Evaluation of the Transient Response of a Servo Motor Using MATLAB/Simulink

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

____

Rosmawati bt. Mat Zain

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ASHFAQ GHAFRAN BIN ABDUL RAHMAN

ABSTRACT

Servo motors are being used in many types of applications which require information to be fed back to allow a device to serve its purposes. For example, servo motor is used in radio-controlled car to provide actuation for the steering system. However, the application in which the servo is used depends on the servo’s performance. Different servos may have similar principle of working but each of it may have its own specifications which set them apart in term of their usability. One way to study the performance of a servo motor is by observing its transient response. Hence the aim of this project which is to conduct a thorough evaluation of the transient response of a servo motor using computer simulation by using MATLAB/Simulink. Computer simulation is a popular way to test the performance of a system, an effective alternative besides testing the actual system. Before the simulation is done, the mathematical model for the servo is studied and a block diagram is established as the representation of the system. The performance of the system is observed by executing simulations from the block diagram using Simulink in which the outputs are the transient responses. The completion of this project will hopefully bring significant aid for future users of a servo motor in analyzing its behavior and performance.

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I would like to extend my sincere gratitude to my supervisor, Mdm. Rosmawati Mat Zain for her assistance and guidance towards the progress of my Final Year Project. My deepest appreciation to the university and also the Final Year Project coordinators whose arrangement of events really helped the progress of my study.

Most of all, I am grateful to my family and friends for their endless encouragement and support they have given me over the years.

Last but not least, a special mention to my advisor for her constant encouragement all this time. Thank you.

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CHAPTER 1
INTRODUCTION

1.1 Background of Project

Robotics is the increasingly popular field of engineering which involves science and technology of robots, and their design, manufacturing and application in aiding human to perform tasks. From factories to shopping malls, from five-star hotels to household areas; robotics applications are practically everywhere. The widespread usage of robotics structures is mainly caused by the rapid growth of science of technology in the past decade. In certain field of works, robots are preferred over the conventional ways of performing tasks due to its high reliability and efficiency, which is why they are built in the first place.

The mechanical structure of a robot usually consists of links, joints and actuators. Links are similar to bones for human while joints are to provide more degrees of freedom for the robot. Actuators can be described as the muscle of a robot as it converts stored energy to movement and they are powered by electric motors, mostly. For small sized robotics appliances, the electric motors used are servo motors (servos). Servo is usually used in radio-controlled model to provide actuation for the mechanical systems such as the steering of a car and control of helicopter rotor.

In the last decade, they have been widely used in the field of robotic systems by virtue of their compactness, high torque-weight ratio, cost performance and easiness-to-use. Nowadays, servo motor is a reasonable choice to realize compact and less expensive mechatronic systems [1]. Servos have various specifications for the users to choose from, depending on the kind of performance they wish to have.

1.2 Problem Statement

In analysing a servo which acts as the core mechanism of robotic appliances, we use computer simulation to study the performance of the motor. Simulation of a model is always used as an alternative tool to study the behaviour of a system besides having the actual system itself to be tested on.

Transient response of a servo serves quite a significant role in determining its performance. The transient part of the response occurs at the beginning of the servo operation and it will proceed to become steady-state once the servo stabilizes itself. If the transient response is long, it will take longer time to reach steady-state thus longer time to stabilize and vice versa. In order to study the said response, a model is used to emulate the actual system behaviour. A model is a representation of a system where we can assign variables and manipulate it so that we can observe any changes resulted from our actions. The significance is that the changes represent how the system would react in real time if we alter the variables.

Studies involving servo motors often associate the output of the response with the rotation angle of the motor [1] [9]. This project revolves around the study of servo motor performance with regards to its speed rather than rotation angle. The justification is simple; if there are two runners A and B competing for a 100-meter run; their performances are measured by who reaches the finishing line first, which means he is the fastest, regardless if the runner A has a longer step than runner B and vice versa. To achieve the target, a servo motor model with speed as its output is built based on information available and the simulations are carried on based on it.

In addition, investigation of the performance of a motor requires other elements in the output response such as armature current and the torque to be included in the studies hence the evaluation on those factors are conducted too and will be presented in the later section.

1.3 Objective

The objective is to evaluate the transient response of a servo motor by using MATLAB/Simulink. The output response produced from the simulations represents the performance of the servo motor and the characteristics of the response are to be studied in order to observe the behaviour of the system.

1.4 Scope of Study

Output response consists of transient and steady-state part. The transient part of the output response possesses a higher significance compared to its steady-state counterpart with regards to the servo performance. Therefore, this project will revolves around the former while the latter can be ignored completely. The transient response is to be studied and its correlation with the behaviour of the actual system will be observed and presented on the later part of this report. The scopes of studies are:

1. To obtain the appropriate mathematical model that represents the servo system.
2. To identify parameters affecting the performance of servo motor.
3. To determine the values of the parameters by performing calculations.
4. To establish an appropriate block diagram of the system using Simulink.
5. To perform simulations to analyse the servo performance.

CHAPTER 2
LITERATURE REVIEW

2.1 History of Servo Motor

The concept of servo motor is much older than the use of the term. The Greeks used wind-driven servo motors to continuously adjust the heading of windmills so the turbine blades always faced into the wind. Early history is difficult to trace because of the differences in language and terms used in various quarters [3]. The study on the origins of servo motor traces all the way back to 1800s in which it will be discussed briefly in this section.

According to Owen (1996)

> The name “Le-Servomoteur” or slave-motor was used by Farcot in 1868 to describe hydraulic and steam engines for use in ship steering. Actual origins of the term are lost in antiquity, but Otto Mayr cites a book published by the Farcot family that contains the first printed use of this term. In 1896, H. Calendar in England developed the first electric servo-mechanism, which was a contactor-actuated “follow-up” device for use with strip chart recorders. In 1898, Nikola Tesla experimented with “wire-less control” of model ships on the Potomac River basin. He also used electric contractor “servo motors” to steer model ships remotely.
>
> In 1908, Elmer Sperry used electric contractor “servo motors” for his gyroscopic compasses. In 1911, Henry Hobart defined servo motor in his electrical engineering dictionary. In 1916, Lawrence Sperry filed a U.S. patent application for an aerial torpedo which a “servo motor” moved the rudder to steer the course. By 1915, the term “servo motor” was firmly

> entrenched within the language of America’s community of electrical engineers and perhaps elsewhere. The term is certainly French origin rather than English.
>
> In 1922, work began at General Electric on “electronic Selsyn-servos” for use in directing naval guns. By 1925, GE engineers had built an electronic servo using proportional control plus rare feedback for stability, all elements of modern servo-mechanisms. By 1930, both GE and Westinghouse were making strip chart recorders that used electronic servo motors for driving the pen mechanism. By 1933, Leeds and Northup offered a chart recorder with a DC servo, similar to the GE approach. All of these developments were empirical in nature, with little or nothing in the way of theory to support them. Minorsky’s work on ship steering was the first effort to bridge the gap between practical applications and analytical or mathematical theory. (p. 74)

The works of these people are some of the earliest form of servo-mechanism manipulation in various applications which also contribute to the development of servo motor until it reaches the shape, size and design as being seen today.

2.2 Servo Motor

A servo motor is any kind of electric motor whose speed or position is controlled by a closed loop feedback circuit [3].

Takashi *et al.* (2009) stated that R/C servo motor is a popular name for a sort of compact DC geared-motor packages including motor drivers and position servo controllers, where R/C stands for Radio-Control. R/C servo motors were originally developed for hobby use such as radio-controlled vehicle or aircraft.

According to Seattle Robotic Society

> A servo is a small device that has an output shaft. This shaft can be positioned to specific angular positions by sending the servo a coded signal. As long as the coded signal exists on the input line, the servo will maintain the angular position of the shaft. As the coded signal changes, the angular

position of the shaft changes. It also draws power proportional to the mechanical load. A lightly loaded servo, therefore, does not consume much energy.

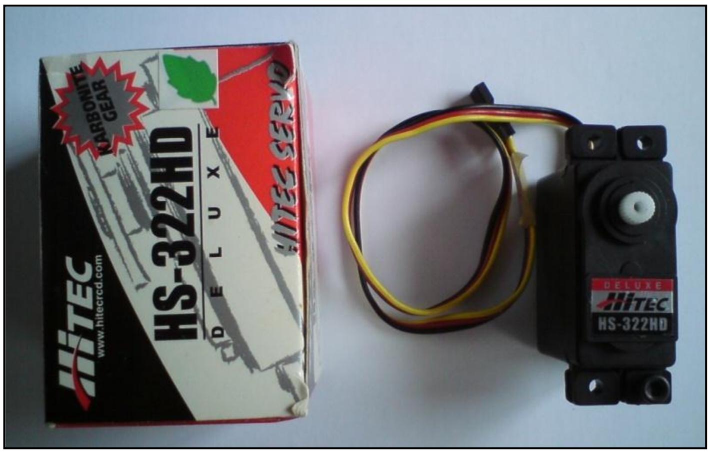


Fig. 2.1: HS-322HD Servo

For this project, model Hitec HS-322HD (see Fig. 2.1) will be used. Below are the specifications [5]:

- Control System: +Pulse Width Control 1500usec Neutral
- Required Pulse: 3-5 Volt Peak to Peak Square Wave
- Operating Voltage: 4.8-6.0 Volts
- Operating Temperature Range: -20 to +60 Degree C
- Operating Speed (4.8V): 0.19sec/60° at no load
- Operating Speed (6.0V): 0.15sec/60° at no load
- Stall Torque (4.8V): 42 oz.in (3.0 kg.cm)
- Stall Torque (6.0V): 51 oz.in (3.7 kg.cm)
- Current Drain (4.8V): 7.4mA/idle and 160mA no load operating
- Current Drain (6.0V): 7.7mA/idle and 180mA no load operating
- Dead Band Width: 5usec
- Bearing Type: Top/Resin Bushing
- Gear Type: Heavy Duty Resin
- 360 Modifiable: Yes
- Dimensions: 1.57" x 0.79"x 1.44" (40 x 20 x 36.5mm)
- Weight: 1.52oz (43g)

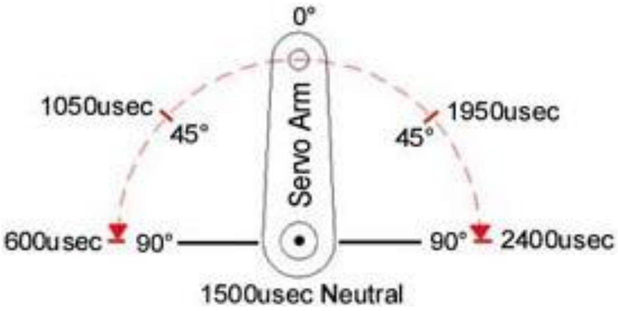


Fig. 2.2: Servo angle schematic [5]

This servo can operate 180° when given a pulse signal ranging from 600usec to 2400usec (see Fig. 2.2) [5]. These details and specifications of the servo will be used in determining the values for the parameters involved in the model developed.

2.3 The Structure and Working Principles of a Servo Motor

As of today, many terms are being associated with servo motor such as servo-mechanism, regulator, controller, feedback control etc. Owen (1996) explained these terms in his article: In modern terms, servo-mechanisms are feedback control systems incorporating servo motors. Therefore, servo motor as now used is only a component of servo-mechanism. It is power actuator that drives the load. Servo-mechanism, regulator and feedback controller all possess several attributes in common. The reference input expresses the desired value. The controlled variable is brought into correspondence with the reference input by the actuator. The disturbance function perturbs the process. A feedback means is used to evaluate the difference (or actuating error) between reference input and some function of the controlled variable. A servo-mechanism is usually associated with positional control.

Storr (2010) stated that a servo motor consists of a DC motor, reduction gearbox, positional feedback device and some form of error correction. The speed or position is controlled in relation to a positional input signal or reference signal applied to the device. The error detection amplifier looks at this input signal and compares it with the feedback signal from the motors output shaft and determines if the motor output shaft is in an error condition and, if so, the controller makes appropriate corrections either speeding up the motor or slowing it down. This response to the positional feedback device means that the servo motor operates within a "Closed Loop System".

Takashi *et al.* (2009) explained that the R/C servo motor (servo) is composed of a DC motor, a potentiometer, an embedded servo controller and an amplifier. The control circuit and the amplifier serve as the controller and the potentiometer outputs the analog voltage which is proportional to the angle of the DC motor. Usually, servo accepts a series of square pulses as its command, and the width of the pulses corresponds to the reference angle of the servo, so that we can specify the reference angle by tuning the duty ratio of the pulse. When the reference angle is input into the servo, the embedded servo controller computes the control input needed to track the reference angle, and apply the voltage to the DC motor.

Fig. 2.3 shows the structure of a servo [2]:

Fig. 2.3: The servo motor structure [2]

2.4 Servo Motor Modelling and Simulation

Before the modelling and simulation could be initiated, a mathematical model representing the system must be identified first. Fig. 2.4 shows the schematic diagram of a servo motor [10].

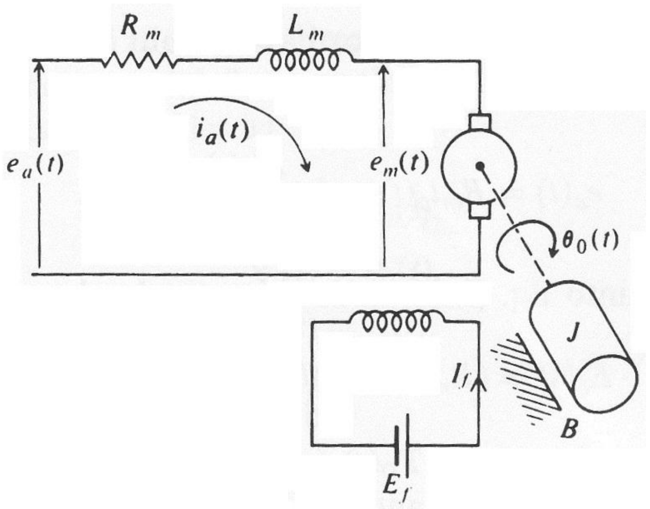


Fig. 2.4: Servo motor schematic diagram [10]

Stanley (1998) explained that the symbols R_m and L_m represent the resistive and inductive components of the armature circuit. The motor is shown driving a load having and inertia J and damping B. As the armature rotates, it develops an induced voltage $e_m(t)$ which is direct opposite to $e_a(t)$. The induced voltage is proportional to the speed of rotation ω_m and the flux created by the field current. Because we are assuming that the field current is held constant, the flux must be constant. Therefore, the induced armature voltage is only dependent on the speed of rotation can be expressed as:

$$e_m(t) = K_e \omega_m = K_e \frac{d\theta_0(t)}{dt} \qquad (1)$$

K_e = voltage constant of the motor, V/(rad/sec)

Voltage equation of the armature is

$$e_a(t) = R_m i_a(t) + L_m \frac{di_a(t)}{dt} + e_m(t) \qquad (2)$$

Substituting (1) into (2) and taking the Laplace transform, we obtain

$$E_a(s) = (R_m + L_m s) I_a(s) + K_e s \theta_0(s) \qquad (3)$$

Developed torque of the motor, $T_D(t)$ is a function of the flux developed by the field current, the armature current, and the length and number of the conductors.

Assuming that the field current is held constant, the developed torque $T_D(t)$ can be expressed as

$$T_D(t) = K_T\, i_a(t) \tag{4}$$

Where K_T = torque constant

$$T_D(t) = J\frac{d^2\theta_0(t)}{dt^2} + B\frac{d\theta_0(t)}{dt} \tag{5}$$

Substituting (4) into (5) and taking the Laplace transform,

$$K_T\, I_a(s) = (Js^2 + Bs)\, \theta_0(s) \tag{6}$$

The overall system transfer function $\theta_0(s)/E_a(s)$ obtained by eliminating $I_a(s)$ between (3) and (6)

$$\frac{\theta_0(s)}{E_a(s)} = \frac{K_T}{JL_m s^3 + (R_m J + L_m B)s^2 + (R_m B + K_e K_T)s} \tag{7}$$

Now that the mathematical model representing the system has been obtained, the next step is to find an appropriate block diagram of the servo. This block diagram must contain the essential parameters that have significant effects on the servo performance so that system behaviour could be studied. The values of the parameters are calculated and will be incorporated in the established block diagram. The calculations will be presented in the later part of this report.

The studies on servo motor are relatively new in the sense that its usage only started to diversify in the last decade thanks to the rapid growth of the robotics field. As been stated before servo motor is preferred in robotics appliances due to its good performance that comes with miniature physical built, making it fits easily into a structure or a moving mechanism. However, servos are rarely used in the studies of control theory in spite of their practical advantages; instead, many control theorists prefer to adopt DC servo motors with current-feedback amplifies capable of torque-command, which are heavy, costly and energy consuming in general [1].

Takashi *et al.* (2009) studied the practical modelling and system identification of R/C servo motors (servo). Fig. 2.5 shows the block diagram of a servo under the assumption that all blocks are linear systems [1]. K(p) and P(p) correspond to the embedded servo controller and the DC motor, respectively. U(t) is the reference angle and Φ(t) is the rotation angle of the DC motor.

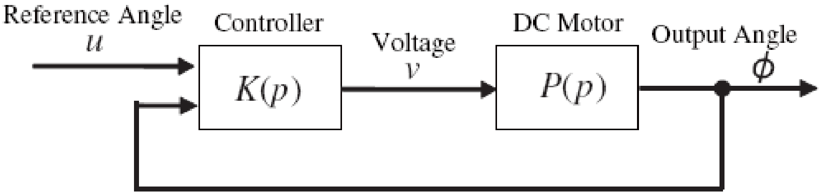


Fig. 2.5: Block diagram of an R/C servo motor [1]

Najib *et al.* (2007) presented a more detailed block diagram representing the system of a servo motor. Fig. 2.6 shows the schematic of the servo motor while Fig. 2.7 is the frequency-domain block diagram constructed based on this schematic [9].

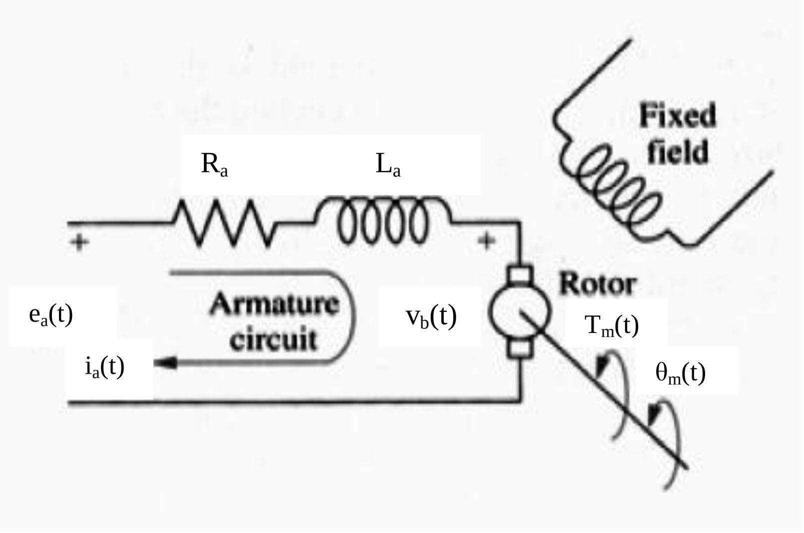


Fig. 2.6: Schematic of the servo motor [9]

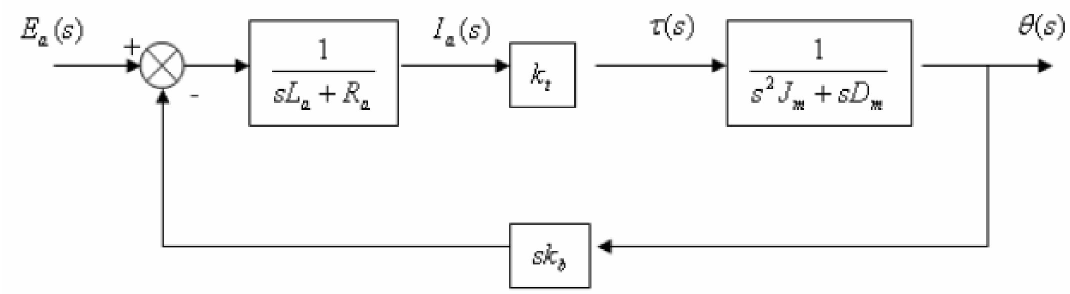


Fig. 2.7: Example of block diagram of a servo system [9]

However, in both cases, the output is the servo rotation angle which is not suitable to reflect the performance of the motor. A model with the motor speed as its output is the more accurate option for the study of transient behaviour of the system. Tan (2003) studied the performance of a large DC motor and presented a block diagram representing the servo system as Fig. 2.8 below [11]. He used the motor speed as the output of the simulation hence deemed this model as the more reasonable choice to be referred to in this study.

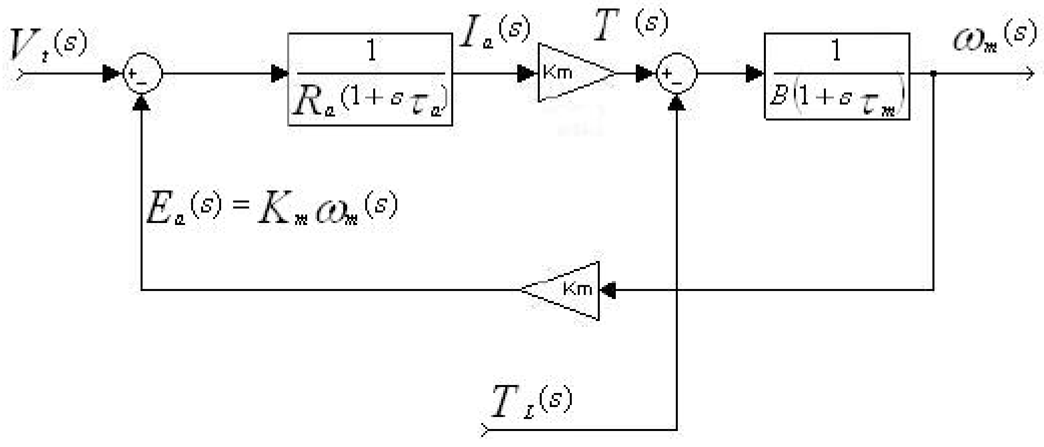


Fig. 2.8: Block diagram representation of a DC motor [11]

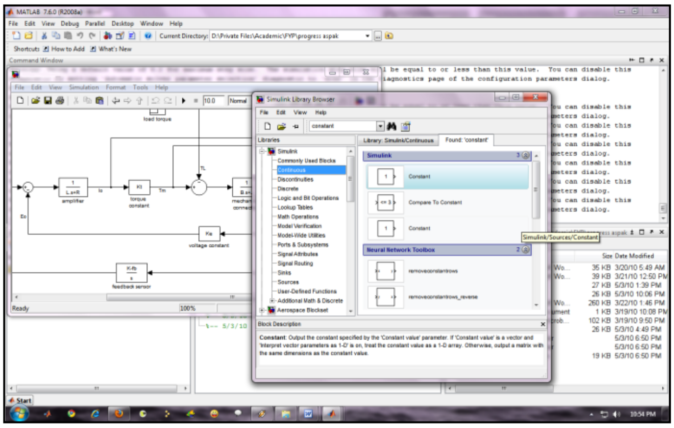
CHAPTER 3

METHODOLOGY

3.1 Tool Description

As stated in the previous chapter, the simulations will be done using MATLAB/Simulink. Tan (2003) suggested the usage of mathematical tool to perform the simulation of a motor system. MATLAB® is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science [7].

Simulink is a software package that enables you to model, simulate, and analyse systems whose outputs change over time. Such systems are often referred to as dynamic systems. Simulink can be used to explore the behaviour of a wide range of real-world dynamic systems, including electrical circuits, shock absorbers, braking systems, and many other electrical, mechanical, and thermodynamic systems [8].



```
l be equal to or less than this value.  You can disable this
iagnostics page of the configuration parameters dialog.
```

Constant: Output the constant specified by the 'Constant value' parameter. If 'Constant value' is a vector and 'Interpret vector parameters as 1-D' is on, treat the constant value as a 1-D array. Otherwise, output a matrix with the same dimensions as the constant value.

Fig. 3.1: MATLAB/Simulink user interface

3.2 Project Flow

1. Obtaining mathematical model for the servo motor – the first important step in establishing the parameters for the servo is to derive the system or to estimate transfer function representing the system. Equations relating the parameters are observed. This mathematical model will also be the basis of the establishment of the system block diagram.

2. Calculation – Once the mathematical model is obtained, the value of the parameters involved can be calculated using the available information on the servo motor specifications prepared by the manufacturer.

3. Finding model for the servo system – Block diagrams are studied from various sources. The most appropriate model is identified and referred to for the build-up using Simulink. Parameters affecting the performance of the servo motor are identified.

4. Establishing block diagram – An appropriate block diagram needs to be established based on the parameters defined before the simulation could be performed.

5. Simulations – The developed block diagram is used as the representation of the servo system so that its performance can be simulated using Simulink. In series of simulations, the parameters of the servo are manipulated for the purpose of observing how the system responds to the changes made.

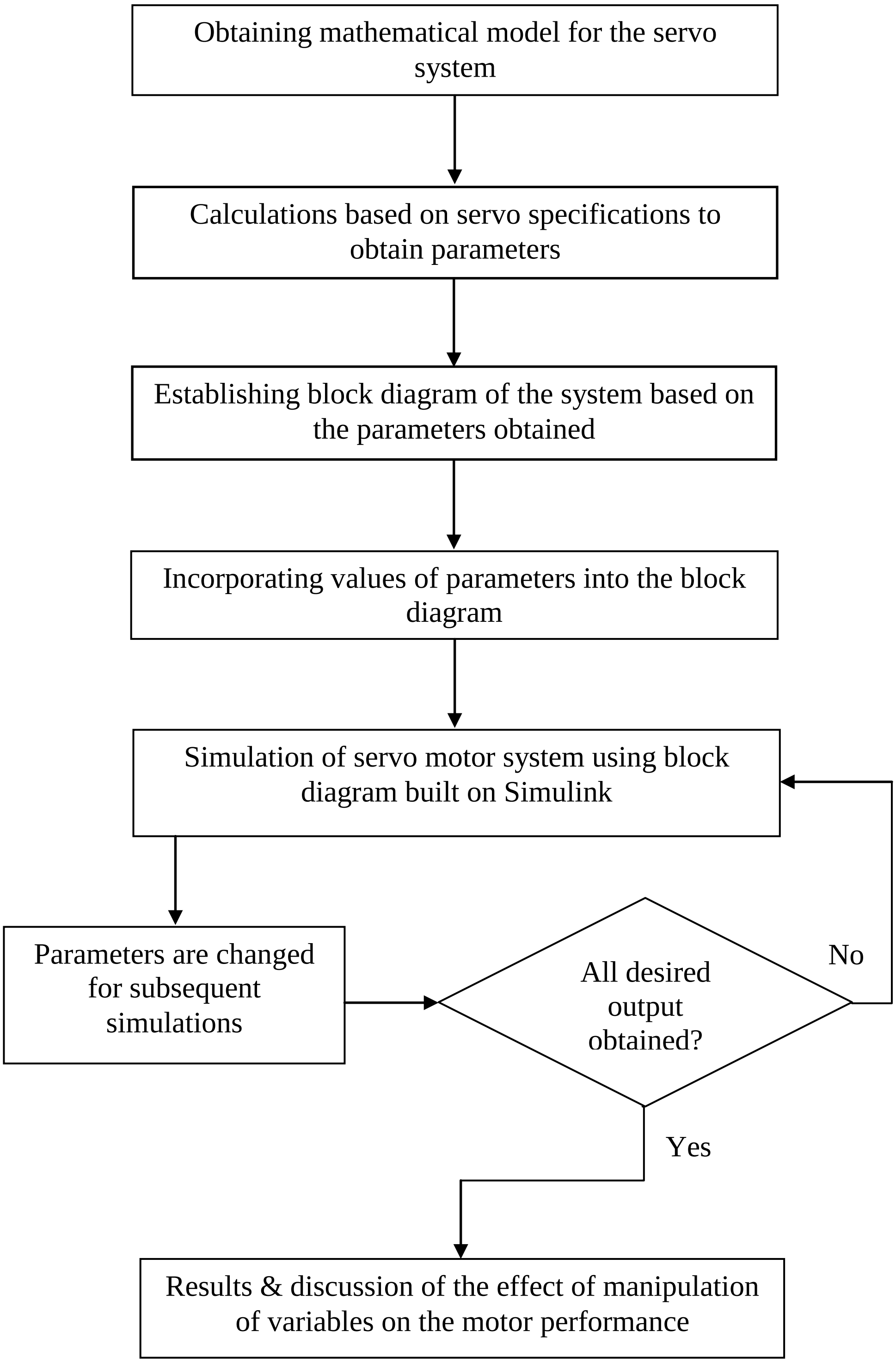


Fig. 3.2: Project flow chart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Calculations of Parameters

With reference to certain specifications of the servo motor, the previously unknown values of the parameters can be obtained through series of calculations. Using the values obtained, a model representing the servo motor system is developed using Simulink and the simulations are performed. The details of the calculation of parameters values are as follow:

The motor's operating voltage, V being used is 5.0V. Using the specifications above, the corresponding parameters values:

Operating speed, ω_m at 5.0V:

$$\frac{6.0-4.8}{5.0-4.8}=\frac{0.15-0.19}{\omega_m-0.19}$$

$$\omega_\mathrm{m}=0.1833\mathrm{sec}/60^\circ \text{ at no load}$$

Stall torque, T_D at 5.0V:

$$\frac{6.0-4.8}{5.0-4.8}=\frac{3.7-3.0}{T_D-3.0}$$

$$\mathrm{T_D}=3.117\mathrm{kg}\cdot\mathrm{cm}$$

Current drain, I at 5.0V:

$$\frac{6.0-4.8}{5.0-4.8}=\frac{180-160}{I-160}$$

$$\mathrm{I}=163.33\mathrm{mA} \text{ at no load}$$

Impedance, $Z = \frac{V}{I}$

$$Z = \frac{5.0V}{163.3mA}$$

$$Z = 30.62\,\Omega$$

Resistance, $R_m = Z \cos \Phi$

$$R_m = 30.62 \cos 60°$$

$$R_m = 15.31\,\Omega$$

Reactance, $X = 2 \sin \Phi$

$$X = 2 \sin 60°$$

$$X = 1.732\,\Omega$$

Servo works on frequency, $f = 50$Hz

Inductance, $L_m = \frac{X}{2\pi f}$

$$L_m = \frac{1.732}{2\pi(50)}$$

$$L_m = 0.005513\text{H}$$

At 5.0V, stall torque = $3.117 kg \cdot cm \times \frac{9.81N}{1kg} \times \frac{0.01m}{1cm}$

$$= 0.3058 N \cdot m$$

Speed, $\omega_m = \left(\frac{0.1833s}{60°} \times \frac{180°}{\pi rad.} \right)^{-1}$

$$= 5.713 rad/s$$

From equation (1),

$$e_m(t) = K_e \omega_m$$

$e_m(t)$ is equivalent to operating voltage 5V.

Therefore, voltage constant of the motor, $K_e = \dfrac{5V}{5.713 rad/s}$

K_e = 0.8752 *V/(rad/s)*

The following calculations are the continuation from page 10:

From equation (4),

$T_D(t) = K_T\, i_a(t)$

Therefore, torque constant, $K_T = \dfrac{0.3058 N \cdot m}{163.3 mA}$

K_T = 1.873 *N. m/A*

From equation (5),

$$T_D(t) = J\frac{d^2\theta_0(t)}{dt^2} + B\frac{d\theta_0(t)}{dt}$$

$$T_D(t) = J\frac{d\omega_m}{dt} + B\omega_m$$

At steady-state both I_a and ω_m stabilized,

$\dfrac{d\omega_m}{dt}$ = 0, therefore $T_D = B\omega_m$

Damping, $B = \dfrac{T_D}{\omega_m}$

$$B = \frac{0.3058}{5.713}$$

B = 0.05353

To find the inertia J, it is assumed that the weight is distributed evenly within the servo width:

$$J = R^2 + M$$

Weight of servo, M = 43g = 0.0043kg

Width of servo = 20mm = 0.02m

Therefore, R = ½(Width) = 0.01m

$$J = R^2 + M$$
$$J = (0.01)^2 + 0.0043$$
$$J = 4.4 \text{ x } 10^{-3}\ kg\ .\ m^2$$

Listed here are the parameters needed for the establishment of an appropriate model:

R_m = 15.31 Ω

L_m = 0.005513H

K_e = 0.8752 *V/(rad/s)*

K_T = 1.873 *N. m/A*

B = 0.05353

$J = 4.4 \text{ x } 10^{-3}\ kg\ .\ m^2$

4.2 Modelling of Servo System Using Simulink

Based on the available parameters of the servo motor and the previous models presented in past works, a model is developed using Simulink as shown in Fig. 4.1. The parameters values obtained as shown in previous section are keyed-in into the respective blocks to complete the model. Once the values are filled in, the simulations are performed and the results can be observed immediately.

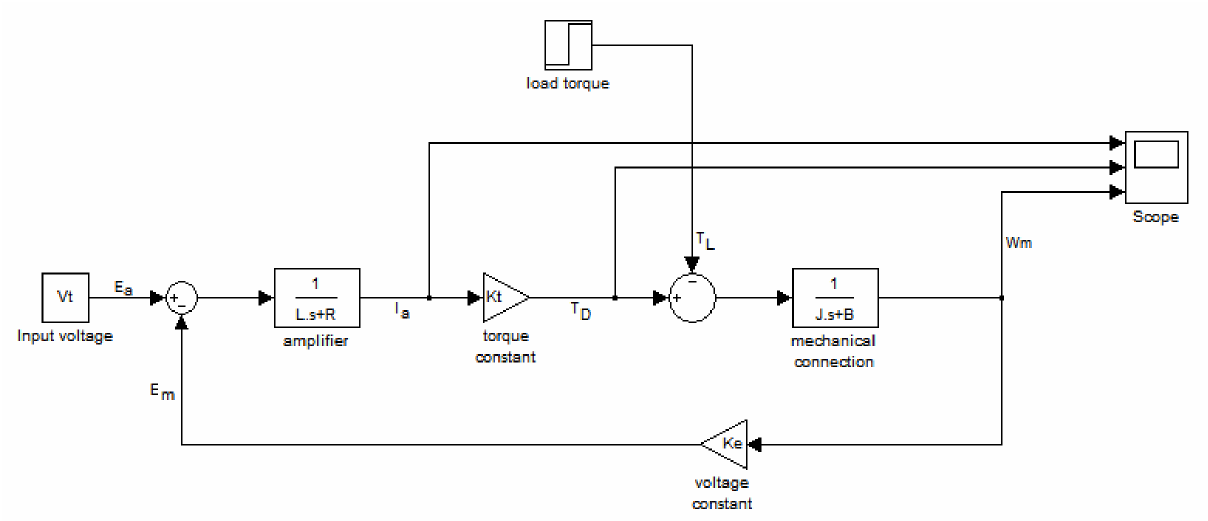


Fig. 4.1: Servo motor block diagram

In order to analyse the performance of the HS-322HD servo motor, the system is simulated using MATLAB/Simulink. For this project, simulation results for 6 case studies are presented for discussion.

4.3 Simulation Results

4.3.1 Case 1: Initial conditions, input voltage, V_t is 5V

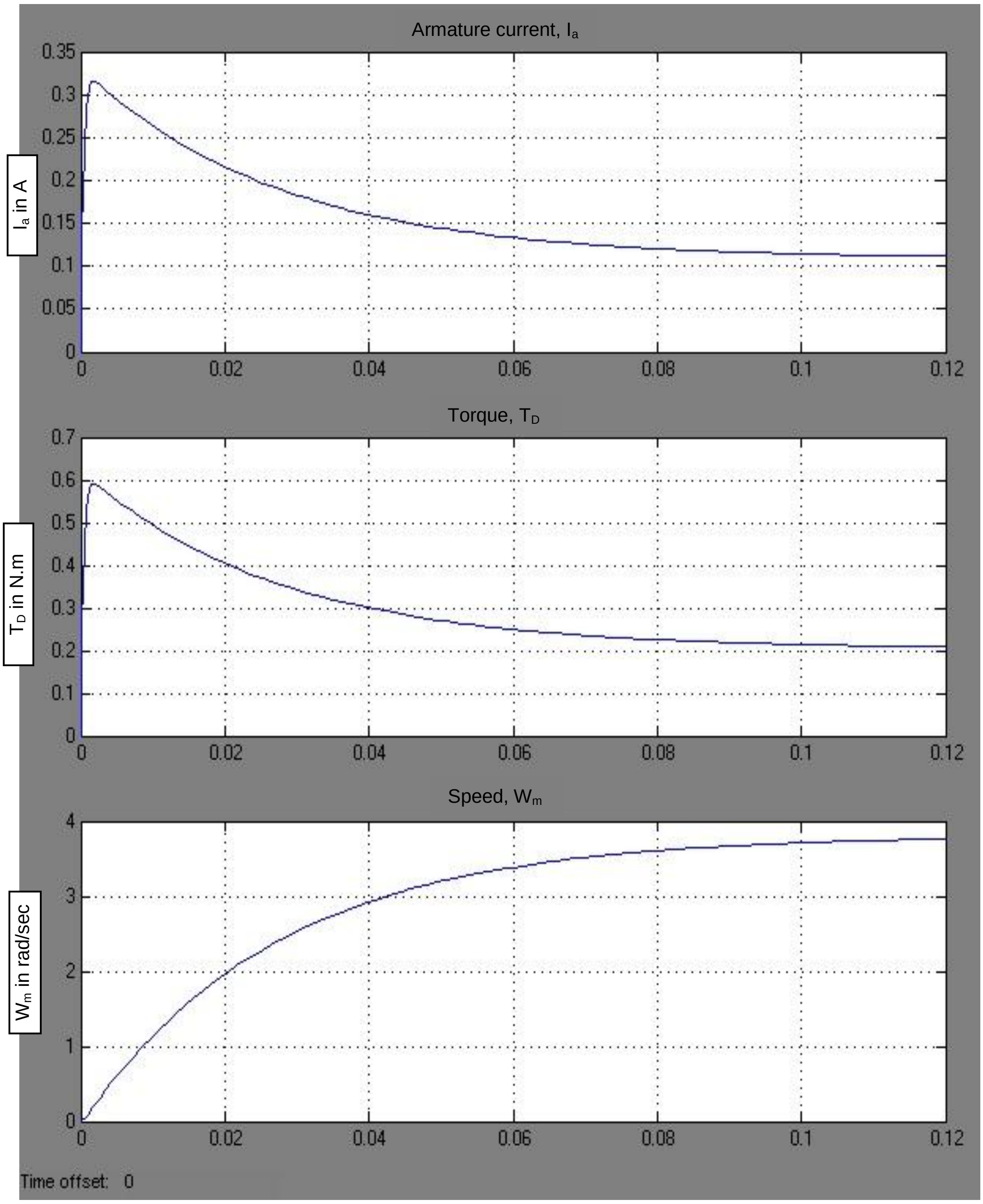


Fig. 4.2: Simulation result for case study 1

Fig. 4.2 shows the output response of the simulation of HS-322HD servo system at initial conditions. Three parameters are being studied: the armature current (I_a), torque (T_D) and speed (W_m). The performance values observed are at the peak of the output response which is tabulated in Table 4.1. These values serve as the reference for the next case studies. Properties of output response are also observed as seen in Table 4.2. From the settling time (T_s) we can obtain the damping coefficient (ζ) which is greater than 1, therefore the response is over-damped (see Appendix B). These results are at initial condition and in the next sections the outcomes of the manipulation of variables will be shown. The purpose of these various simulations is to simulate how the servo will respond if these changes are implemented on the actual system.

Table 4.1: Performance result for case 1

Output	Peak Value
Armature Current, I_a (A)	0.32
Torque, T_D (N.m)	0.59
Speed, W_m (rad/s)	3.80

Table 4.2: Properties of output response for case 1

Properties	Value
Settling time, T_s (s)	0.12
Damping coefficient, ζ	8.77

4.3.2 Case 2: Input voltage, V_t increased from 5V to 6V

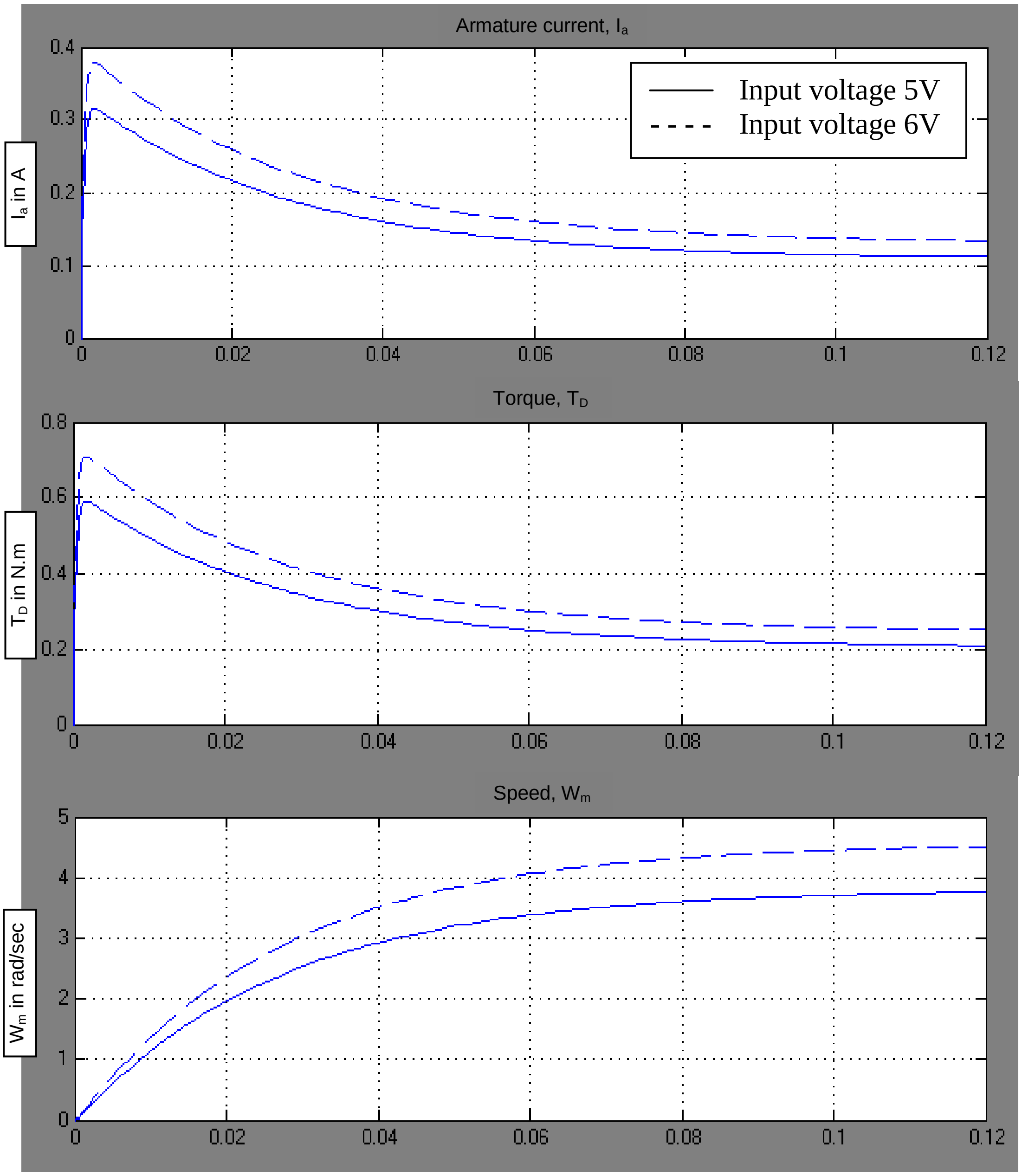


Fig. 4.3: Simulation result for case study 2

For this simulation, circuit resistance and the current are kept constant. Fig. 4.3 shows the output response when the input voltage is increased to 6V which is the maximum input recommended by the manufacturer of the HS-322HD servo. The output shows increment in the current, torque and motor speed as compared to the initial conditions as shown in Table 4.3. Table 4.4 shows the properties of output response for case study 2. The settling time decreases along with the damping coefficient but it still greater than 1; therefore it is an over-damped response.

Table 4.3: Performance result for case 2

Output	Peak Value	
	V_t = 5V	V_t = 6V
Armature Current, I_a (A)	0.32	0.38
Torque, T_D (N.m)	0.59	0.71
Speed, W_m (rad/s)	3.80	4.55

Table 4.4: Properties of output response for case 2

Properties	Value	
	V_t = 5V	V_t = 6V
Settling time, T_s (s)	0.12	0.11
Damping coefficient, ζ	8.77	7.99

4.3.3 Case 3: Input voltage, V_t reduced from 5V to 4.8V

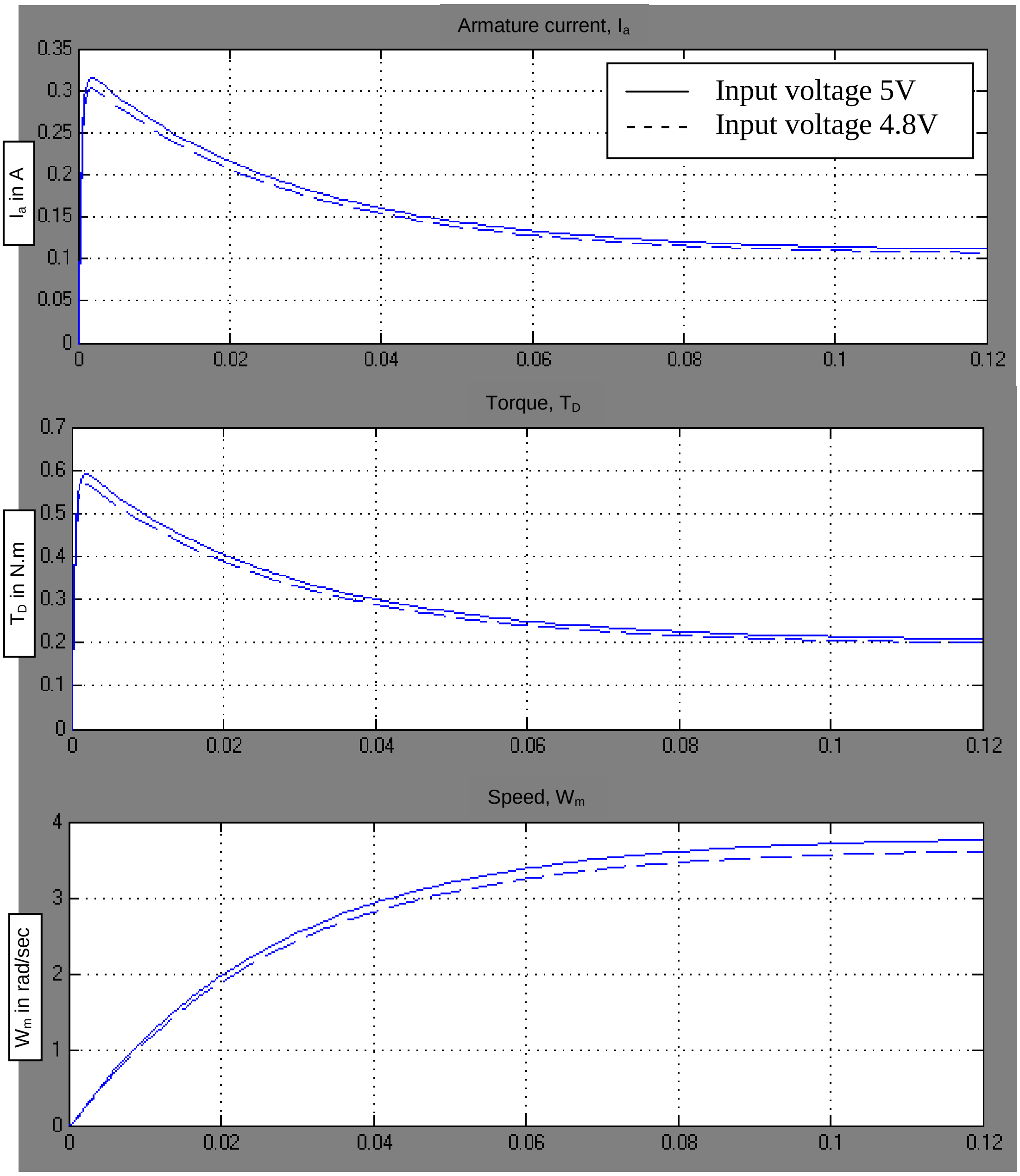


Fig. 4.4: Simulation result for case study 3

For this simulation, circuit resistance and the current are kept constant. Fig. 4.4 shows the output response when the input voltage is reduced to 4.8V which is the minimum input voltage recommended by the manufacturer of HS-322HD servo motor. The output shows reduction in the current, torque and motor speed as compare to the initial output. The values are tabulated in Table 4.5. Table 4.6 shows the properties of output response for case study 3. In comparison with case study 1, the settling time decreases but the damping coefficient is larger due to the difference in motor speed in both cases. The coefficient is greater than 1; therefore it is an over-damped response.

Table 4.5: Performance result for case 3

Output	Peak Value	
	V_t = 5V	V_t = 4.8V
Armature Current, I_a (A)	0.32	0.30
Torque, T_D (N.m)	0.59	0.57
Speed, W_m (rad/s)	3.80	3.65

Table 4.6: Properties of output response for case 3

Properties	Value	
	V_t = 5V	V_t = 4.8V
Settling time, T_s (s)	0.12	0.11
Damping coefficient, ζ	8.77	9.96

4.3.4 Case 4: Armature resistance, R_m doubled from 15.31Ω to 30.62Ω

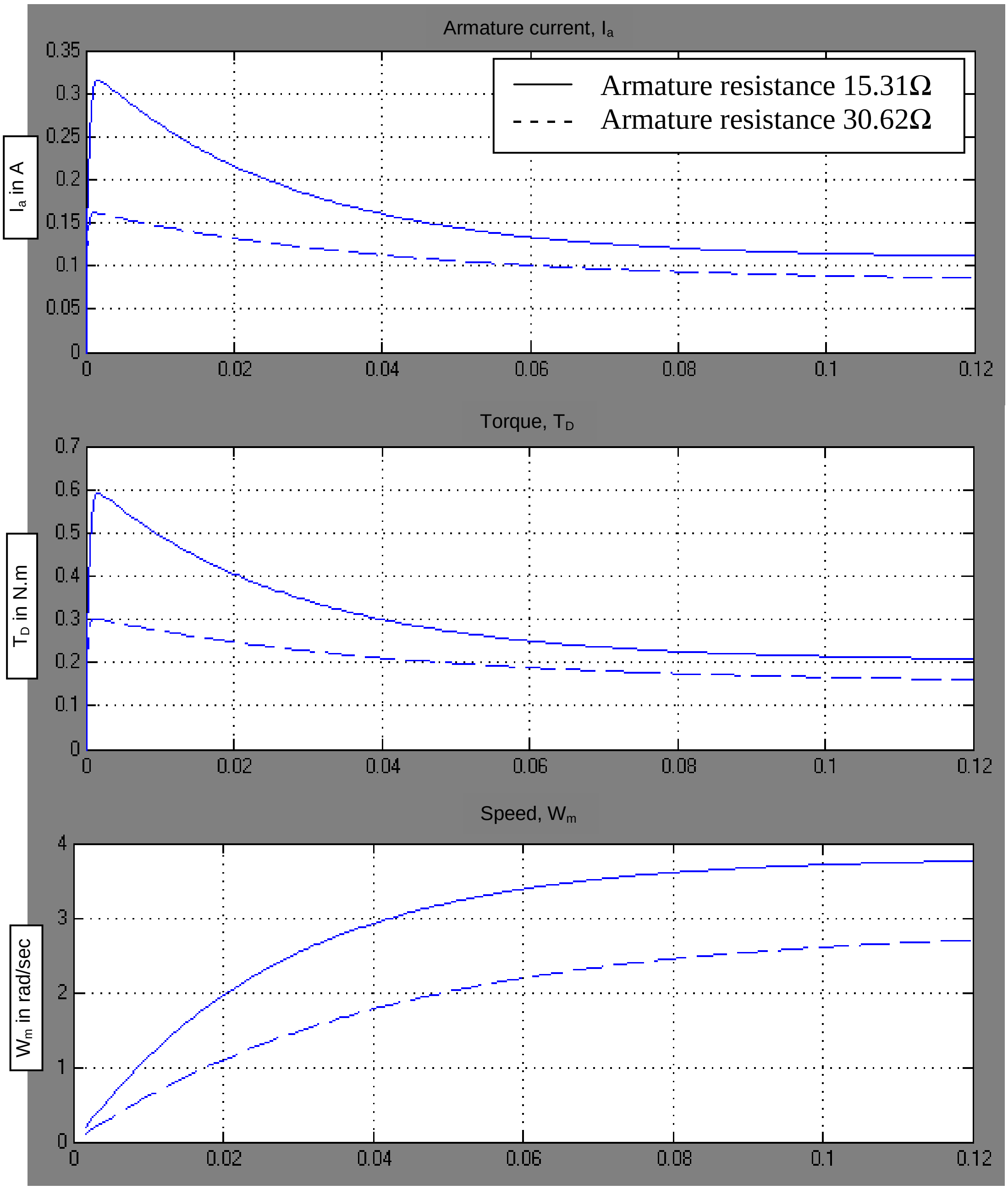


Fig. 4.5: Simulation result for case study 4

For this simulation, input voltage and the current are kept constant. Fig. 4.5 shows the output response when the circuit resistance is increased to 30.62Ω. The outputs show reduction as compared to the initial output as shown in Table 4.7. Table 4.8 shows the properties of output response for case study 4. In comparison with case study 1, the settling time increases in which it takes almost double the time to reach steady-state. The damping coefficient is smaller due to the huge difference in settling time between both cases. The coefficient is greater than 1; therefore it is an over-damped response.

Table 4.7: Performance result for case 4

Output	Peak Value	
	R_m = 15.31Ω	R_m = 30.62Ω
Armature Current, I_a (A)	0.32	0.16
Torque, T_D (N.m)	0.59	0.30
Speed, W_m (rad/s)	3.80	2.85

Table 4.8: Properties of output response for case 4

Properties	Value	
	R_m = 15.31Ω	R_m = 30.62Ω
Settling time, T_s (s)	0.12	0.23
Damping coefficient, ζ	8.77	6.10

4.3.5 Case 5: Armature resistance, R_m halved from 15.31Ω to 7.655Ω

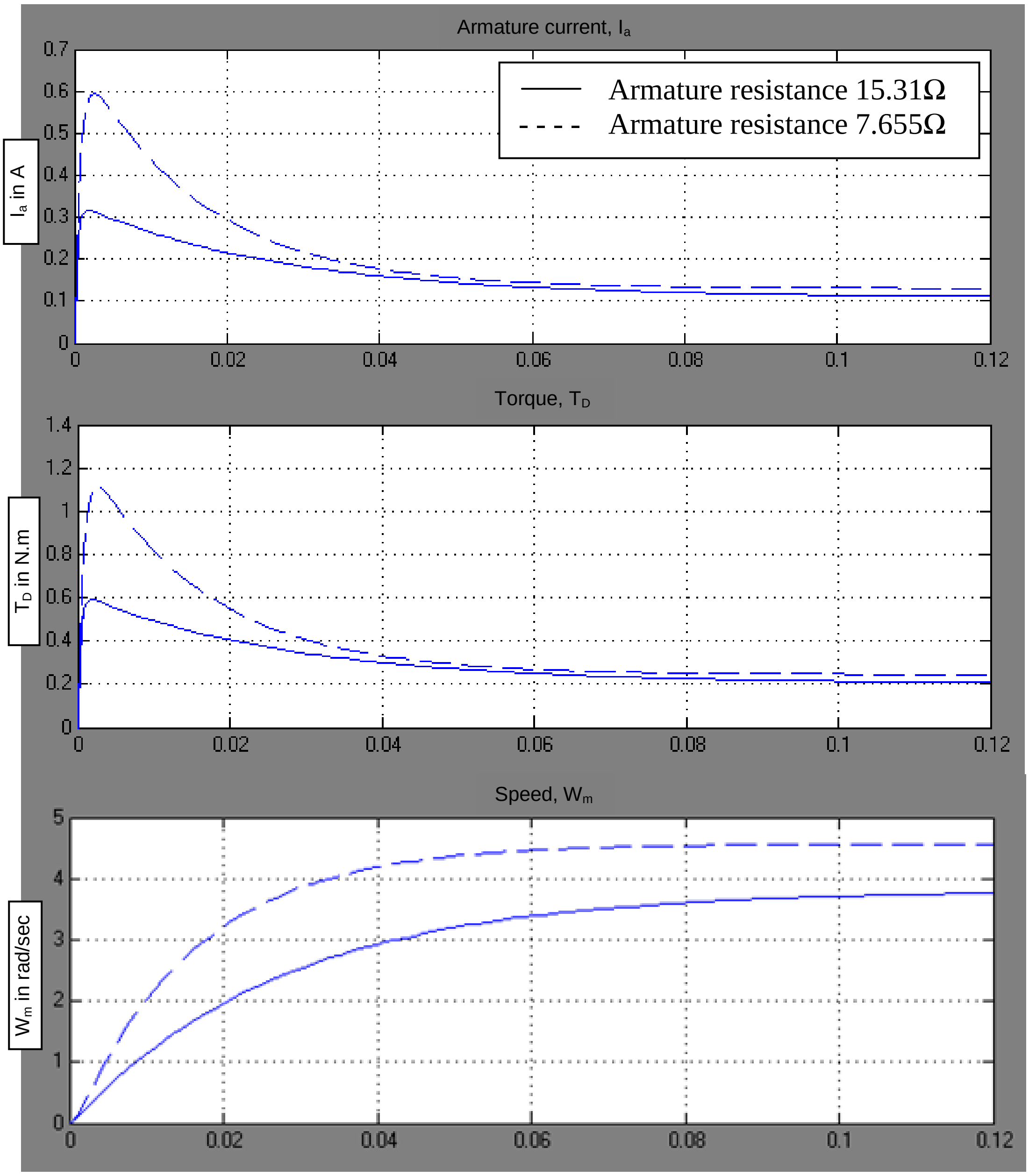


Fig. 4.6: Simulation result for case study 5

For this simulation, input voltage and the current are kept constant. Fig. 4.6 shows the output response when the circuit resistance is decreased to 7.655Ω. The outputs show increment as compared to the initial output as shown in Table 4.9. Table 4.10 shows the properties of output response for case study 5. In comparison with case study 1, the settling time decreases in which it takes shorter time to reach steady-state. The damping coefficient is larger, and greater than 1; therefore it is an over-damped response.

Table 4.9: Performance result for case 5

Output	Peak Value	
	R_m = 15.31Ω	R_m = 7.655Ω
Armature Current, I_a (A)	0.32	0.60
Torque, T_D (N.m)	0.59	1.12
Speed, W_m (rad/s)	3.80	4.56

Table 4.10: Properties of output response for case 5

Properties	Value	
	R_m = 15.31Ω	R_m = 7.655Ω
Settling time, T_s (s)	0.12	0.08
Damping coefficient, ζ	8.77	10.96

4.3.6 Case 6: Constant torque, T_L 0.3058N.m is applied

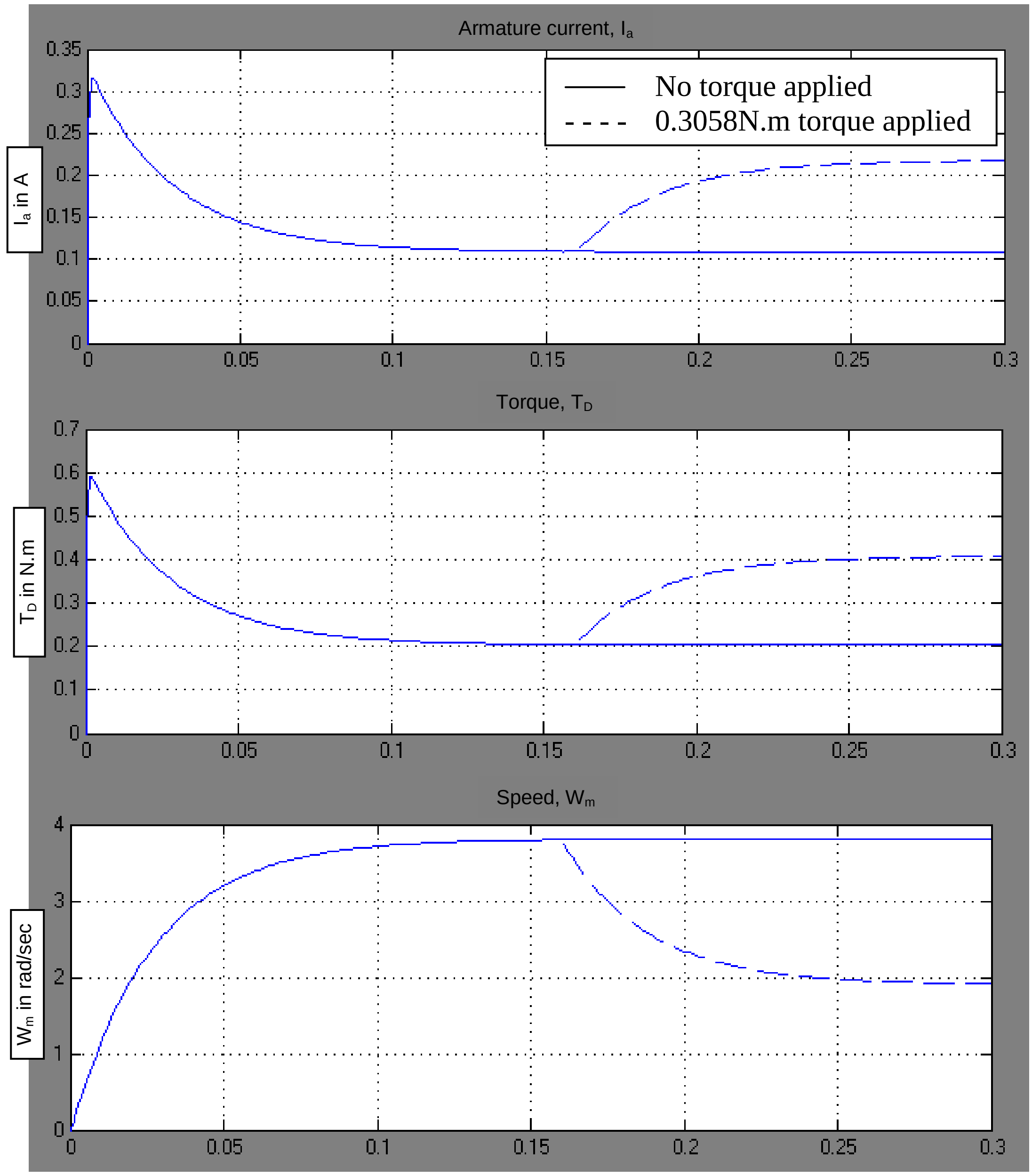


Fig. 4.7: Simulation result for case study 6

Fig. 4.7 shows the output response when a constant torque load is applied on the motor. In order to study the effect of torque on the servo, the value of steady-state response is observed instead of the transient part. At first, the pattern is similar as in case 1 when there is no disturbance on the servo performance. However, the response began to change when there is 0.3058N.m torque applied to the shaft. The small no-load current does not produce enough torque to carry the load and the motor begins to slow down. In order to sustain the load while at the same time maintaining the motor speed, more current is needed to be supplied as shown in Fig. 4.7.

The performance values are tabulated as shown in Table 4.11. Table 4.12 shows the properties of output response for case 6. With the presence of load, the servo took a longer time to reach steady-state; along with smaller speed resulting in smaller coefficient as compared to case 1 but it still remains as over-damped response.

Table 4.11: Performance result for case 6

Output	Steady-state Value	With Torque
Armature Current, I_a (A)	0.11	0.22
Torque, T_D (N.m)	0.20	0.41
Speed, W_m (rad/s)	3.80	1.90

Table 4.12: Properties of output response for case 6

Properties	Value	
	No torque	Torque applied
Settling time, T_s (s)	0.12	0.30
Damping coefficient, ζ	8.77	7.02

4.4 Discussion

6 case studies are presented for the purpose of studying the performance of HS-322HD servo motor. The performance results of case 1 to 6 are compiled together in Table 4.13:

Table 4.13: Compilation of simulation readings

	Peak Value			Value	
Output / Condition	Armature current, I_a	Torque, T_D	Speed, W_m	Settling time, T_s	Damping coeff., ζ
Initial condition, $V_t = 5V$	0.32	0.59	3.80	0.12	8.77
Input voltage increased, $V_t = 6V$	0.38	0.71	4.55	0.11	7.99
Input voltage reduced, $V_t = 4.8V$	0.30	0.57	3.65	0.11	9.96
Resistance increased, $R_m = 30.62\Omega$	0.16	0.30	2.85	0.23	6.10
Resistance decreased, $R_m = 7.655\Omega$	0.60	1.12	4.56	0.08	10.96
Constant torque applied, $T_L = 0.3058N.m$	0.32	0.59	3.80	0.30	7.02

1. Armature Voltage Control

When input voltage, V_t is increased, the values of the output increased. When input voltage, V_t is decreased, the values of the output decreased. Therefore, it is theoretically proven that input voltage is directly proportional to the output values. As in real-life application, if the users desire better performance from the servo they could just increase the input voltage. The effect of voltage control on the servo is yet to be studied. Ying (2005) mentioned about voltage control of a DC motor in which he stated that you only needed to control the armature voltage to vary the motor's speed. Because there are mechanical components inside the motor, they would produce sparks and cause damage when the motor was running, which was one major shortcoming of the DC motor [13]. Tan (2003) stated that the method of controlling motor speed by using armature voltage control is expensive as it requires variable DC supply for the armature circuit.

2. Armature Resistance Control

When the resistance in the armature circuit, R_m is increased, the values of the output decreased. When the resistance in the armature circuit, R_m is decreased, the values of the output increased. Therefore, it is theoretically proven that armature resistance is inversely proportional to the output values. Zahim (2010) stated the advantages of armature resistance control on DC motor are it costs much less than other system that permits control down to zero speed and it is a simple method too. The disadvantages are it introduces more power loss in rheostat (or potentiometer as in the case of a servo motor), the speed regulation is poor and low efficiency due to rheostat (potentiometer) [4].

3. Change in Mechanical Load

When a change of mechanical load is applied on a motor during its operation, the machine adjusts to the new condition through an electromechanical transient. If a constant load suddenly applied to a motor running at no-load speed, it causes the system to adjust to it in which the no-load current is small and does not produce sufficient torque to carry load resulting the motor to slow down. This causes the counter EMF to become smaller, resulting in a higher current and a higher torque. When the torque developed by the motor is equal to the torque imposed by the mechanical load, then only the speed remains constant. To sum it all up, as mechanical load increases, the armature current rises and the speed drops [12].

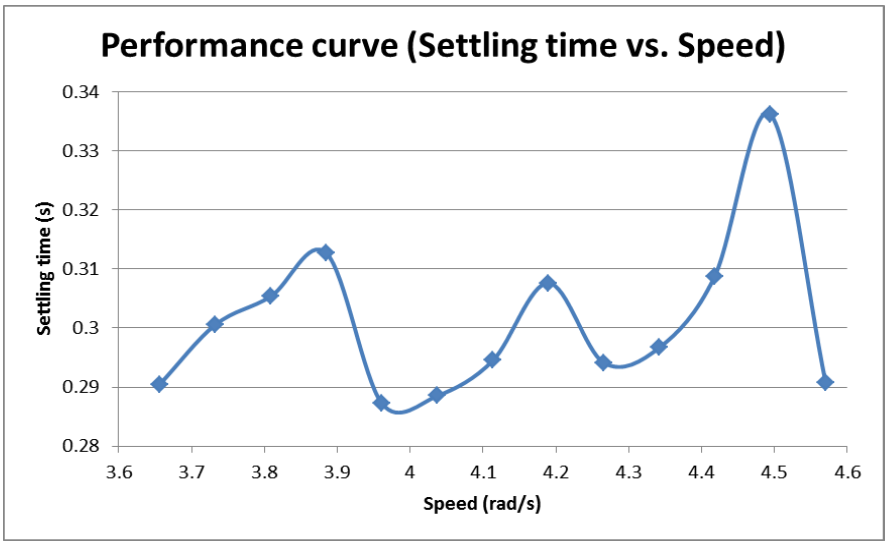


Fig. 4.8: Performance curve of the servo motor

Table 4.14: Data of servo performance

Voltage (V)	Settling Time (s)	Speed (rad/s)	Voltage (V)	Settling Time (s)	Speed (rad/s)
4.8	0.2905	3.6564	5.5	0.3077	4.1897
4.9	0.3006	3.7326	5.6	0.2941	4.2658
5.0	0.3054	3.8088	5.7	0.2967	4.3420
5.1	0.3127	3.8850	5.8	0.3088	4.4182
5.2	0.2872	3.9611	5.9	0.3362	4.4944
5.3	0.2885	4.0373	6.0	0.2907	4.5705
5.4	0.2945	4.1135			

Fig. 4.8 shows the performance curve of HS-322HD servo motor. The settling time is plotted against the motor speed operating at the recommended input voltages as stated by the manufacturer. The best performance is interpreted as the operating voltage in which the lowest settling time is achieved, or in other words the motor stabilizes quicker. From the graph, it is observed that the lowest settling time and the corresponding motor speed is approximately 0.287s and 3.96rad/s. Therefore, it is concluded that the servo motor performs best at nearest input voltage which is 5.2V.

Based on the results of the simulations, it is theoretically proven that any significant changes to the involved parameters will also bring significant changes to the output response of the HS-322HD servo motor.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This project has presented the outcomes of the evaluation of the transient response of the servo motor using MATLAB/Simulink. The theoretical results of the system performance are obtained and presented in the form of different case studies and a performance curve. Each case study represents one of the changeable parameters that affecting the performance of HS-322HD servo motor in particular. The behaviour of the response are observed and discussed in the previous section of this report.

In achieving the goal of this project, all of the objectives have been completed. An appropriate mathematical model representing the servo system is obtained. This mathematical model serves as the basis of the system model built on Simulink. Parameters affecting the performance of the servo motor are also identified before it is studied. Then, calculations are performed to determine the values of parameters identified. Using Simulink, a block diagram is established based on researches on past journals and by incorporating the parameters values calculated, simulations are performed and the results are studied.

From the results, it is concluded that parameters studied bring significant changes to the transient response of the servo motor. These changes allow the observation of the servo performance behaviour and how the system reacts to the new condition it is being put in.

Throughout the course of the project, the author has identified several improvement or suggestions which will hopefully will be able to enhance the study of evaluation of transient response of a servo motor. So far the outcomes of this project are on theoretical basis only. The effects of the manipulation of variables on actual system are presented based on facts obtained in previous works. Therefore, experimental data of the performance of HS-322HD servo motor will greatly strengthen the studied outcomes of this project. In this case, it could not be made possible due to time and equipment constraints faced by the author.

Besides, there are other parameters to be explored in studying the performance of a servo motor. In this project, the focus is on the manipulation of armature voltage, armature resistance and constant torque applied on the shaft which are pretty common in the study of motor system. If there is one parameter that is exclusive for a servo motor in which it is not associated with other type of motors, it would be interesting to see what it can do with the motor performance.

Last but not least, the effect of damping on the actual system could be studied for future works. In this project, all the output responses fall in the over-damped response category. Further studies could be performed on the performance of the servo motor if the damping is reduced and the effects to the output; the armature current, torque and motor speed.

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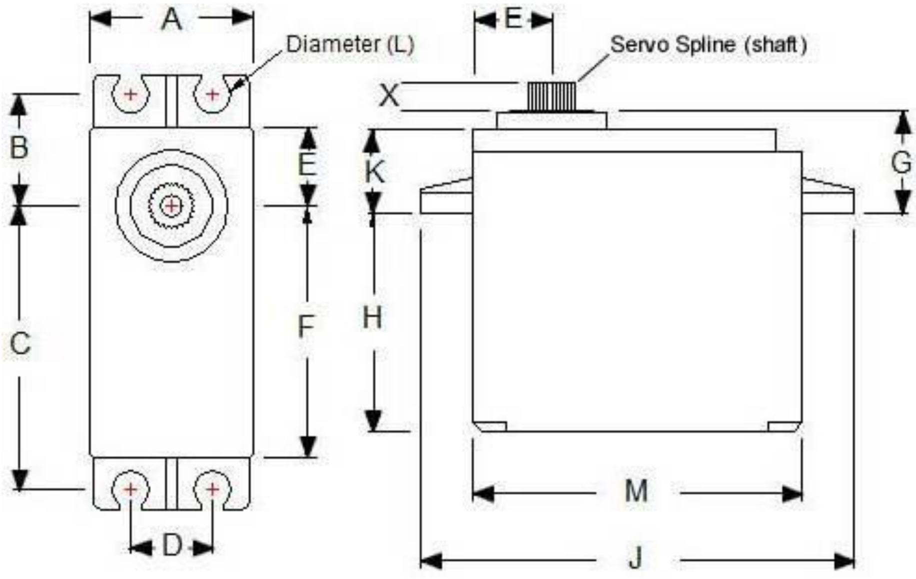
APPENDIX A

SCHEMATIC DIAGRAM OF HS-322HD SERVO



Dimensions:

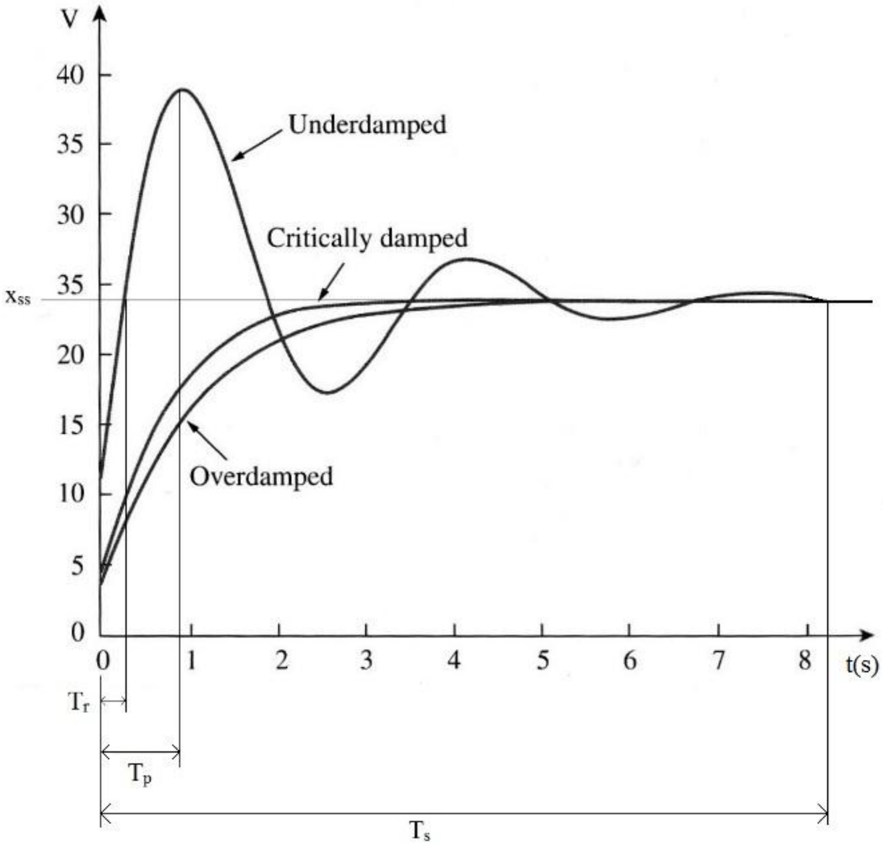
A = .780” (19.82mm)
B = .530” (13.47mm)
C = 1.33” (33.79mm)
D = .400” (10.17mm)
E = .380” (9.66mm)
F = 1.19” (30.22mm)
G = .460” (11.68mm)

H = 1.05” (26.67mm)
J = 2.08” (52.84mm)
K = .368” (9.35mm)
L = .172” (4.38mm)
M = 1.57” (39.88mm)
X = .120” (3.05mm)

APPENDIX B

TRANSIENT RESPONSE

The behaviour of transient response is studied in this project after the model is completed and simulations are performed. The total response of a control system can be considered to be made up of two aspects, the steady-state response and the transient response. Transient response is that part of a system response which occur when there is a change in input and which dies away after a short interval of time. The steady-state response is the response that remains after all transient responses have died.



Simply said, transient response is the portion of output response before it reaches steady-state. Fig. B shows the response with three degrees of damping [6]. It has properties such as rise time (T_r), settling time (T_s), peak time (T_p), and percentage overshoot (*%OS*).

The calculation for damping coefficient is shown for case 1 only:

As in case 1, the motor speed, ω_m is 3.80rad/s. The settling time, T_s is 0.12s.

Damping coefficient, $\zeta = 4/(T_s \omega_m)$

$= 4/(0.12)(3.80)$

$= 8.722 > 1$

ζ is larger than 1, therefore the response is over-damped.