Designing The Stirrer Machine by PI-Controller Using Simulink Design Optimization for Checking Step Response Characteristics

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Abstract:— Nowadays, there are several techniques for controlling the system. This paper shows how to create a transfer function of the stirrer machine at a speed range of 500-800 RPM. (Maximum speed of the stirrer machine is 2000 RPM.) by system identification toolbox technique in MATLAB/Simulink, when know the transfer function of the stirrer machine, that can generate feedback control to design. The stirrer works in this speed range only, if the speed of rotation is less than 500 RPM. or more than 800 RPM. That is not the range of design data, The system will be unstable and unable to control as desired. Since the transfer function of the stirrer is type zero, the appropriate controller is the PI controller, but this paper will show examples of how to optimize the PI value that puts the system in the range of a Rising time of 1.5 sec, settling time of 2.5 sec (%Settling time 2%) and percent overshoot less than 10 percent using the Check Step Response Characteristics method in MATLAB/Simulink.

1. Introduction

Control system theory is a branch of mathematics and engineering. dynamic control to have the desired output value. by entering the appropriate input values into the system[1].

Control systems may also be divided into open-loop control system is a control system that does not use a signal from the output to indicate the nature of the control, The closed-loop control or feedback system uses the measured value from the output to calculate the controller value. In addition, may also be classified according to system characteristics, such as linear or non-linear, time-varying or not-time-varying and continuous-time or discontinuous time [2].

Simulink[®] Design Optimization[™] provides functions, interactive tools, and blocks for analyzing and tuning model parameters [3]. That can determine the model's sensitivity, fit the model to test data, and tune it to meet requirements. Using techniques like PID-Tuner simulation and Design of Experiments, can explore your design space and calculate parameter influence on model behavior.

Simulink Design Optimization helps you increase model accuracy. You can preprocess test data, automatically estimate model parameters such as friction and aerodynamic coefficients, and validate the estimation results [4-5].

Nowadays, computer applications have evolved a lot in both hardware and software. As a result, working on engineering works is easy, fast and accurate. Because computers have fast and accurate calculations. One of the programs that facilitate most engineering calculations is MATLAB.

MATLAB has many functions for calculating engineering tasks. This paper discusses the System Identification Toolbox function and Signal Constraints, which is one of the tools used to determine parameters for designing a control system.

2. Data-Driven Control

2.1 Modeling of The Stirrer Machine

Figure 1 shows the operation of the stirrer control circuit at 500-800 RPM. To collect input and output data, open-loop data acquisition is used to estimate the transfer function in the speed range to control

Fig. 1. The Stirrer Machine.

From the block diagram, the stirrer machine is Open-loop as show in Figure 2 and used the Simout Workspace toolbox to return the parameters input and output data into the Workspace in MATLAB. And, the system identification toolbox will find the transfer function from the relationship graph of the input (Voltage) and output (RPM).
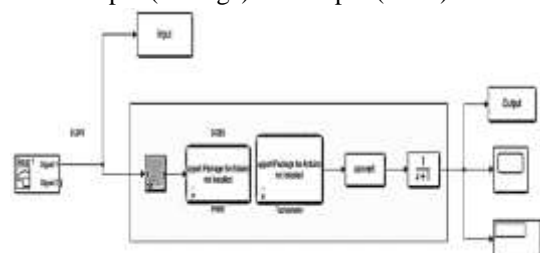

Fig. 2. Open-Loop of The Stirrer Machine.

2.2 The relationship between the input (Voltage) and Output (RPM) graphs.

From the Figure 2. Set up the signal voltage desired to design the speed in SIMULINK. The input voltage directly affects the speed of rotation. As the voltage increases, the speed of rotation increases and when the voltage declines, the speed of rotation declines as show in the graph in Figure 3. Use SIMOUT to Workspace toolbox for storing input and output graphs signal before data is sent to Workspace MATLAB.
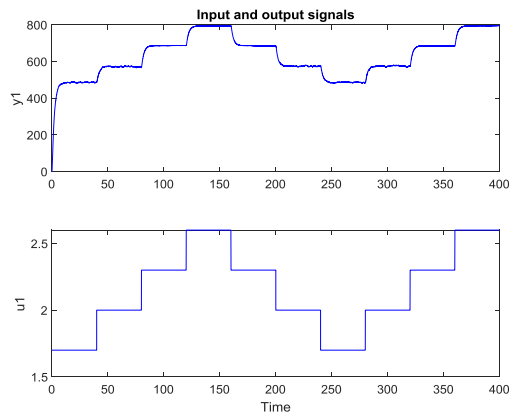

Fig. 3. Input (Voltage) and Output (RPM) signal.

2.3 Input-Output data is sent to the Workspace.

From the input and output graphs, Used the SIMOUT to Workspace toolbox from Figure 2, the data is sent to the Workspace in MATLAB as show in Figure 4. for determining the transfer function from the System Identification Toolbox in the next chapter.

Fig. 4. Input-Output data from the graph.

3. Methodology

System Identification is one method used to find a mathematical model for the PLANT system. When a mathematical model is obtained, that is used to design a closed-loop system. Including the design of the controller used to control the system[6].

This paper is a development and modeling of open-loop system. Once a mathematical model is obtained [7-8], that will be simulated as a closed-loop system. In other words, the system used in this development will have a controller in the system. Which the controller will cause the stability of the system. This makes it possible to design the speed of rotation.

3.1 Model Estimation and Validation

Use the system Identification Toolbox and import measured time-domain or frequency-domain data as show in

Figure 5. Select the transfer function in function estimate for design POLE and ZERO in figure 6. And the next step shows the open-loop transfer function of the stirrer machine in Figure 7.
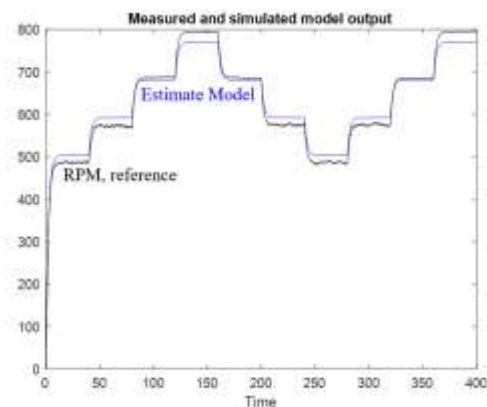

Fig. 5. Import measured Time-domain.

Fig. 6. Estimate Transfer Function.

In Figure 6, the black line is the speed reference graph and the blue line is the system design, In general, the stirrer or DC motor is second-order, it has 2 poles and in Figure 5 when creating a number of poles is 2, the number of zeros is 0 (From Figure 5) then the transfer function show in Figure 7.
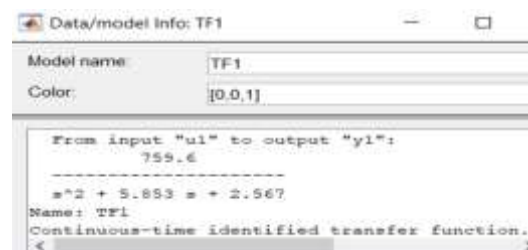

Fig. 7. Transfer Function Model.

3.2 Check Model of Open loop Transfer function

When knowing the transfer function of the stirrer machine. Consider Figure 3. Just set up the input voltage show in Figure 8, and see if the desired speed of rotation is obtained, when the desired speed of rotation is obtained the model of the stirrer machine is correct. Can be designed as a closed system in the next method.
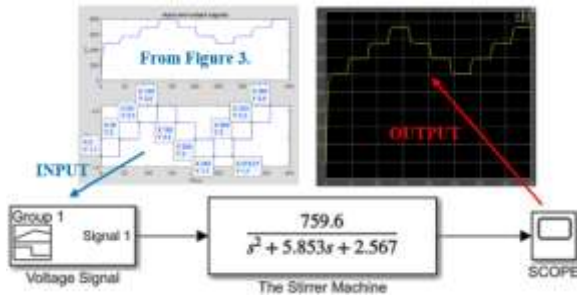
Fig. 8. Check Model of Openloop Transer Function.

3.3 Analysis and Design Closed-loop

When knowing the Plant model, it can be designed as a closed-loop system to control the required rotation speed show in figure 9. to make it easier to design, choose the PID-Tuner block and Optimize the signal to find the P, I value.
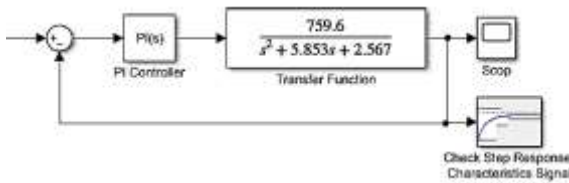

Fig. 9. Closed-loop of the Stirrer Machine.

Transfer function has type 0, choose the PI control block to design, set Proportional (P) to P and Integral (I) to I, then configure PI with an initial value of 1 to allow the program to determine the appropriate value for the controller within that scope. The controller settings can be done as show in Figure 10.
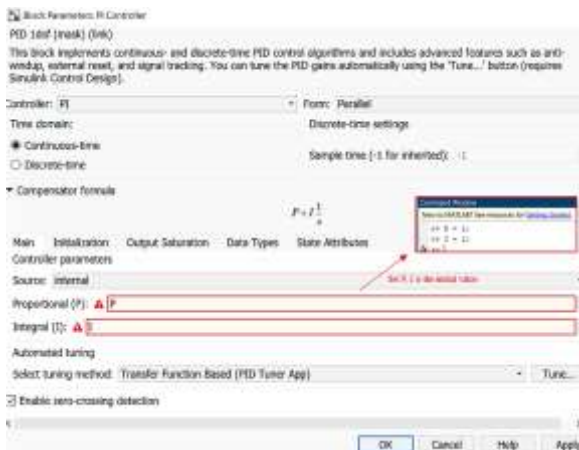

Fig. 10. PI-Control block.

In the Check Step Response Characteristics Signal block, define the boundaries of the system design and find the most suitable P, I signal for the system as shown in Figure 11. Determining the boundaries of the design, in this paper, the system designer set the Rise time to 1.5 sec, settling time to 2.5 sec (%Settling time 2%) and %Overshoot is less than 10%, (it depends on you to design) then the Response Optimization Signal will show in Figure 12.
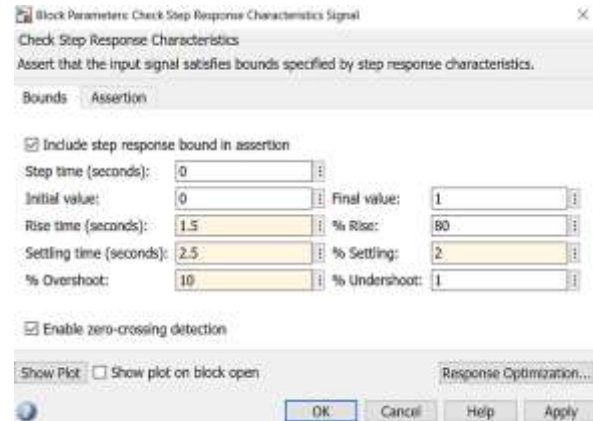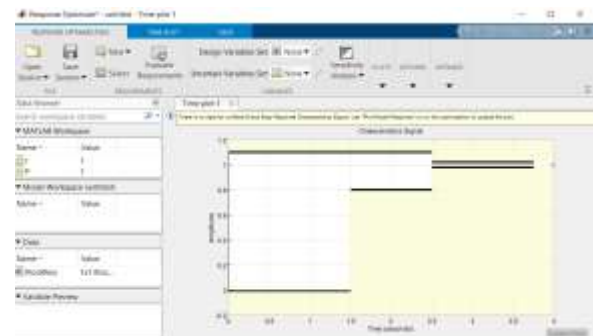

Fig. 11. Scope of system design

Fig. 12. Optimization Signal block.

3.4 Formula of Equations

-Transfer function of DC Motor is equation

$$TF(S) = \frac{K\omega_n^2}{s^2 + 2\xi\omega_n^2 s + \omega_n^2}$$ (1)

When   K   is Gain

       ξ is Damping Ratio

       ω_n is Natural Frequency

-Transfer function of PI-Controller is equation

$$G_{PI}(S) = \frac{Ps + I}{S}$$ (2)

When   P   is proportional

       I   is integral

-Steady-State error of Unit-Ramp is equation

$$K_v^{new} = C \times K_v^{old}$$
$$I^{new} = C \times I^{old}$$ (3)

When   C   is Constant value

   K_v^{new} is velocity constant (Calculate)

   K_v^{old} is velocity constant (1/Error Unit-Ramp)

   I^{new} is integral gain (Calculate)

   I^{old} is integral gain, a turning parameter

When setting the scope and initial value of PI and set the time of the program to less than 10 seconds to run the

program to optimize the parameters of P and I at the best in the next result chapter.

4. Result

There are many methods for designing a speed control system. This paper is an example of control speed at 500-800 RPM. by System Identification. To determine the transfer function and design to a closed-loop system. From the scope in figure 10 and setting optimize PI signal block in Figure 11 when running the program, it was found that the signal PI caused the optimal contract as show in Figure 13. And Table 1.
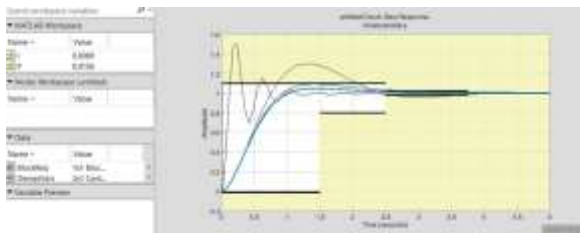

Fig. 13. Response Optimizer.

TABLE I. PARAMETER OF PI-CONTROLLER

Signal	P	I
Initial Value	1	1
Optimize Value	0.0156	0.0089

When knowing the PI values obtained from finding the appropriate values and uploading instead of the initial PI values, from Figure 8 when changing the new PI values, to see if the system is in scope or not? that can check the response in Figure 13. And Table 2.
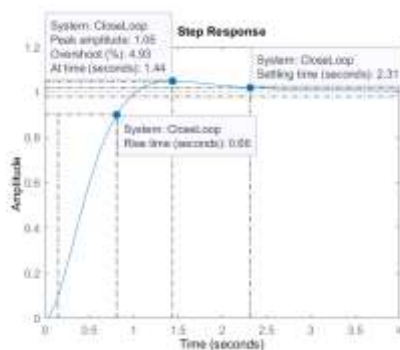

Figure 14. Response Optimizer Signal.

TABLE II. SCOPE OF AFTER DESIGN

SCOPE	AFTER DESIGN
Rise Time 1.5 sec	0.66 sec
Settling time to 2.5 sec	2.31 sec
% Overshoot is less than 10%	4.93%

5. Conclusion

From finding the appropriate signal value of the PI controller that can control the speed at 500-800 RPM. That show the P-value was 0.0156 and I-value was 0.0089 which

resulted in the controller signal being within the specified range. Therefore, this method of optimizing the design of a closed-loop control system is one of the methods for controlling the system accordingly. The simulation result through a stirrer is shown in Figure 15.
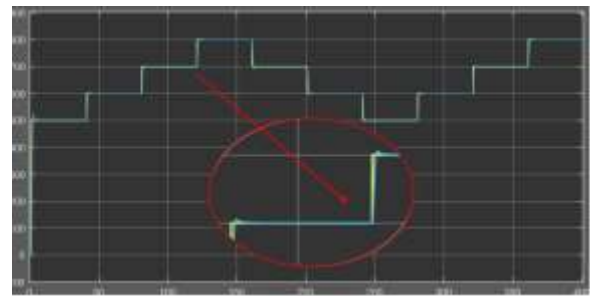

Fig. 15. the simulation result through a stirrer at 500-800 RPM

Acknowledgment

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