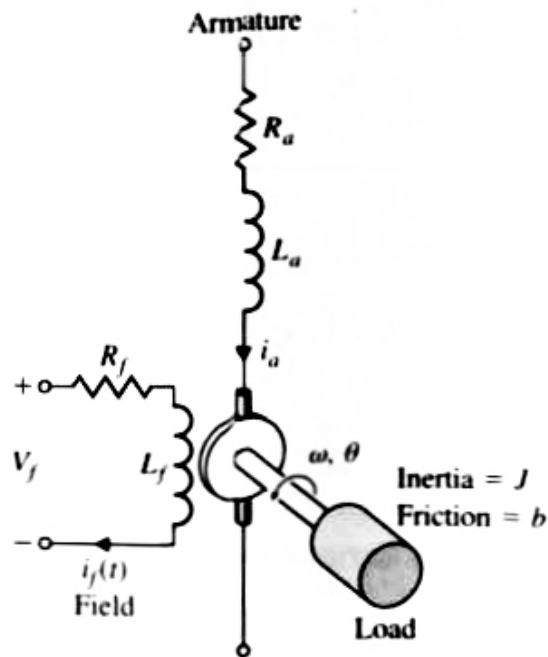


Servo System Blockset

For Use with Simulink[®]



User's Guide

Version 1.0

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ABOUT THE SERVO SYSTEM BLOCKSET

THE SERVO SYSTEM BLOCKSET [VERSION 1.0] is designed to provide a modern design tool that will allow scientists and engineers to rapidly and easily build models that simulate servo systems. The blockset uses the Simulink ® environment, allowing a model to be built using simple *click and drag* procedures.

ABOUT THE AUTHOR

THE SERVO SYSTEM BLOCKSET [VERSION 1.0] is developed by:

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He is the author of another Simulink Block “Single Pulse Generator” which can also be looked at MATLAB CENTRAL FILE EXCHANGE at

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HOW TO INSTALL THE BLOCKSET

Following is the step-wise procedure for the installation of the “Servo System Blockset”:

- ❖ Unzip the file ‘servosystem_bs’ in the MATLAB Folder “...\matlabR12\toolbox\”.
- ❖ Add the path of the folder ‘...\matlabR12\toolbox\servosystem_bs’ in the MATLAB path directory through Path Browser, that is, Path Browser >> Path >> Add to Path...
Choose the option box “Add to front”.
When MATLAB prompts that *“Your changes to the MATLAB path are only in effect for this session. Would you like to save the path in pathdef.m for future sessions?”* reply in **“Yes”**.
- ❖ Now, in the MATLAB Command Prompt, type **slblocks**.
- ❖ Open Simulink Library Browser. The Servo System Blockset will be appearing in the list of Libraries.
- ❖ Simulate your Servo System and Have Fun!!!

The Block Reference Page Description

The Block Dialog Box

The Servo System Blockset Libraries

ED 4400 DC Servo Motor

Field Controlled DC Servo Motor

Permanent Magnet DC Servo Motor

RPM to rad/s

rad/s to RPM

Degrees to Radians

Radians to Degrees

BLOCK REFERENCE PAGE DESCRIPTION

Blocks appear in alphabetical order and contain the following information:

- ❖ The block name, icon, and block library that contains the block
- ❖ The purpose of the block
- ❖ A description of the block's use
- ❖ The block dialog box and parameters
- ❖ Additional information, as it applies to the block:
- ❖ Inputs and outputs - A description of the inputs and outputs of the block
- ❖ Assumptions and limitations to the block's use
- ❖ An example using the block
- ❖ A "See Also" of related blocks

THE BLOCK DIALOG BOX

You configure Servo System Blockset blocks with a parameter dialog box. The parameter dialog box provides you with:

- The name and block type at the top of the dialog box
- A brief description of the block's behavior below the title
- Zero or more editable parameter fields, check boxes, or parameter lists below the description. You specify the parameter values using valid MATLAB expressions.
- A row of four buttons labeled **OK**, **Cancel**, **Help**, and **Apply** at the bottom of the dialog box. The **OK** button sets the current parameter values and closes the dialog box. The **Cancel** button reverts all the parameter values back to their values at the time the dialog box was opened, losing any changes you made. The **Help** button displays the HTML-based reference information. The **Apply** button sets the current parameter values and but does not close the dialog box.

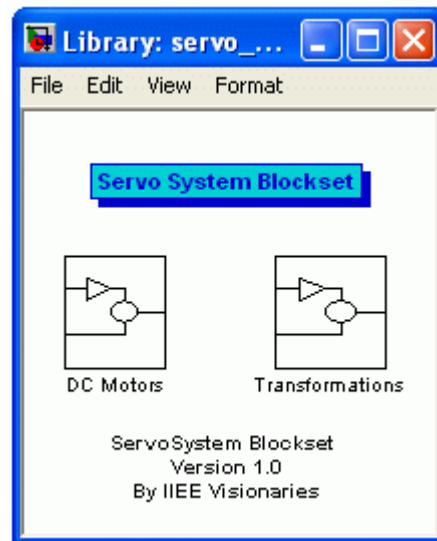
SIMULINK stores the strings entered in these fields and passes them to MATLAB for evaluation when a simulation is started. If MATLAB variables are used, the simulation uses the values that exist in the workspace at the start of the simulation. These variables are not necessarily the same as when the variables are entered into the dialog box fields. If a simulation is running when a parameter is changed, MATLAB evaluates the parameter as soon as you press the **OK** or **Apply** button.

THE SERVO SYSTEM BLOCKSET LIBRARIES

To open the main Servo System Blockset, at the MATLAB prompt type

```
>> servo_system_lib
```

This opens the main library window as shown below.



The main library contains two sublibraries. To open a sublibrary, double-click on its icon. The following table describes how the Servo System Blockset blocks are grouped into the sublibraries.

The Servo System Blockset's main library **servo_system_lib** organizes its blocks into libraries according to their behavior. The **servo_system_lib** window displays the block library icons and names:

- The **DC Motors** library contains blocks of different types of DC Motors.
- The **Transformations** library contains blocks that are used for transformation of a quantity from one unit to another (unit conversion) in Servo Systems.

All of these blocks are documented in the block reference section.

Table 1 : DC Motors	
ED 4400 DC Servo Motor	Simulates ED 4400 DC Servo Motor, as DEMO
Field Controlled DC Servo Motor	Models a Field Controlled DC Servo Motor
Permanent Magnet DC Servo Motor	Models a Permanent Magnet DC Servo Motor

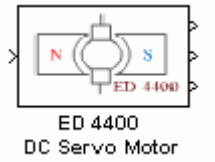
Table 2 : Transformations	
RPM to rad/s	Convert RPM into rad/s.
rad/s to RPM	Convert rad/s into RPM.
Degrees to Radians	Convert Degrees into Radians.
Radians to Degrees	Convert Radians into Degrees.

ED 4400 DC Servo Motor

Purpose Simulates ED 4400 DC Servo Motor, as DEMO

Library DC Motors

Description This block is a sort of demo of "PM DC Motor Block". The basic block structure of the above mentioned block has been used to create this block.

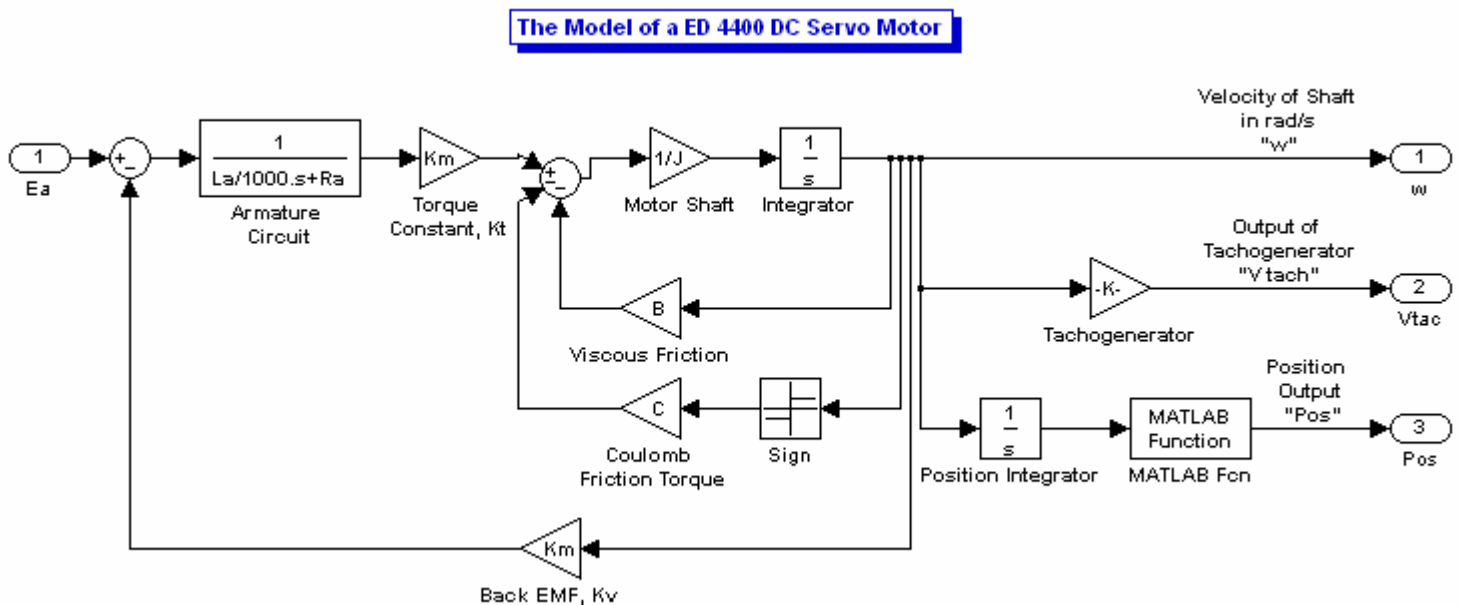


This block simulates the DC Servo Motor of the ED-4400 Modular Servo System. The Armature Voltage E_a is input to the block. The outputs are the Speed of Motor " w " in rad/s, Tachometer Output " V_{tac} " and Position of the Shaft " Pos " respectively.

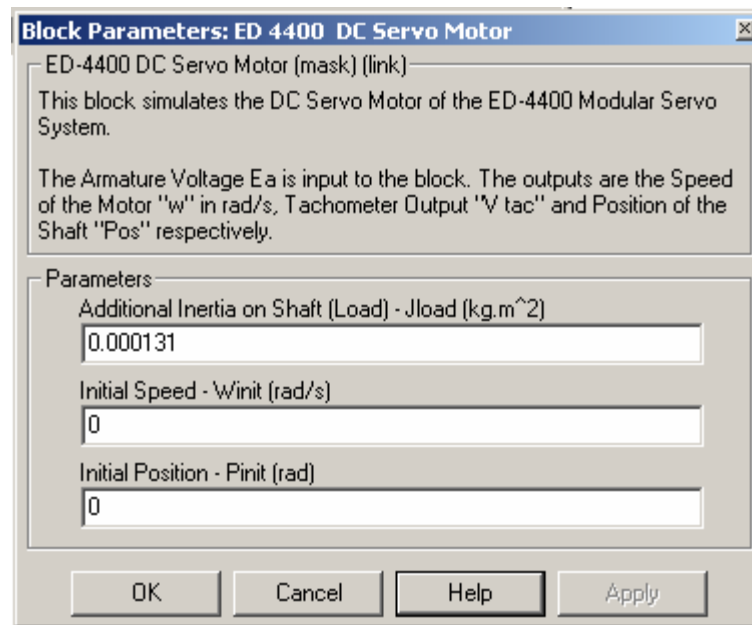
The parameters of this motor are:

Armature Resistance - $R_a = 4$ ohms,
 Armature Inductance - $L_a = 1$ mH approx.,
 Shaft Inertia - $J = 0.000131$ kg.m²,
 Viscous Friction Coefficient - $B = 0.0000001$ N.m.s/rad,
 Coulomb Friction Torque - C [Function of Direction of w] = 0.0002802 N.m,
 Torque or Back EMF Constant - $K_m = 0.0162$ V.s/rad or N.m/A,
 Tachometer Gain - $K_{tach} = 0.00573$ V.s/rad.

The masked model of the Ed 4400 Motor, with values of variables defined above, is



Parameters and Dialog Box

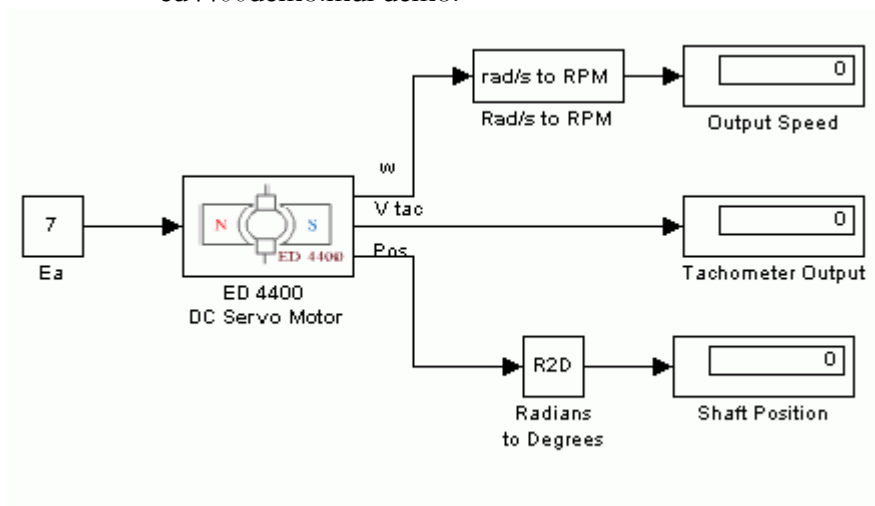


The parameters to be inputted by the user are:

- Additional Inertia on Shaft (Load) – J_{load} (kg.m²)
- Initial Speed – W_{init} (rad/s)
- Initial Position - P_{init} (rad)

Examples

The following model illustrates the open loop operation of ED-4400 DC Servo motor. The simulink model is available in the ed4400demo.mdl demo.



See Also

Field Controlled DC Servo Motor Block
Permanent Magnet DC Servo Motor Block

Field Controlled DC Servo Motor

Purpose Implements a Field Controlled DC Servo Motor.

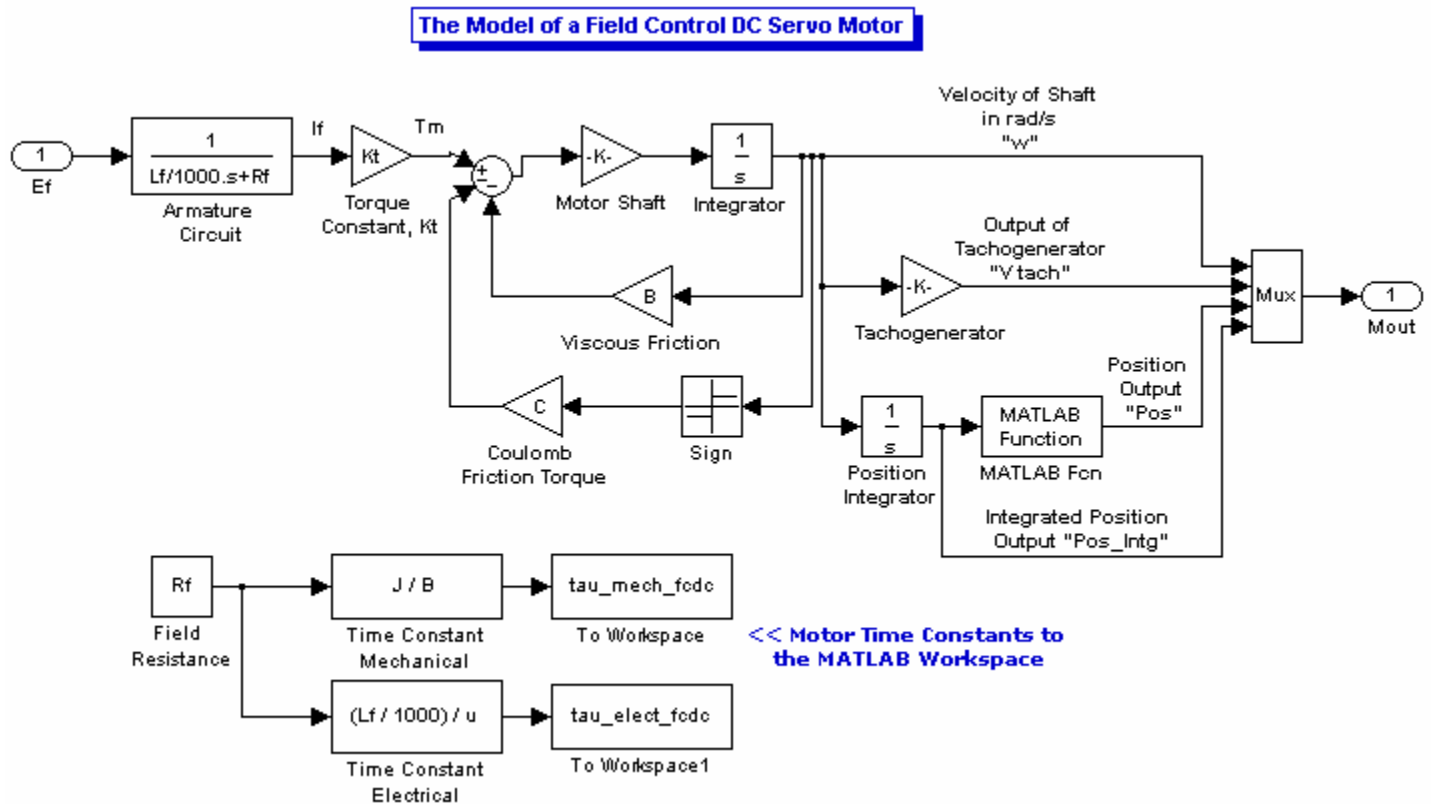
Library DC Motors

Description This block implements a Field Control DC Servo Motor.

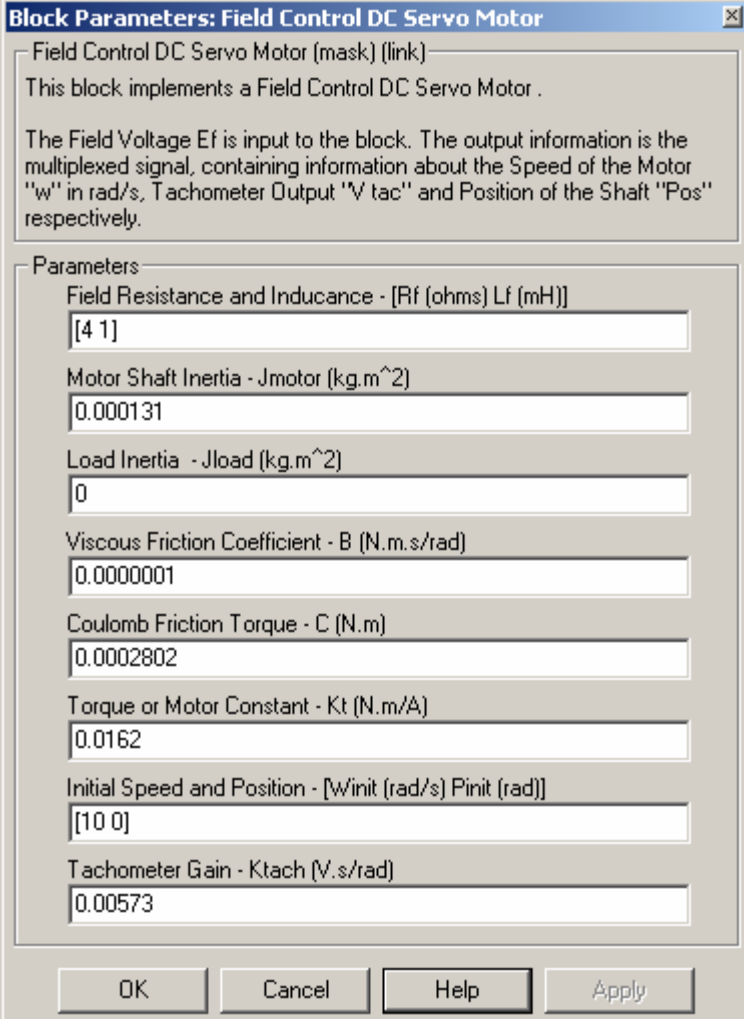


The Field Voltage E_f is input to the block. The output information is the multiplexed signal, containing information about the Speed of the Motor " w " in rad/s, Tachometer Output " V_{tac} " and Position of the Shaft " Pos " respectively.

The masked model of the Field Controlled DC Motor is as shown below:



Parameters and Dialog Box



Block Parameters: Field Control DC Servo Motor

Field Control DC Servo Motor (mask) (link)

This block implements a Field Control DC Servo Motor .

The Field Voltage E_f is input to the block. The output information is the multiplexed signal, containing information about the Speed of the Motor " w " in rad/s, Tachometer Output " V_{tac} " and Position of the Shaft "Pos" respectively.

Parameters

Field Resistance and Inductance - $[R_f \text{ (ohms)} L_f \text{ (mH)}]$
[4 1]

Motor Shaft Inertia - $J_{motor} \text{ (kg.m}^2\text{)}$
0.000131

Load Inertia - $J_{load} \text{ (kg.m}^2\text{)}$
0

Viscous Friction Coefficient - $B \text{ (N.m.s/rad)}$
0.0000001

Coulomb Friction Torque - $C \text{ (N.m)}$
0.0002802

Torque or Motor Constant - $K_t \text{ (N.m/A)}$
0.0162

Initial Speed and Position - $[w_{init} \text{ (rad/s)} P_{init} \text{ (rad)}]$
[10 0]

Tachometer Gain - $K_{tach} \text{ (V.s/rad)}$
0.00573

OK Cancel Help Apply

- Field Resistance and Inductance – $[R_f \text{ (ohms)} L_f \text{ (mH)}]$
- Motor Shaft Inertia – $J_{motor} \text{ (kg.m}^2\text{)}$
- Load Inertia – $J_{load} \text{ (kg.m}^2\text{)}$
- Viscous Friction Coefficient – $B \text{ (N.m.s/rad)}$
- Coulomb Friction Torque – $C \text{ (N.m)}$ (Function of Direction of w)
- Torque or Motor Constant – $K_t \text{ (N.m/A)}$
- Initial Speed and Position – $[w_{init} \text{ (rad/s)} P_{init} \text{ (rad)}]$
- Tachometer Gain – $K_{tach} \text{ (V.s/rad)}$

The motor mechanical and electrical time constants are passed to the MATLAB Workspace as variables **tau_mech_fcdc** and **tau_elect_fcdc** respectively.

See Also

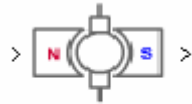
ED 4400 DC Servo Motor Block
Permanent Magnet DC Servo Motor

Permanent Magnet DC Servo Motor

Purpose Implements a Permanent Magnet DC Servo Motor.

Library DC Motors

Description This block implements a Permanent Magnet DC Servo Motor (Armature Control).

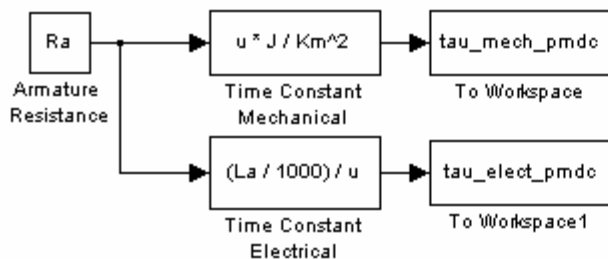
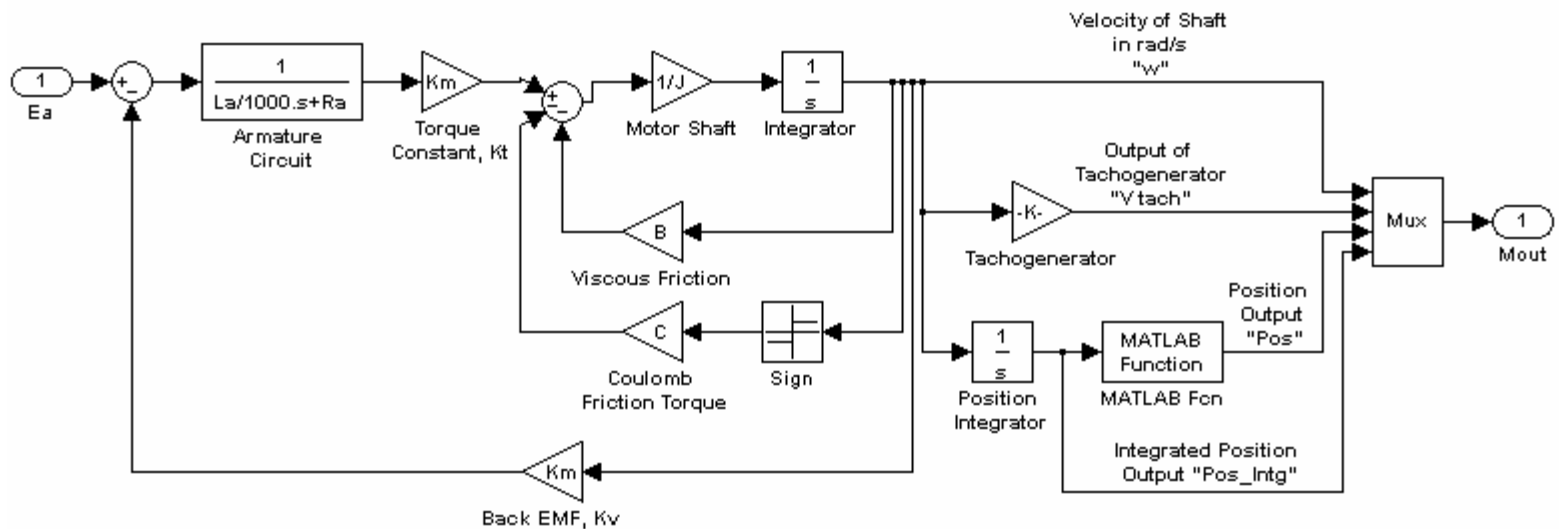


Permanent Magnet
DC Servo Motor

The Armature Voltage E_a is input to the block. The output information is the multiplexed signal, containing information about the Speed of the Motor " w " in rad/s, Tachometer Output " V_{tac} " in Volts dc, Position of the Shaft " Pos " in rad, and Integrated Position Output " Pos_Intg " also in rad respectively.

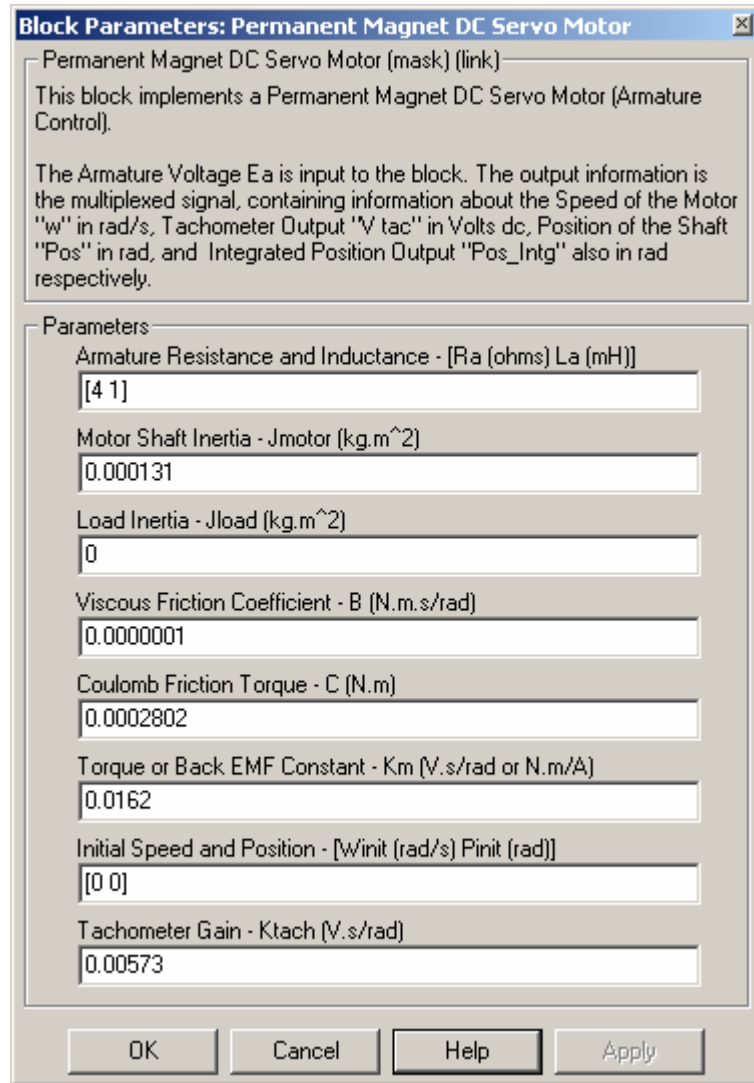
The masked model of the Permanent Magnet DC Motor is as shown below:

The Model of a Permanent Magnet DC Servo Motor



<< Motor Time Constants to
the MATLAB Workspace

Parameters and Dialog Box



Block Parameters: Permanent Magnet DC Servo Motor

Permanent Magnet DC Servo Motor (mask) (link)

This block implements a Permanent Magnet DC Servo Motor (Armature Control).

The Armature Voltage E_a is input to the block. The output information is the multiplexed signal, containing information about the Speed of the Motor "w" in rad/s, Tachometer Output "V tac" in Volts dc, Position of the Shaft "Pos" in rad, and Integrated Position Output "Pos_Intg" also in rad respectively.

Parameters

Armature Resistance and Inductance - [Ra (ohms) La (mH)]
[4 1]

Motor Shaft Inertia - Jmotor (kg.m²)
0.000131

Load Inertia - Jload (kg.m²)
0

Viscous Friction Coefficient - B (N.m.s/rad)
0.0000001

Coulomb Friction Torque - C (N.m)
0.0002802

Torque or Back EMF Constant - Km (V.s/rad or N.m/A)
0.0162

Initial Speed and Position - [Winit (rad/s) Pinit (rad)]
[0 0]

Tachometer Gain - Ktach (V.s/rad)
0.00573

OK Cancel Help Apply

The parameters to be inputted by the user are:

- Armature Resistance and Inductance – [Ra (ohms) La (mH)]
- Motor Shaft Inertia – Jmotor (kg.m²)
- Load Inertia – Jload (kg.m²)
- Viscous Friction Coefficient – B (N.m.s/rad)
- Coulomb Friction Torque – C (N.m) (Function of Direction of w)
- Torque or Back EMF Constant – Km (V.s/rad or N.m/A)
- Initial Speed and Position – [Winit (rad/s) Pinit (rad)]
- Tachometer Gain – Ktach (V.s/rad)

The motor mechanical and electrical time constants are passed to the MATLAB Workspace as variables **tau_mech_pmdc** and **tau_elect_pmdc** respectively.

See Also

ED 4400 DC Servo Motor Block
Field Controlled DC Servo Motor Block

DC MOTOR IDENTIFICATION [PERMANENT MAGNET TYPE]

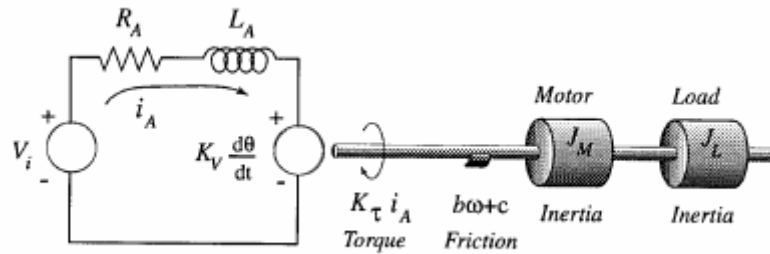
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OBJECTIVES:

The objective is to perform SYSTEM IDENTIFICATION FOR THE DC SERVO MOTOR BY THE TIME DOMAIN METHOD.

MOTOR IDENTIFICATION TASK:

[PARAMETERS TO BE IDENTIFIED]

System Identification allows you to build mathematical models of a dynamic system based on measured data.

The motor system identification task is to identify motor parameters such as

- ❖ Armature Resistance (or Terminal Resistance), R_a (Ω)
- ❖ Armature Inductance, L_a (mH)
- ❖ Back EMF Constant, K_v (V.s / rad)
- ❖ Torque Constant, K_T (N.m / A)
- ❖ Electrical Time Constant, T_E (s)
- ❖ Mechanical Time Constant, T_M (s)
- ❖ The Total Inertia seen by the motor, J (Kg. m^2)
- ❖ Viscous Friction Coefficient, B (N.m.s / rad)
- ❖ Coulomb Friction, C (N.m)

Each of these motor parameters can be determined directly through experimental testing. This following section outlines a procedure to identify motor parameters.

❖ ARMATURE RESISTANCE (OR TERMINAL RESISTANCE), R_a (OHMS)

METHOD 1:

Terminal resistance can be determined with acceptable accuracy by measuring the resistance across the motor's terminal leads with a multimeter.

METHOD 2:

A more accurate reading can be achieved after the motor has run for a period of time, and has adjusted to ambient temperature conditions.

In this method, the armature resistance R_a is measured by observing the steady-state behavior, while the rotor is locked. This is done as follows:

So apply a certain armature voltage. Then stop the shaft of the motor either by hand (if you can!) or by applying a flywheel. So that its velocity reduces to zero (i.e. $w = 0$). After the steady-state has been attained, measure the current $i_a(\text{inf})$ (or I_a) flowing into the motor. The DC Armature Resistance can now be evaluated using Ohm's Law (Voltage to Current Ratio).

$$(1) \quad R_a = V_a / I_a$$

NOTE:

Typical values for DC motors range from 1 to 10 ohms.

It should be noted that most motor manufacturer's catalog values for terminal resistance are scaled from accumulated test data for a particular winding that is usually in the middle of the range of windings offered. This value also includes a typical brush resistance. Tolerances stated in a manufacturer's motor data sheet can be in error by as much as $\pm 15\%$. Also, note that this method for determining resistance assumes that the motor is a series combination of resistance and inductance.

❖ **ARMATURE INDUCTANCE, L_a (MH)**

METHOD 1:

The Armature Inductance can also be determined in a similar fashion just like that of resistance. Apply a sinusoidal voltage of a certain frequency " f " to the armature input of the motor. Then stop the shaft of the motor either by hand (if you can!) or preferably by applying a flywheel. So that its velocity reduces to zero (i.e. $w = 0$). Measure the ac current i_a flowing into the motor.

The Armature Impedance can now be evaluated using Ohm's Law (Voltage to Current Ratio).

$$(2) \quad Z = v_a / i_a$$

Now, the total impedance of the armature circuit can be given as

$$(3) \quad Z = \sqrt{X_L^2 + R_a^2}$$

So, the inductive reactance is,

$$(4) \quad X_L = \sqrt{Z^2 - R_a^2}$$

and finally, the armature inductance can be evaluated as,

$$(5) \quad L_a = X_L / (2 * \pi * f)$$

METHOD 2:

The Armature Inductance, L_a can also be determined from the Electrical Time Constant, T_E of the motor. The Armature Inductance, L_a is measured by observing the step-response of the armature circuit, while the rotor is locked. The time constant of the armature circuit, also called as the “Electrical Time Constant” of the motor, T_E is defined as,

$$(6) \quad T_E = L_a / R_a$$

$$\text{so} \quad L_a = T_E * R_a$$

The procedure of experimental evaluation of Electrical Time Constant, T_E is explained later in this section.

❖ **BACK EMF CONSTANT, K_V (V.S / RAD)**

METHOD 1:

The back EMF constant, also commonly called the voltage constant, can be tested and determined by the following method.

The armature loop equation, by KVL, is given by

$$(7) \quad E_a = e_{IND} + I_a (R_a + L_a D)$$

$$\text{or} \quad e_{IND} = E_a - I_a (R_a + L_a D)$$

After attaining steady-state condition, $D = 0$.

So

$$(8) \quad e_{IND} = E_a - I_a R_a$$

Now consider the dc motor with the rotor free to turn. The back EMF constant can be obtained from *steady-state* step response data, that is from the measurements of $w(\text{inf})$ and $i_a(\text{inf})$, when a known constant input voltage E_a is applied.

So now apply certain armature voltage E_a , and measure the steady-state armature current I_a flowing into the motor. Then calculate e_{IND} by equation (8). Measure the steady-state motor shaft velocity $w(\text{inf}) = w_{SS}$.

$$(9) \quad e_{IND} = K_V * w_{SS}$$

So the back EMF constant can be calculated as,

$$K_V = e_{IND} / w$$

Repeat this procedure for more than one times, applying different input voltages. You will use an average of the estimates of K_V .

METHOD 2:

The back EMF constant can also be tested and determined by running the motor as a generator and measuring the generated voltage, e_{IND} , while measuring the shaft speed, w . The constant K_V can be obtained from the previous equation,

$$(9) \quad K_V = e_{IND} / w$$

The motor under test can be driven as a generator by coupling its shaft to another motor that is under speed control. A calibrated tachometer attached to the test motor's shaft, a hand tachometer, or a stroboscope can be used to determine the shaft speed, w .

❖ **TORQUE CONSTANT, K_T (N.M / A)**

The back-EMF constant K_V and the motor torque constant K_T are equal under the SI system. So

$$(10) \quad K_V = K_T$$

where K_V is in VOLTS-SECOND/RADIAN and K_T is in NEWTON-METER/AMPERE.

So the benefit of testing for K_V is that it directly determines the torque constant, K_T .

With these terms identified, the other significant motor parameters can be determined from the motor's time constants.

❖ **ELECTRICAL TIME CONSTANT, T_E (S)**

METHOD 1:

The time constant of the armature circuit, also called as the “Electrical Time Constant” of the motor, T_E is defined as,

$$(6) \quad T_E = L_a / R_a$$

So knowing the values of R_a and L_a , Electrical Time Constant, T_E can be evaluated.

METHOD 2: [FREQUENCY RESPONSE TEST]

Frequency response testing requires a function generator and an oscilloscope, or a frequency analyzer. To identify the break frequencies, f_B , in a frequency response test, the motor is excited with sine waves of unit amplitude over a range of frequencies. Stochastic test signals may also be used and have the advantage of easily spreading the excitation energy over a band of frequencies. If the amplitude ratios of the output to the input and the phase shift of the output sine wave with respect to the input sine wave have been measured at a significant number of frequencies within the frequency range of interest, then this data may be plotted on a Bode diagram. (If a stochastic signal is used, it is important to note the signal coherence in order to determine whether the test signal is valid.) Note that the measured signal for the frequency response test is motor velocity. Therefore, it is necessary to have a calibrated tachometer attached to the motor.

Once the experimental frequency data is obtained, asymptotes are drawn on the magnitude plot to determine the location of the break frequencies and the corresponding slopes. The motor's transfer function should show two break frequencies with slopes that decay at the rate of -20 dB /decade. The motor's gain, K, is essentially the inverse of the back EMF constant.

The first break frequency, f_{B1} , of a motor's frequency response test corresponds to the mechanical time constant, τ_M , and is located where the magnitude's response goes from a slope of zero to -20 dB/decade, usually in the 1 to 100 Hz frequency range. Specifically, f_{B1} occurs where the magnitude drops -3.03 dB from its static dc gain, and where the phase shifts by -45°.

The second break frequency, f_{B2} , occurs at a much higher frequency, usually in the range of 400 to 800 Hz, and demonstrates the same first-order factor characteristics as the f_{B1} break frequency. As the excitation frequency approaches infinity for a motor, the magnitude plot approaches negative infinity and the phase angle approaches -180°.

Once the break frequencies are identified, the motor's time constants can be determined from the following equations.

$$(11) \quad T_M = 1 / (2 * \pi * f_{B1}), \text{ and}$$

$$(12) \quad T_E = 1 / (2 * \pi * f_{B2})$$

where the time constants are in SECOND,
and the break frequencies are in HERTZ.

❖ MECHANICAL TIME CONSTANT, T_M (S)

METHOD 1:

The mechanical time constant can be computed from a velocity step response in the time domain. For time domain testing, the motor should be connected to a velocity sensor and given a step voltage. The time it takes the motor to reach 63.2 % of its final speed is its mechanical time constant.

ALTERNATIVELY, the mechanical time constant can be determined by opening the motor circuit (i.e. making $I_a = 0$), when the motor is rotating, and observing the time-constant of the resulting decay of the motor speed.

METHOD 2: [FREQUENCY RESPONSE TEST]

AS OUTLINED ABOVE UNDER THE HEADING OF THE ELECTRICAL TIME CONSTANT

❖ VISCOUS FRICTION COEFFICIENT, B (N.M.S / RAD) AND COULOMB FRICTION, C (N.M)

The output motor shaft Torque equation is,

$$(13) \quad T_M = J D w + B w + C,$$

where B = Viscous Friction Coefficient, and
 C = Coulomb Friction.

After attaining steady-state condition, $D = 0$.

So

$$(14) \quad T_M = B w + C,$$

where T_M is the torque applied by the motor and $T_M = K_T I_a$.

So [14] becomes

$$(15) \quad K_T I_a = B w + C,$$

You can compute the viscous- and Coulomb-friction coefficients B and C using the steady state equation [15].

Now consider the dc motor with the rotor free to turn. The Friction coefficients B and C can be obtained from *steady-state* step response data, that is from the measurements of $w(\text{inf})$ and $i_a(\text{inf})$, when a known constant input voltage E_a is applied.

So now apply certain armature voltage E_a , and measure the steady-state armature current I_a flowing into the motor. Measure the steady-state motor shaft velocity $w(\text{inf}) = w_{ss}$.

Repeat this experiment for more than one times, applying different input voltages. Record your data in tabular form. You will obtain a linear curve between I_a and w . Determine the best fit line between I_a and w [LINEAR REGRESSION]. The coefficients of this best-fit line determine the values of b and c

❖ ROTOR MOMENT OF INERTIA, J (KG.M²)

The rotor moment of inertia can be inferred from the mechanical time constant T_M . The motor mechanical time constant is given by the equation,

$$(16) \quad T_M = R_a J / K_M^2$$

where $K_M = K_V = K_T$.

So the motor's Moment of Inertia is,

$$J = T_M K_M^2 / R_a$$