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Effect of plant parameter variation on feedback control loop (DC motor temperature effect model)

Musaab Ali mohammed Sidahmed[1]
PG student
Control Engineering Department, Faculty of Engineering
AL Neelain University
Khartoum – Sudan

Muawia Mohamed Ahmed Mahmoud[2]
Associate Professor
Control Engineering
AL Neelain University
Khartoum – Sudan

Abstract: The variation of system parameters in field of control represents a series problem. This variation should be determined and measured. This paper focuses on the effects of temperature variation on DC motor. This effect is usually not considered by the designers of control system, which may lead to misleading in the controller design.

Keywords: DC motor; temperature; parameter variation; feedback.

I. INTRODUCTION

DC motor is a power actuator which converts electrical energy into mechanical energy. DC motor is used in many applications. The greatest advantage of dc motors control may be the speed control. The term speed control stand for speed variation carried out manually or automatically. DC motors are most suitable for wide range speed control and are therefore used in many adjustable speed produced by its poles, adjusting the armature voltage and/or the field current will change the rotor speed. DC motors have been widely used in many industrial applications such as electric vehicles, steel rolling mills, electric cranes, and robotic manipulators due to precise, wide, simple, and continuous control characteristics [3]. One of the problems facing the operation of the dc motor is the temperature rising during operation. The increase in temperature leads to some deviation in the internal parameters of the dc motor transfer function. The following sections of the paper study this variation and describe its effect.

II. DC MOTOR MODELING

A common actuator in control system is the DC motor. It directly Provides rotary motion and, coupled with wheels or drums and cables, can provide transitional motion. The electric circuit of the armature and the free body diagram of the rotor are shown in the Fig. 1.

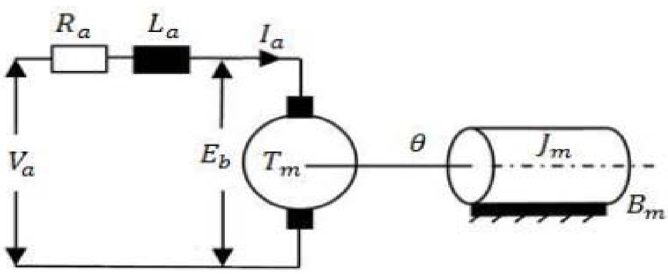

Fig. 1 DC motor modelling

The motor torque, T, is related to the armature current, I_a, by a constant factor Kt. The back emf e_b is related to the rotational velocity by the constant factor K_b as in the following equations:

$$v_{a(t)} = R_a I_a(t) + L_a * \frac{dI_a(t)}{dt} + e_b(t) \tag{1}$$

The motor back emf, which is also known as speed voltage, is expressed as:

$$e_{b(t)}= K_b * \omega(t) \quad (2)$$

The torque developed by the motor:

$$T_m(t) = K_t * I_a(t) \quad (3)$$

$$T_m(t) = J_m * \frac{d\omega(t)}{dt} + B_m * \omega(t) \quad (4)$$

Substituting equations (2) in (1) and (3) in (4)

$$v_{a(t)} = R_a\, I_a(t) + l_a * \frac{dI_a(t)}{dt} + k_{b} * \omega(s) \quad (5)$$

$$K_t * I_a(t) = J_m * \frac{dw(t)}{dt} + B_m * \omega(t) \quad (6)$$

Used Laplace transforms of equations (5) and (6)

$$v_a(s) = R_a\, I_a(S) + s * L_a * I_a(s) + k_b * \omega\,(s) \quad (7)$$

$$K_t * I_a(s) = J_m * \omega(s) * s + B_m * \omega(s) \quad (8)$$

Simplification and eliminating the current from equations and get the result

$$v_a(s) = \omega(s) * \frac{1}{K_t}\left[L_a * J_m s^2 + (R_a * J_m + L_a * B_m)s + (R_a * B_m + K_{b*K_t})\right] \quad (9)$$

The transfer function from the input armature voltagev_a (s), to the rotational speed in (rad/sec)ω(s), directly follows:

$$\frac{\omega(s)}{V_{a(S)}} = \frac{K_t}{L_a * J_m s^2 + (R_a * J_m + L_a * B_m) * s + (R_a * B_m + K_{b*K_t})} \quad (10)$$

Where

v_a	Armature voltage	(V)
R_a	Armature resistance	(Ω)
I_a	Armature current	(A)
L_a	Armature inductance	(H)
W	angular speed	(rad/s)
T_m	Motor torque	(Nm/A)
J_m	Motor inertia	(kgm^2)
B_m	Viscous fraction constant	(Nms/rad)
K_t	Torque constant	(Nm/A)
K_b	Back emf constant	(vs/rad)

III. Effect of Temperature on DC Motor Transfer Function

The phrase "motor constants", however, is somewhat of a misnomer. Winding resistance and permanent magnet flux density will change as temperature changes. As the motor temperature increases, winding resistance will increase based on the temperature coefficient of copper. The flux density of the permanent magnets will also decrease as a function of temperature. This will lead an effect of dc motor performance during operation under varies temperature.[1]

A. Temperature Effects of Motor Winding Resistance

Motor winding resistance (R_{mt}) is the main cause of heat generation within the motor. In order for any electric motor to generate torque, current needs to be forced through the motor windings. Copper is an excellent conductor, however, it's not perfect; material physics and impurities will cause the atoms to vibrate at a faster rate as more current flows. The result is a steady temperature increase in temperature increases, the resistance of the material also increases as a function of the type of conductor used. Electric motors typically use copper conductor material, follow Equation illustrate the relationship between winding temperature, winding resistance[1].

$$R_{mt(f)} = R_{mt(i)} \times[1+\alpha_{conductor}(\vartheta_f\_\vartheta_i) \quad (11)$$

Where

$\alpha_{conductor}$ ≡ Temperature coefficient for copper which is 0.0040

$R_{mt(i)}$ winding Resistance at 25 for copper which is 0.59Ω

B. Temperature Effects on Magnetic Flux Density

The motor torque constant (K_T) and voltage constant (K_E) are directly related to the magnetic flux density (B_m) of the permanent magnets. Depending on the physics of the magnet material used, overall flux density will change at a given percentage with an increase in magnet temperature. As the material temperature increases, atomic vibrations cause once-aligned magnetic moments to "randomize" resulting in a decrease in magnetic flux density. Assuming the motor is operating within its intended design window, the decrease in flux density is temporary and will begin to recover as the magnet cools. If the maximum temperature rating of the magnets is exceeded, however, partial demagnetization will occur and permanently alter the performance of the motor.[1]

$$K_{mt(f)} = K_{mt(i)} \times[1+\alpha_{magnet}(\vartheta_f\_\vartheta_i)] \quad (12)$$

Where

α_{magant} ≡ Temperature coefficient for permanent magnet which is -0.0020 for copper

$K_{mt(i)}$ ≡ Motor torque and voltage continent which is 0.71 at temp 25°C

IV. Feedback Characteristics

Estimated motor characteristics at elevated temperature of 125°C

Using the equations (11) & (12) to find the value of $R_{mt(f)}$& $K_{mt(f)}$ at 125°C

$$R_{mt(f)} = .59\Omega \times [1 + .0040(125°C - 25°C)]$$

$$R_{mt(f)} = .83\Omega$$

$$K_{mt(f)} = 0.071\, v/rad/s \times [1 + (-0.0020)(125°C - 25°C)]$$

$$K_{mt(f)} = 0.057\, v/rad/s$$

Substituting the real value of K_T K_E & R_{mt} into the transfer function equation (10)

At temperature 25°C the real transfer function for DC motor will be as

$$\frac{\omega(s)}{V_{a(S)}} = \frac{0.071}{0.005s^2+0.0559s+0.064} \quad (13)$$

At temperature 125°C the transfer function will be as

$$\frac{\omega(s)}{V_{a(S)}} = \frac{0.057}{0.005s^2+0.0583s+0.086} \quad (14)$$

applying feedback control to the transfer function of dc motor at temperature 25°C& 125°C

at temperature 25 the controlled system will be as

$$gf1 = \frac{0.071}{0.005s^2+0.0559s+0.135} \quad (15)$$

At temperature 125 the controlled system will be as

$$gf2 = \frac{0.057}{0.005s^2+0.0583s+0.143} \quad (16)$$

V. RESULTS

Mat labs Plot for two controlled systems are shown in Fig 2.

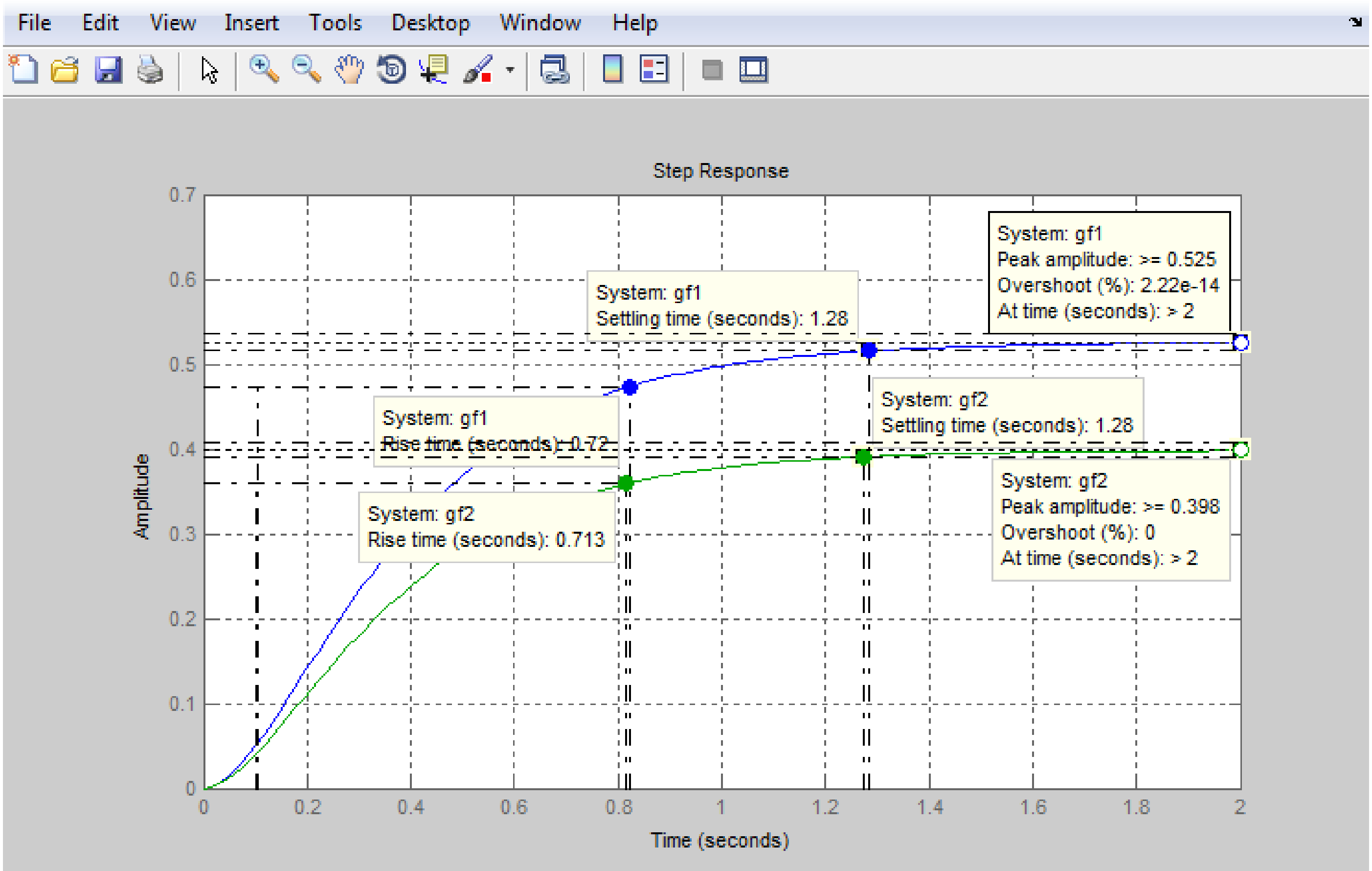

Fig. 2 Mat lap plot for $gf1$ and $gf2$

As shown in the table there are some differences in system response when temperature increase to 125°C the rise time will increase with small value, this will also lead to decrease the peak amplitude of the system response, noted that the settling time is fixed for both responses of the systems, also the differences seem small but have considerable effect on control design process. Knowing that for high power DC motor this effect will be greater.

TABLE 1. Characteristics of step response of effected and unaffected systems

Controlled System at Temperature (°C)	**Rise Time (s)**	**Settling Time (s)**	**Peak AMP& Overshoot**
25	0.72	1.28	PEAK AMP>= 0.525 OVERS HOOT (%):2.22e^{-14}
125	0.713	1.28	PEAK AMP>= 0.398 OVER SHOOT(%):0

VI. CONCLUSION

From the previous discussed cases, it is clear that changing in temperature due to actual operation for a well defined period of time has an effect on DC motor performance after applying feedback control, so the theoretical treatment of DC motor characteristics could not obtain the desired performance of DC motor. However the controller designers should take the variations of these parameters into account.

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