Controlling a Servo DC Motor using LEGO Mindstorms

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Overview

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What is a DC Servo Motor?

- A Motor is a device that converts *electrical energy* into *mechanical energy*.
- A *servomotor* allows for precise control of angular position using a *rotary encoder* for position feedback.
- Input: Voltage
- Output: Angular displacement of shaft

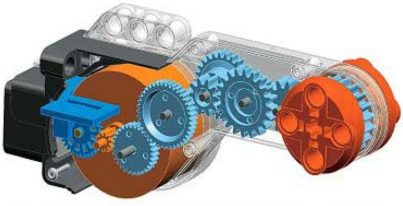

Figure : LEGO DC Servo Motor

http://www.philohome.com/

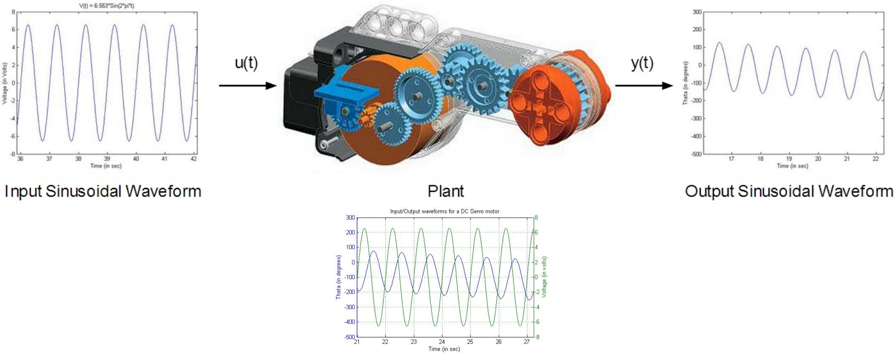

Figure : Block diagram showing Input/Output waveforms for a Servo Motor.

For a Linear system, a sinusoidal input produces a sinusoidal output which might be scaled and phase-shifted.

Frequency Analysis using Simulink & Matlab

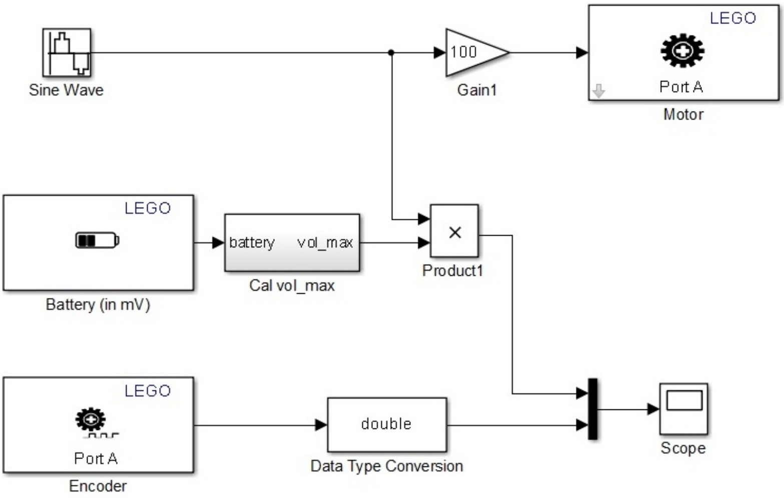

Figure : Block Diagram for observing frequency response of DC Servo Motor

Frequency response of Servo DC Motor

The Magnitude and phase difference is tabulated as shown in Table. The DC Servo does not respond beyond $10Hz$ or $62.8rad/s$.

Frequency(Hz)	**Magnitude**	**Phase**
0.10	227.70	-88.81
0.50	43.65	-97.98
1.00	20.38	-112.30
1.50	12.44	-121.47
2.00	8.64	-130.63
3.00	4.29	-143.81
4.00	2.57	-148.97
5.00	1.72	-159.28
6.00	1.20	-157.56
7.00	0.92	-157.56
8.00	0.72	-155.85
10.00	0.39	-169.53

Table : Frequency response of the DC Servo Motor

Bode Plot

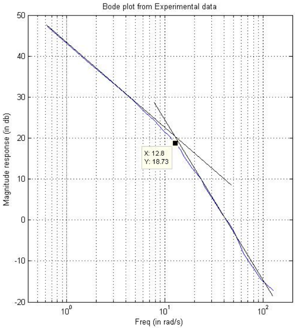

Figure : Bode Plot from measured frequency response

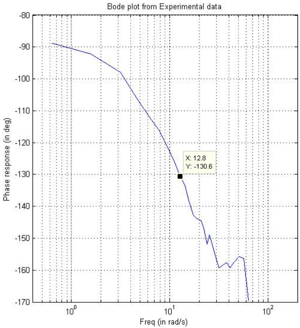

Figure : Bode Plot from measured frequency response

From the bode plot, it is observed that the system has poles at $s = 0$ and $s = 13$.

Transfer Function model

The transfer function of the DC Servo motor is of the form:

$$H(s) = \frac{A}{s(s+\alpha)} \tag{1}$$

Fitting the model to the datapoint $(12.8 rad/s,\ 8.64 db, -130.63^\circ)$, we get the transfer function of the motor to be:

$$H(s) = \frac{2018}{s(s+13)} \tag{2}$$

This model can now be used to design a *PI-controller* for position control.

PI Controller for position tracking

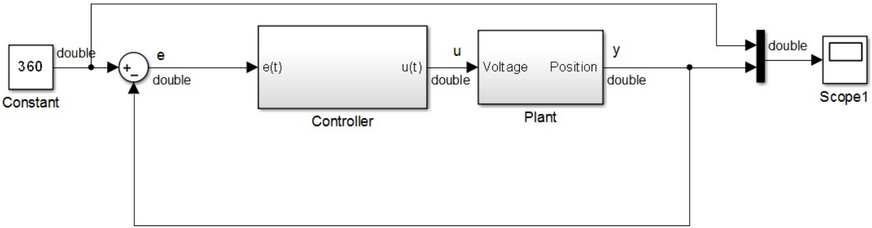

Figure : Simulink block diagram of PI Controller for position tracking

The k_p and k_i values are calculated using the experimentally determined Transfer function model.

Calculation of Controller parameters

The transfer function model of the motor is,

$$P(s) = \frac{A}{s(s+\alpha)} \tag{3}$$

For PI Control,

$$C(s) = k_p + \frac{k_i}{s} = \frac{k_p s + k_i}{s} \tag{4}$$

The loop transfer function becomes,

$$L(s) = \frac{(k_p s + k_i)A}{s(s+\alpha)} \tag{5}$$

The characteristic polynomial is

$$(s^2 + 2\zeta\omega_0 s + \omega_0^2)(s + \beta\omega_0) = s^3 + s^2\alpha + Ak_p s + Ak_i \tag{6}$$

Cont...

Taking ω_0 to be a free variable,

$$\omega_0 = \frac{\alpha}{\beta + 2\zeta} \qquad k_p = \frac{(1 + 2\beta\zeta)\omega_0^2}{A} \qquad k_i = \frac{\beta\omega_0^3}{A} \tag{7}$$

Substituting the values for A, α and taking $\beta = 1, \zeta = 1$ gives,

$$\boxed{k_p = 0.0279, k_i = 0.0403} \tag{8}$$

Performance of PI Controller

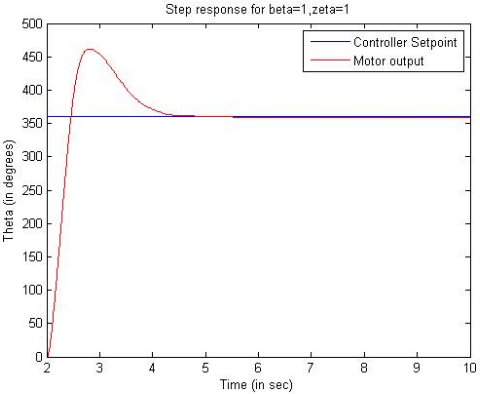

Figure : Step response of PI Controller

The system performance can be further improved by tuning the PI controller parameters.

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