An Analytical Series DC Motor Model from Experimental Test Data

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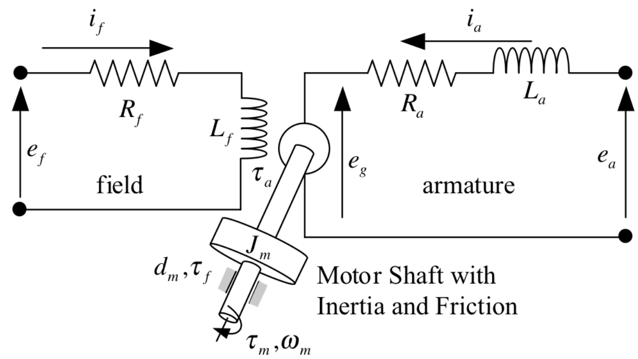
Motivation

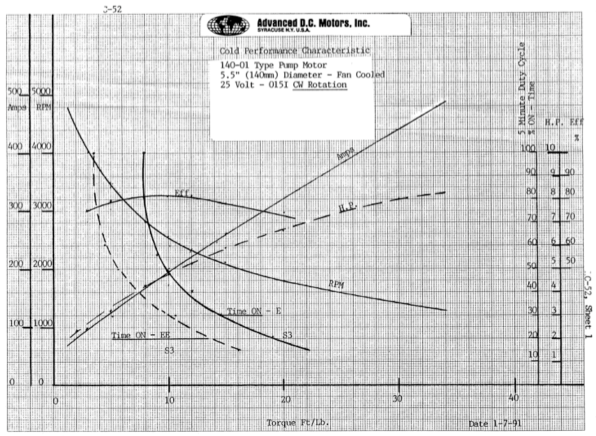
- Direct Current (DC) Motors:
  - common mechatronic actuators
  - important for
    - electromechanical systems
    - battery powered appliances &
    - electric vehicles.
  - wound DC motors are common in electric and hybrid vehicles.

The DC Motor System



SCHEMATIC OF A DC MOTOR
WITH SEPARATE FIELD AND ARMATURE WINDINGS

Manufacturer Data



Model 140-01 5.5”, Advanced DC Motors, Inc

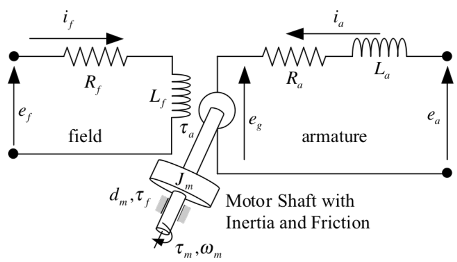
The Inverse Problem

- Given:
  - Manufacturer performance data
  - A conceptual model
- How do I generate an analytical model and its parameters that best match the <u>real</u> measured performance?

Steps

- Generate analytical model from schematic concept
- Fit manufacturer's data to the model
- Use fit to determine important physics and associated parameters
  - Neglect the unimportant physics

The Analytical Model

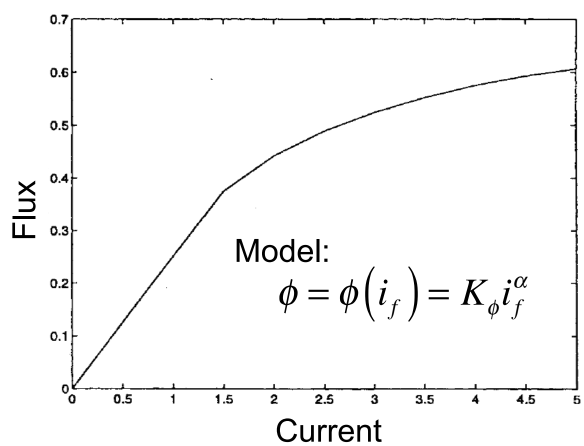


For a series wound motor

$$e_m = e_f + e_a$$

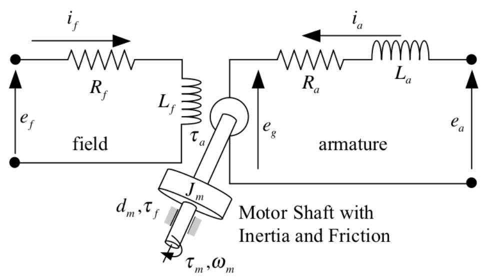
$$i_m = i_f = i_a$$

Field Saturation



Magnetization Curve showing Saturation of Wound Field Flux with increasing Current

Analytical Model (cont)



- The Series Wound DC Motor Model

$$e_m = R_m i_m + L_m \frac{di_m}{dt} + K_m \omega_m i_m^{\alpha}$$

$$\tau_m = K_m i_m^{(1+\alpha)} - d_m \omega_m - \tau_d - J_m \frac{d\omega_m}{dt}$$

Only Steady-State Manufacturer Data

- The Non-linear Steady-State Model

$$e_m = R_m i_m + K_m \omega_m i_m^{\alpha}$$

$$\tau_m = K_m i_m^{(1+\alpha)} - d_m \omega_m - \tau_d$$

- Inputs: Load Torque τ_m , Drive e_m
- Outputs: Current i_m, Speed ω_m
- Parameters: R_m, K_m, α, d_m , τ_m

Physical Parameters

Motor electrical resistance R_m (Ohm)

Motor constant K_m *(N-m/amp) or (volt-sec/rad)*

Torque and back EMF

Field saturation constant α, *(NA)*

Viscous Drag coefficient, d_m*(N-m-sec/rad),*

Coulomb Drag τ_m *(N-m)*

Note no Aerodynamic drag

The MS Error Function

$$E^2 = \sum_i \left[\left[1 - \frac{\left(R_m i_m + K_m \omega_m i_m^{\alpha}\right)}{e_m} \right]_i^2 + \left[1 - \frac{\left(K_m i_m^{(1+\alpha)} - d_m \omega_m - \tau_d\right)}{\tau_m} \right]_i^2 \right]$$

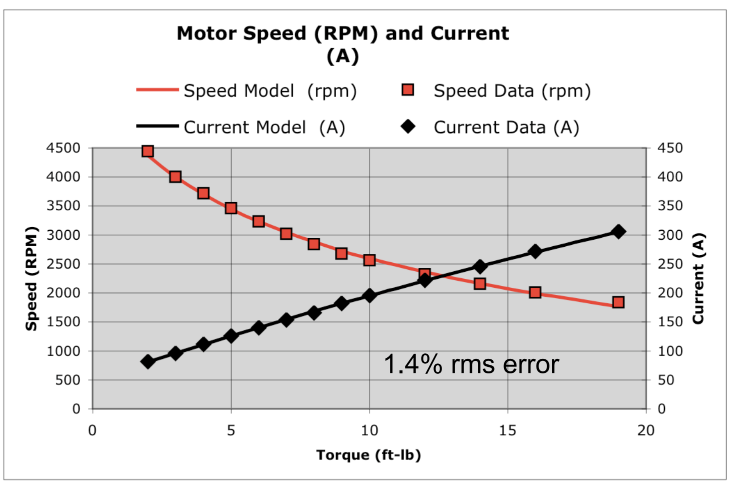
- Accuracy requires a non-dimensional error function

Excel Spreadsheet

Torque (ft-lb)	Drive (volt)	Torque (N-m)	Speed Data (rpm)	Current Data (A)	Speed Data (rad/s)	Model Drive (v)	Model Torque (N-m)	Drive Error^2 (ND)	Torque Error^2 (ND)	Total Error^2 (ND)
2	25	2.71	4440	82	465.0	25.46	2.72	0.00034	6E-06	0.0003
3	25	4.07	4000	96	418.9	24.95	4.05	4.1E-06	2E-05	3E-05
4	25	5.42	3720	112	389.6	25.19	5.46	5.6E-05	5E-05	0.0001
5	25	6.78	3460	126	362.3	25.07	6.77	7.7E-06	2E-06	1E-05
6	25	8.14	3230	140	338.2	24.94	8.10	5.3E-06	2E-05	2E-05
7	25	9.49	3020	154	316.3	24.78	9.46	7.4E-05	1E-05	8E-05
8	25	10.85	2840	166	297.4	24.54	10.66	0.00034	0.0003	0.0006
9	25	12.20	2680	182	280.6	24.63	12.25	0.00021	1E-05	0.0002
10	25	13.56	2560	196	268.1	24.77	13.66	8.7E-05	6E-05	0.0001
12	25	16.27	2320	222	242.9	24.70	16.40	0.00014	6E-05	0.0002
14	25	18.98	2160	246	226.2	24.93	18.98	7.8E-06	1E-07	8E-06
16	25	21.70	2010	272	210.5	25.22	21.86	7.5E-05	6E-05	0.0001
19	25	25.76	1840	306	192.7	25.62	25.77	0.00062	1E-07	0.0006
									Sum(E^2) =	0.0026
									RMS(E) =	0.0141

$R_m =$ 0.0322 Ohm
$d_m =$ 0.0075 (N-m-s/rad)
$K_m =$ 0.0089 (N-m/A^2)
$\alpha =$ 0.3881
$\tau_d =$ -2.18 N-m

Model Matches Measurement



Modeled and Measured Responses vs Torque (ft.-lb.)
(Model 140-01 5.5”, Advanced DC Motors, Inc)