Analysis of DC Current Regulators for High Performance Drives

Current Regulation in DC Machines

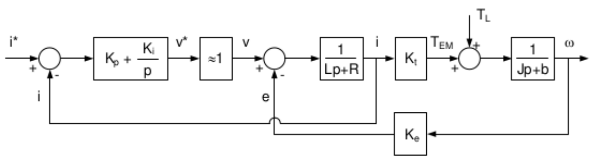


Fig. 1. Analyzing Current Regulator at Locked Rotor

	Ki	Kp
MGFQK 063-32	51.6515	0.1432
MGFQK 160-22	0.8316	0.1432

Table 1. Current Regulator Coefficients

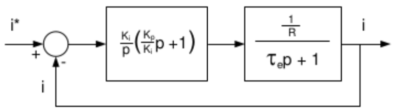


Fig. 2. Current Loop

Tuning the current loop at locked rotor decouples the effects of Back EMF. The current loop in the DC machine is rewritten with constants $\tau_c = \frac{K_p}{K_i}$, and $\tau_e = \frac{L}{R}$. The current loop is simplified by setting $\tau_c = \tau_e$. Note, an additional gain constant K_v should be included after the controller. Further analysis simplifies the current regulator to transfer function

$$\frac{I}{I^*} = \frac{\frac{K_i K_v p}{R_a}}{\frac{K_i K_v p}{R_a} + 1} \quad (1)$$

Knowing the response of the current regulator, the gain coefficients can be solved for 1000Hz bandwidth.

$$K_i = 2\pi f R_a / K_v \quad (1)$$
$$K_p = 2\pi f L_a / K_v \quad (2)$$

The coefficients are listed in Table 1.

The magnitude and phase of the current regulators are provided.

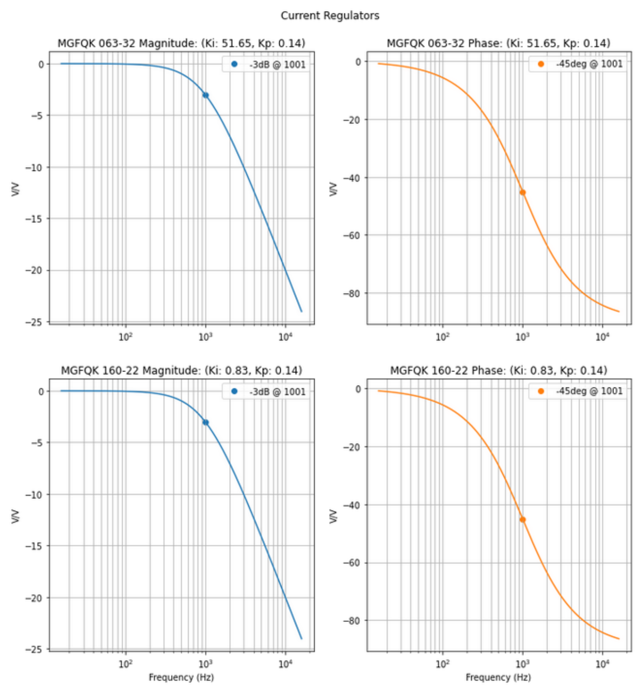


Fig. 3. Current Regulator Frequency Response

Locked Rotor Current Response

The next section simulates the motors at locked rotor conditions and ideal voltages. The command and response currents are measured with varying frequencies. The command current is defined as

$$i^*(t) = I_o sin(2\pi f_c t) \quad (1)$$

where Io = 5A and fc = 1, 10, 100, 1000 Hz.

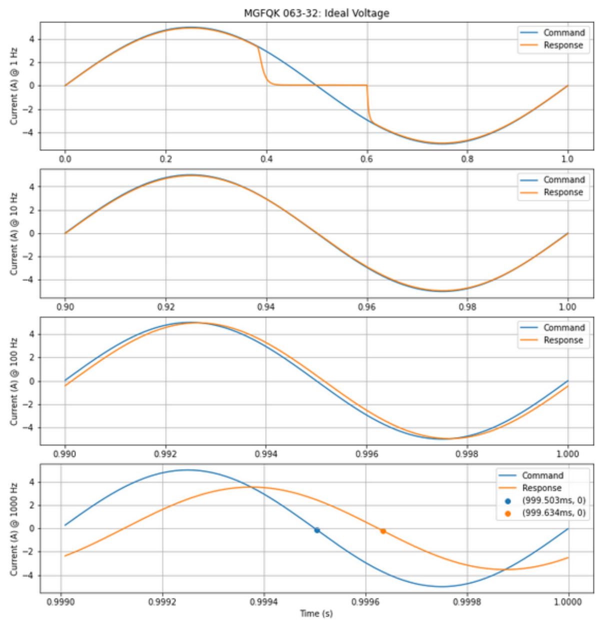


Fig. 4. MGFQK 063-32: PI Controller

At 1Hz, there is unexpected behavior in the response current near the 0 crossing. The current regulator produces a voltage that reaches the upper limit of the saturation block (680 volts) and clips the armature voltage. The current agrees with the frequency response from Figure 3. At 1000Hz, the response current has a peak voltage of 3.54V, equivalent to -3dB. The phase is 131 μs, equivalent to 46.8 degrees. Note, measurements must be in steady state otherwise they will provide values from transient response. Also both motors yield very similar responses, however the larger motor doesn't clip.

1 Hz	10 Hz	100 Hz	1000 Hz
4.9319	4.9335	4.9612	3.5366

Tbl 2. MGFQK 063-32: Controller Resp. (V)

1 Hz	10 Hz	100 Hz	1000 Hz
4.9242	4.9485	4.9747	3.5283

Tbl 3. MGFQK 160-22: Controller Resp. (V)

Locked Rotor Speed Performance

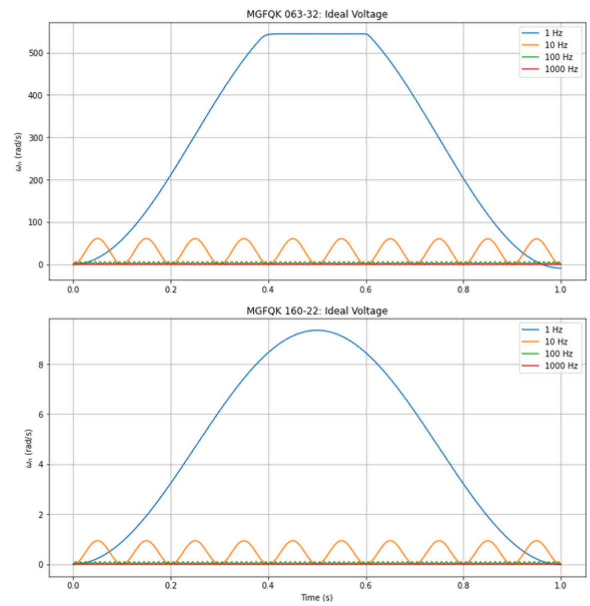


Fig. 5. Locked Rotor Speed Response

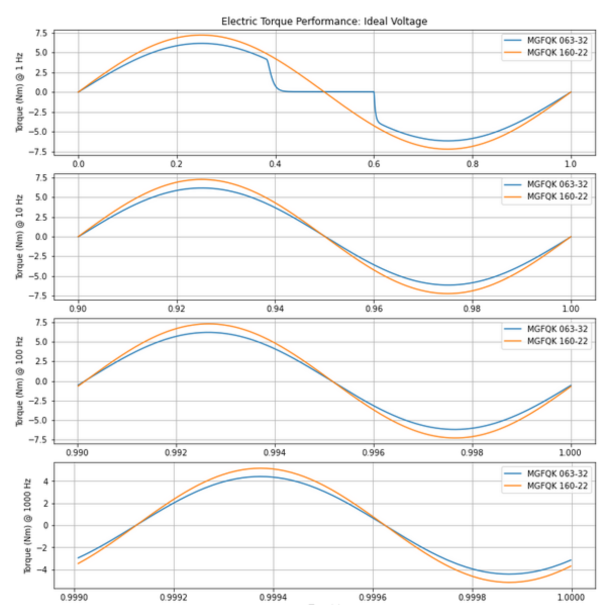


Fig. 6. Locked Rotor Electric Torque

	ω_{pk}	ω_{avg}	t_{em-pk}
1 Hz	544.35	273.24	6.16
10 Hz	61.22	30.16	
100 Hz	6.15	3.02	
1000 Hz	0.53	0.30	

Table 4. MGFQK 063-32 Speed (rad/s)

	ω_{pk}	ω_{avg}	t_{em-pk}
1 Hz	9.35	4.33	
10 Hz	0.94	0.47	
100 Hz	0.094	0.047	
1000 Hz	0.0081	0.0047	

Table 5. MGFQK 160-22 Speed (rad/s)

Analyzing the speed response, the smaller motor clips at 1 Hz and obtains a maximum speed of 544 rad/s. As expected, the larger motor operates more slowly than the smaller motor and with greater electromagnetic torque.

Unlocked Rotor Current Response

Fig. _. MGFQK 063-32: PI Controller

1 Hz	10 Hz	100 Hz	1000 Hz

Tbl _ MGFQK 063-32: Current Response (V)

1 Hz	10 Hz	100 Hz	1000 Hz

Tbl _ MGFQK 160-22: Current Response (V)

Unlocked Rotor Speed Performance

Fig. 5. Unlocked Rotor Speed Response with Varying Carrier Frequencies

	ω_{pk}	ω_{avg}	t_{em-pk}
1 Hz			
10 Hz			
100 Hz			
1000 Hz			

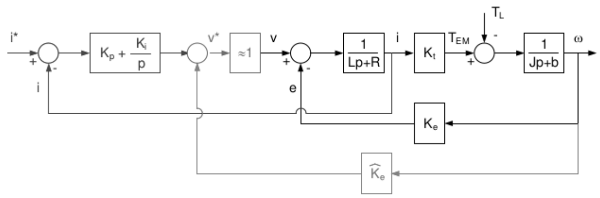
Table _. MGFQK 063-32 Speed (rad/s)

	ω_{pk}	ω_{avg}	t_{em-pk}
1 Hz			
10 Hz			
100 Hz			
1000 Hz			

Table _. MGFQK 160-22 Speed (rad/s)

H-Bridge Performance

Performance Improvements


i*
+
-
i
$K_p + \frac{K_i}{p}$
v*
≈1
v
+
-
e
$\frac{1}{Lp+R}$
i
K_t
T_{EM}
T_L
-
+
$\frac{1}{Jp+b}$
ω
K_e
$\widehat{K}_e$