# SRV02-ET
# Speed Control Experiment

## 1 Objective

The objective in this experiment is to design a feedback controller that would regulate the speed of the output shaft.

## 2 Open loop model

The model is derived from the basic equations of a DC motor:

$\theta$ = angle of output shaft
$w_m$ = angular velocity of motor shaft
w = angular velocity of output shaft
$K_g$ = gear ratio

*Electrically*

$$
\begin{aligned}
V_{in} &= I_m R_m + K_m \omega_m \\
&= I_m R_m + K_m K_g \omega_l
\end{aligned}
$$

*Mechanically*

$T_m$ = torque generated by motor
$T_o$ = torque at the output after the gearbox
$J_m$ = motor inertia
$J_l$ = load inertia

$$
\begin{aligned}
T_o &= K_g T_m \\
&= K_g (J_m \dot{w}_m + J_l \frac{\dot{w}_l}{K_g}) \\
&= J_m K_g^2 \dot{w}_l + J_l \dot{w}_l \\
&= \dot{w}_l (J_m K_g^2 + J_l) \\
\text{but } T_m &= K_m I_m
\end{aligned}
$$

then

$$
\begin{aligned}
I_m &= \frac{T_m}{K_m} \\
&= \frac{T_o}{K_m K_g} \\
&= \dot{w}_l \frac{K_g^2 J_m + J_l}{K_m K_g} \\
&= \dot{w}_l \frac{J_{eq}}{K_m K_g}
\end{aligned}
$$

Note that $J_{eq} = Kg^2 J_m + J_l$ is the equivalent inertia seen at the output of the gearbox.

hence

$$\frac{\theta(s)}{V_{in}(s)} = \frac{1}{s\frac{R_m J_{eq}}{K_m K_g} + K_m K_g}$$

## 3 Control system design

There are a variety of methods that can be used to design the feedback controller for the system. In this case we shall design a lead compensator.
Substituting parameter values, we obtain an open loop transfer function, including an integrator in the loop, (since the steady state gain shall not be unity without one) having the following open loop frequency response.

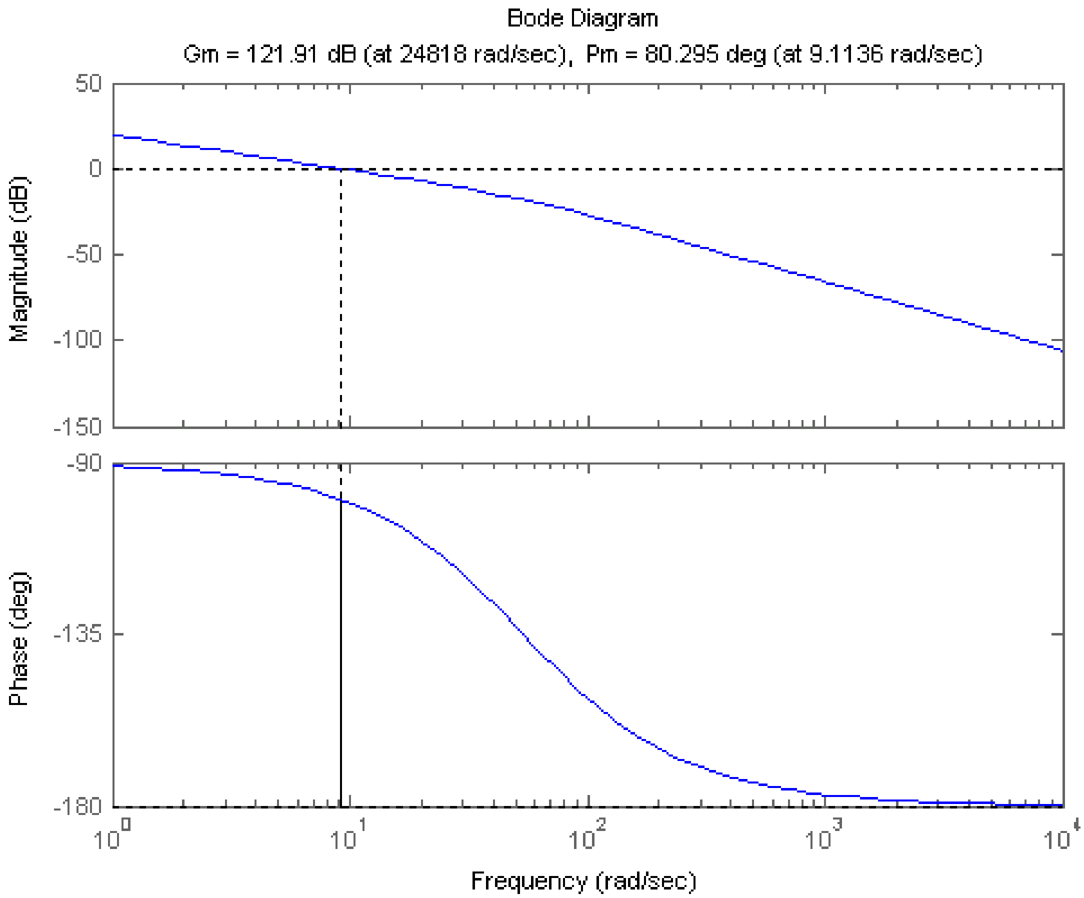


**Figure 2** Open loop characteristics

We would like the bandwidth to be approximately 100 rad/sec. So we add about 28 dB so the crossover is at 100 rad/sec. Doing so results in an open loop bode plot with a phase margin of 27 degrees. We than add a lead compensator to add about 60 degrees of phase at 100 rad/sec. Adding the above compensator to the system results in the open loop and closed loop bode plots shown below.

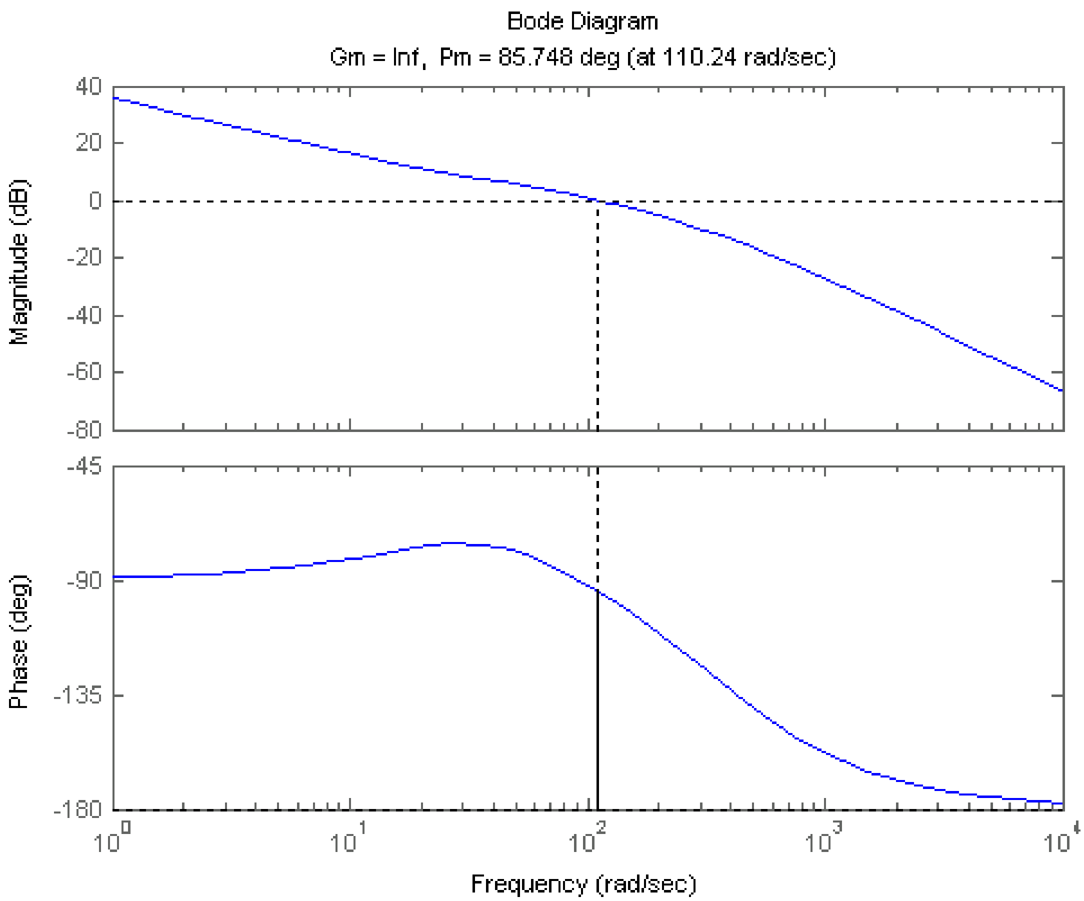


**Figure 3** Open loop characteristics with lead compensator and gain

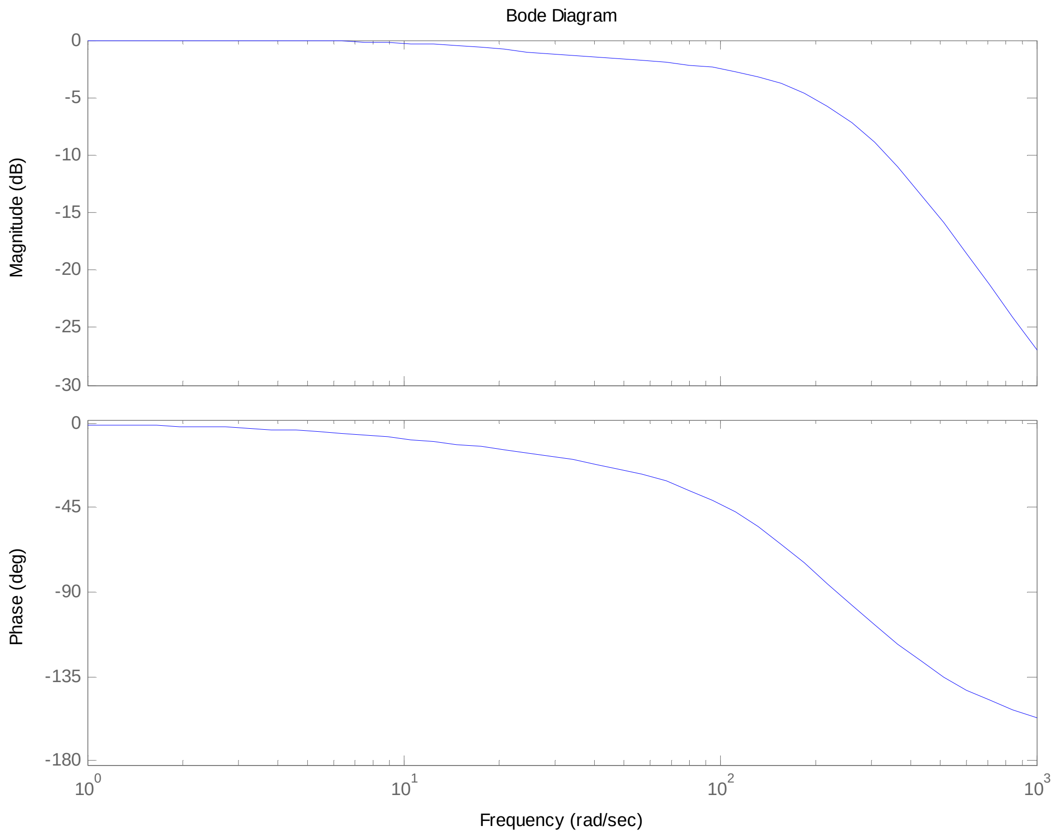


**Figure 4** Closed loop frequency response.

## 4 Setting up

Wire up the system as shown in the following photographs.


**Figure 5** Wiring the Servo. You do not need the potentiometer gear so you may remove it if you wish.


**Figure 7** Connections to Power Module

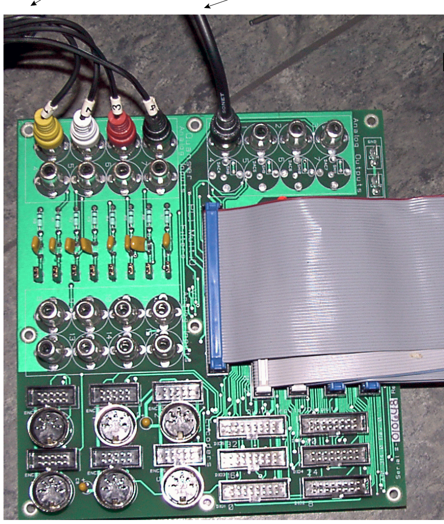


**Figure 6** Connections to MultiQ terminal board. Shown here are connections to the PCI MultiQ terminal board. You may have another board and the connections will look different.

## 5 Implementation and results

The controller is implemented using Simulink and WinCon. The diagram ***q_tacho_lead.mdl*** is available for download as well as a design file **d_tacho_lead.m** that can be used to design a lead type controller. The results are shown in figure 6 where we see the actual response to step inputs in prate commands. The controller also runs a realtime simulation of the closed loop system and we can compare the simulation with the actual output. We note that the simulation and actual response match quite well. The small variations about the command are due to commutation of the tachometer signal.

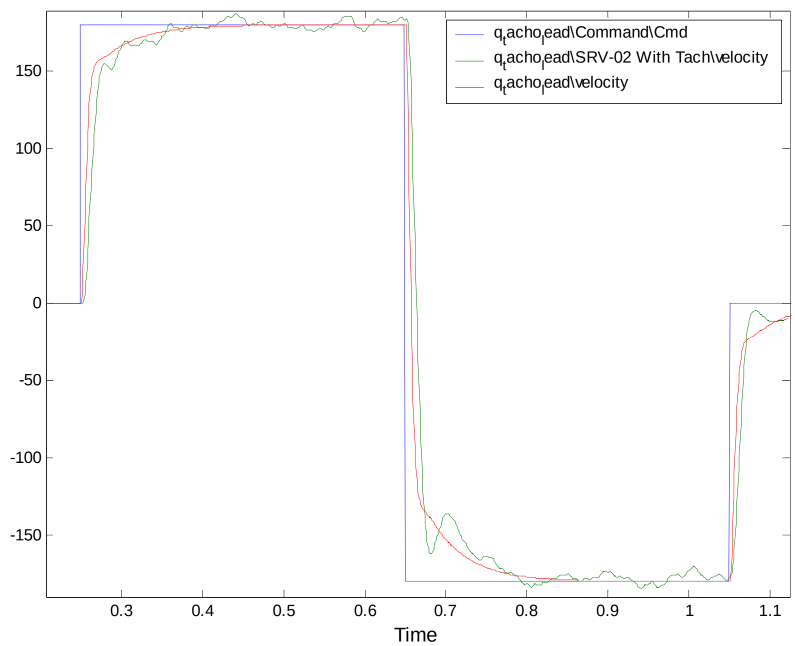


**Figure 8** Step response of feedback system. Blue trace is command, red is simulation and green is actual.

A short video of the system performance can also be seen by playing **v_tacho_lead**.

## 6 System Parameters

| **Symbol** | **Value** | **Units** |
|---|---|---|
| Kt | 0.00767 | Nm/Amp |
| Km | 0.00767 | V/(rad/sec) |
| Rm | 2.6 | Ω |
| Kg | 14.1 | NA |
| Jm | 3.87e-7 | Kg $m^2$ |
| Jl | 7.2200e-006 | Kg $m^2$ |
| Jeq | 8.4159e-005 | Kg $m^2$ |