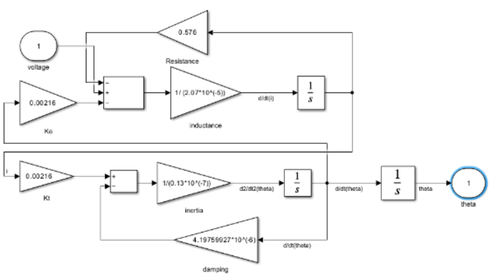

Figure 4: Motor diagram used in Simulink

D. Ziegler-Nichols method

The Ziegler-Nichols method is a technique used to determine the parameters of a PID (Proportional-Integral-Derivative) controller for a given process. This method typically involves finding initial parameters through practical experimentation[2]. In this report there is a simulations instead of experimentation. Basically this method consists of three steps. The first step is the finding naturally critical oscillation period and ultimate gain . Second step is using Ziegler-Nichols table to determine Kp, Ki, and Kd values. Third step is testing and tuning with respect to previous results. This method used to find values of PID and these values given in next heading.

Simulations (Heading 3)

Applied Ziegler-Nichols method steps given follow:
When every gain value settled up as initials result graph observed as *Figure 5.*

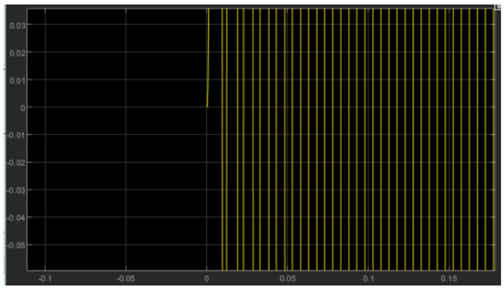

Figure 5: Graph for Kp=1,Ki=0 and Kd=0

With the several trials naturally oscillations observed for ultimate gain approximately 0.2 with critical oscillation period 0.2 as shown in *Figure 6.*

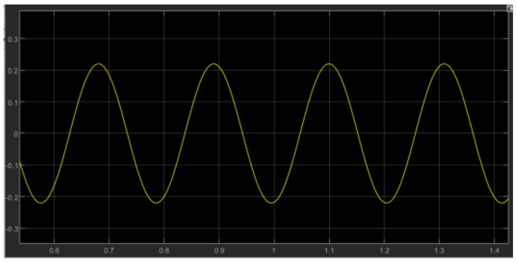

Figure 6: Graph for Ku=0.2

For that gain value proportional, integral and derivative gains calculated as; Kp=0.12 , Ki=1.2,Kd=0.003. With these value PID system reconstructed and result graph observed as shown in *Figure 7.*

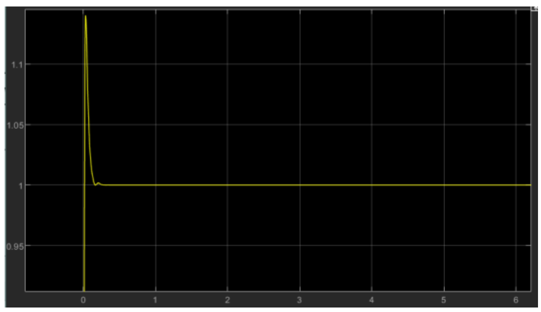

Figure 7: Resulting graph

With the table of effects of parameters shown in *Table 1* [3] PID system redesigned for a several time and overall PID gain values obtained. Overall PID system shown in *Figure 8.*

Parameters	Rise Time, t_r	Overshoot, M_p	Settling Time, t_{ss}	Steady-state error , e_{ss}	Stability
K_p	Decrease	Increase	Small change	Decrease	Decrease
K_i	Decrease	Increase	Increase	Decrease significantly	Decrease
K_d	Minor Decrease	Minor Decrease	Minor Decrease	No effect	Improves

Table 1: Effects of increasing PID parameters

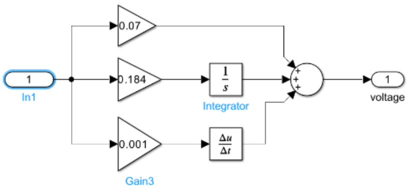

Figure 8: Overall PID system.

A overall diagram of system consists of step input (with degree to radian converter), a feedback sum point, PID controller, DC motor , gear box ,rudder and scope for obtaining the position outputs as shown in *Figure 9.*

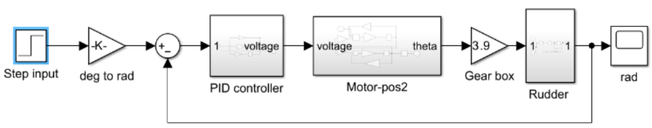

Figure 9:Overall diagram of system.

Finally several inputs entered into system and obtained the responses of these inputs. As a result, the system have a general overshoot as 4.74% , rise time as 0.04 seconds and settling time as 1.2 seconds.
Results of inputs as 35° 15° -15° and 35° are given in *Figure10.*

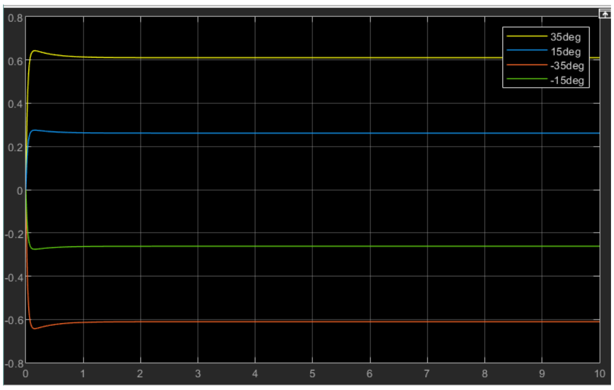

Figure 10: resulting graph for inputs in radians

Conclusion (Heading 4)

Consequently this report showed that the basic processes for understanding PID control systems and their responses to physical environment as a rudder and DC motor that moves rudder. Within the scope of this study, various simulations and analyses were conducted using PID control systems. The obtained results demonstrate the effectiveness of PID control algorithms in achieving the desired performance in specific systems.

References

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[2] K Ogata, Discrete–Time Control Systems, University of Minnesota, Prentice Hall, 1987.

[3] M. Kasahara, T. Matsuba, “Design and tuning of robust PID controller for HVAC systems,” ASHRAE Trans, vol.105, no. 2, pp. 154-166, 1999.