

Practice # 3

Motor model construction.

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1 Introduction

§1.1 Student information & & variant

- ★ Name: Xu Miao
- ★ ITMO Number: 293687
- ★ HDU Number: 19322103
- ★ Variant: $k = 7$

My $k = 7$, the parameters of my motor *MT23FB30115M3(s)* are as shown below:

Model No.	No. of poles	No. of phase	Rated Voltage	Rated Speed	Rated Torque	Rated Power	Peak Torque	Peak Current	Line to line resistance	Line to line inductance	Torque constant	Back E.M.F.	Rotor Inertia	Body Length	Mass
			Vdc	rpm	Nm	W	Nm	A	Ω	mH	Nm/A	V/Krpm	gcm ²	mm	Kg
MT23FB30115M3(S)	4	3	36	4000	0.22	92	0.7	11.5	0.7	2.16	0.063	6.6	119	75	0.75

Fig. 1.1. Motor parameters

2 Notations

Table 2.1: Notation used in this report

Symbol	Definition
E	counter electromotive force(EMF)
I	rotor current
I_p	Peak Current
\hat{I}	Measured current
J_M	motor moment of inertia
J_A	moment of inertia of the actuator (load).
J_Σ	moment of inertia reduced to the motor shaft
k_E	EMF coefficient (the first constructive constant)
k_M	torque coefficient (the second constructive constant)
k_y	gain of ACD
L	rotor inductance
M_E	engine torque
M_r	moment of resistance, reduced to the motor shaft
R	rotor resistance.
T_y	time constant of ACD.
U, U_m	maximum voltage at the input of an ACD
U_H	ratio motor voltage
\hat{U}_y	Measured voltage
ω	rotor angular velocity
$\hat{\omega}$	Measured velocity
$\hat{\alpha}_M$	Measured angle of rotation

★ Other notations instructions will be given in the text.

3 Solution of problem

§3.1 The Mathematical Model of electromechanical object

§3.1.i ACD Model

ACD with a high degree of accuracy can be represented as aperiodic link:

$$T_y \frac{dU_y}{dt} + U_y = k_y U \quad (3.1)$$

The required gain k_y is a ratio motor voltage U_H and maximum voltage U_m at the input of an ACD $k_y = U_H/U_m$, (usually $U_m = 10$ V).

In summary, we can get the mathematical model of the ACD part

$$\begin{cases} T_y \frac{dU_y}{dt} + U_y = k_y U \\ k_y = \frac{U_H}{U_m} \\ T_y = \frac{1}{U_m} \end{cases} \quad (3.2)$$

§3.1.ii Electric Motor Model

In accordance with Ohm's law, for the electric circuit of the engine we obtain the following equation:

$$U_y = E + IR + L \frac{dI}{dt} \quad (3.3)$$

Set $T_r = L/R$, $K_M = 1/R$, the equation (3.3) is rewritten in the form:

$$T_r \cdot \frac{dI}{dt} + I = K_M (U_y - k_E \omega) \quad (3.4)$$

The equation of rotation of the rotor of the motor has the form

$$M_E - M_r = J_\Sigma \frac{d\omega}{dt} \quad (3.5)$$

where $M_E = k_M \cdot I$ is engine torque

The mechanical characteristics of the motor and the production mechanism are shown in the figure below:

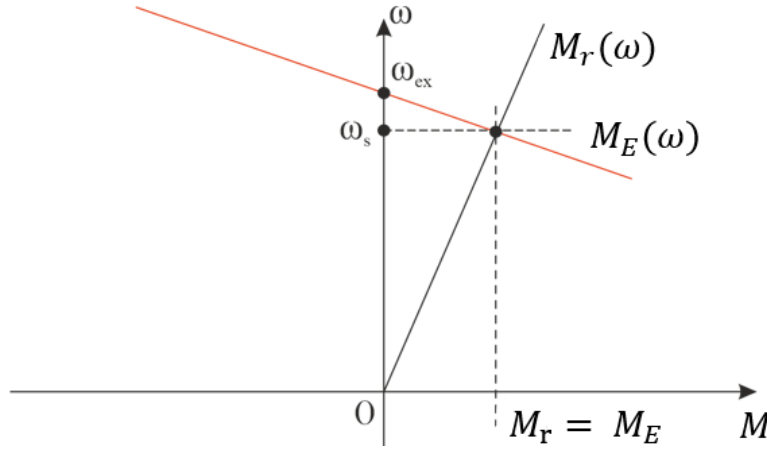


Fig. 3.1. Motor Torque-Angular Velocity Characteristics

From the above figure, generally speaking, when the motor starts, the load torque M_r is proportional to the rotational speed ω , we assume that they are linear, and the proportionality coefficient is k which is

$$M_r = k \cdot \omega \quad (3.6)$$

The moment of inertia reduced to the motor shaft is determined by the formula:

$$J_\Sigma = J_M + J_A \quad (3.7)$$

To sum up, we can get the mathematical model of the motor part as:

$$\begin{cases} T_r \frac{dI}{dt} + I = K_M (U_y - k_E \omega) \\ T_r = \frac{L}{R}; K_M = \frac{1}{R} \\ M_E - M_r = J_\Sigma \frac{d\omega}{dt} \\ M_E = k_M \cdot I \\ M_r = k \cdot \omega \\ J_\Sigma = J_M + J_A \end{cases} \quad (3.8)$$

§3.1.iii Measuring Model

Actuator is considered instantaneous. Measured voltage \hat{U}_y , current \hat{I} , velocity $\hat{\omega}$, angle of rotation $\hat{\alpha}_M$ values are formed at the output of measuring devices.

$$\hat{U}_y = K_U U_y, \quad \hat{I} = K_I I, \quad \hat{\omega} = K_\omega \omega, \quad \hat{\alpha}_M = K_\alpha \alpha_M \quad (3.9)$$

That is, the mathematical model of the measuring device part is:

$$\begin{cases} \hat{U}_y = K_U U_y \\ \hat{I} = K_I I \\ \hat{\omega} = K_\omega \omega \\ \hat{\alpha}_M = K_\alpha \alpha_M \end{cases} \quad (3.10)$$

§3.2 The calculations

My $k = 7$, the parameters of my motor $MT23FB30115M3(s)$ are as shown below:

Model No.	No. of poles	No. of phase	Rated Voltage	Rated Speed	Rated Torque	Rated Power	Peak Torque	Peak Current	Line to line resistance	Line to line inductance	Torque constant	Back E.M.F.	Rotor Inertia	Body Length	Mass
			Vdc	rpm	Nm	W	Nm	A	Ω	mH	Nm/A	V/Krpm	gcm ²	mm	Kg
MT23FB30115M3(S)	4	3	36	4000	0.22	92	0.7	11.5	0.7	2.16	0.063	6.6	119	75	0.75

Fig. 3.2. Motor parameters

The parameters in the model are calculated according to the motor passport as follows:

§3.2.i Motor parameters

Some parameters of the motor can be obtained from the above figure as follows:

$$\left\{ \begin{array}{l} U_H = 36 \text{ V} \\ R = 0.7\Omega \\ L = 2.16\text{mH} \\ k_M = 0.063\text{Nm/A} \\ k_E = 6.6 \text{ V/krpm} \\ \quad \approx 0.063 \text{ V/(rad/s)} \\ I_M = 119 \text{ g} \cdot \text{cm}^2 \\ \quad = 119 \times 10^{-7} \text{ kg} \cdot \text{m}^2 \\ \omega_r = 4000\text{rpm} \approx 46.1062\text{rad/s} \end{array} \right. \quad (3.11)$$

§3.2.ii Known Parameters

Assuming there is no error in the measuring device, the known parameters are as follows:

$$\left\{ \begin{array}{l} U = 10 \text{ V} \\ J_A = 4.5 \times 10^{-5} \text{ kg} \cdot \text{m}^2 \\ K_U = 1; K_I = 1 \\ K_I = 1; K_\alpha = 1 \end{array} \right. \quad (3.12)$$

§3.2.iii Parameter calculation

When the motor works at rated power, the motor rotates at a constant speed, and the current, torque, etc. are rated values and do not change.

We can use this state to calculate the proportional coefficient k between the motor's load torque M_r and the angular velocity ω

$$\begin{aligned} T_r \cdot \frac{dI_r}{dt} + I_r &= K_M (U_y - k_E \omega_r) \\ \frac{dI_r}{dt} &= 0 \end{aligned} \quad (3.13)$$

Through (3.4) we can calculate the rated current I_r of the motor under rated working conditions

$$I_r = K_M (U_y - k_E \omega_r) \approx 11.2629 \quad (3.14)$$

At this time, the motor is in steady state, that is $\frac{d\omega}{dt} = 0$, So, from (6) we can get:

$$M_E^{\text{rated}} - M_r^{\text{rated}} = J_\Sigma \frac{d\omega}{dt} = 0 \quad (3.15)$$

Taking (15) into the calculation, we can get:

$$M_r^{\text{rated}} = M_E^{\text{rated}} = k_M \cdot I_r \approx 0.7245 \quad (3.16)$$

Then we can get the scale factor k :

$$k = \frac{M_r^{\text{rated}}}{\omega_r} \approx 0.0016 \quad (3.17)$$

§3.3 The transfer function "ACD Voltage - Angular Velocity"

The differential equation for the motor part is shown below:

$$\begin{cases} T_r \cdot \frac{dI}{dt} + I = K_M (U_y - k_E \omega) \\ M_E - M_r = J_\Sigma \frac{d\omega}{dt} \\ M_E = k_M \cdot I \\ M_r = k \cdot \omega \end{cases} \quad (3.18)$$

Simplifying it we can get:

$$\begin{cases} T_r \cdot \frac{dI}{dt} + I = K_M (U_y - k_E \omega) \\ k_M \cdot I - k \cdot \omega = J_\Sigma \frac{d\omega}{dt} \end{cases} \quad (3.19)$$

Applying the Laplace transform to (3.19) we can get :

$$\begin{cases} T_r \cdot s \cdot I(s) + I(s) = K_M (U_y(s) - k_E \omega(s)) \\ k_M \cdot I(s) - k \cdot \omega(s) = J_\Sigma \cdot s \cdot \omega(s) \end{cases} \quad (3.20)$$

Computationally simplifying (3.20) we can get:

$$W(s) = \frac{\omega(s)}{U_y(s)} = \frac{K_M \cdot k_M}{(J_\Sigma \cdot s + k)(T_r \cdot s + 1) + K_M \cdot k_M \cdot k_E} \quad (3.21)$$

$$\approx \frac{0.09}{1.7558 \times 10^{-7} s^2 + 6.1808 \times 10^{-5} s + 0.0073}$$

§3.4 Block Diagram of the Model

Using (3.2), (3.8), (3.10) to build a model block diagram in simulink is as follows:

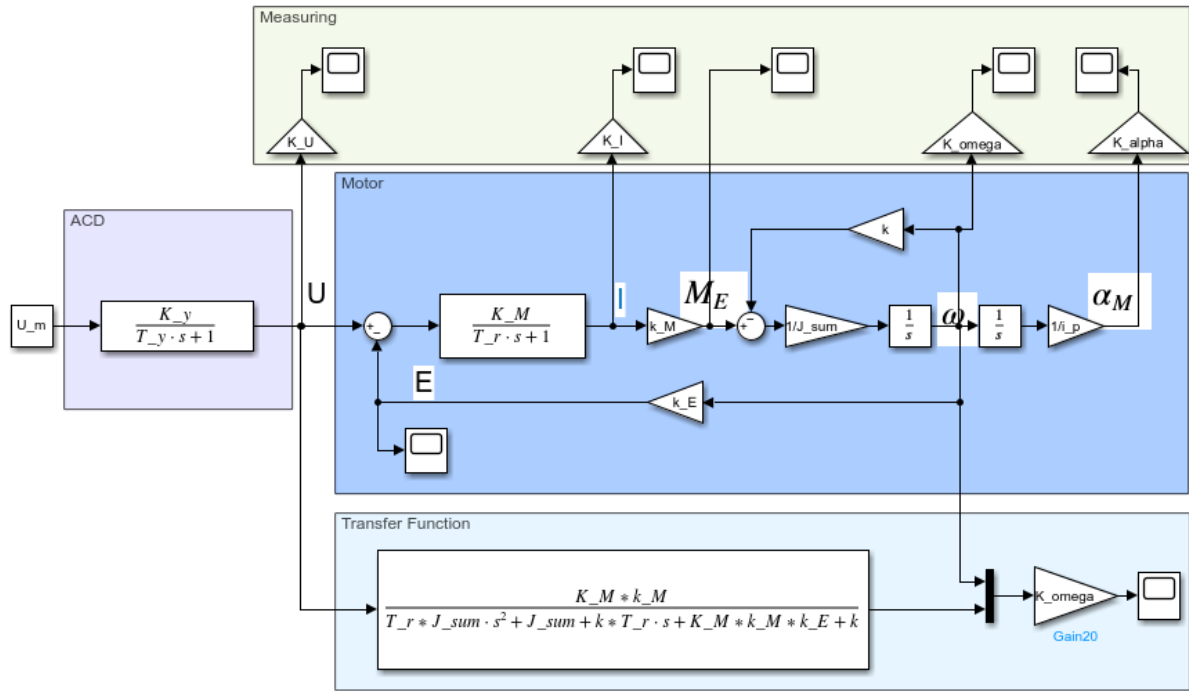


Fig. 3.3. Block Diagram of the Model

§3.5 Simulation

Using the parameters in (3.11), (3.12), (3.17) to simulate the system, the results are shown in Fig3.4 - Fig3.8 :

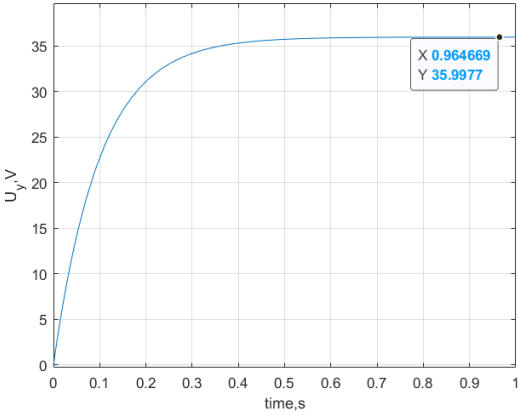


Fig. 3.4. Measured voltage

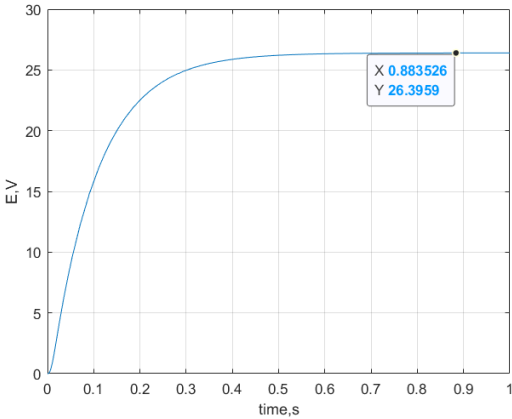


Fig. 3.5. Measured counter electromotive force(EMF)

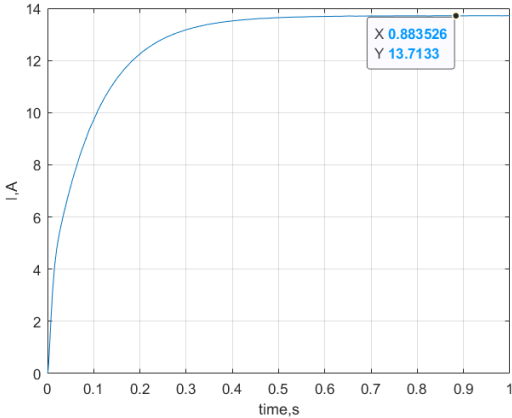


Fig. 3.6. Measured Current

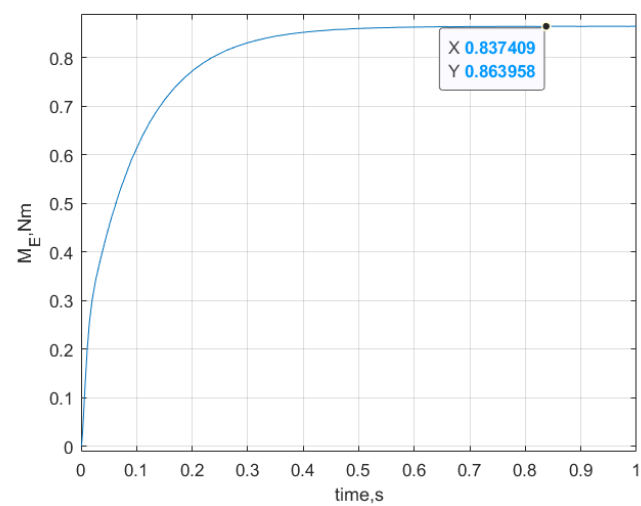


Fig. 3.7. Measured engine torque

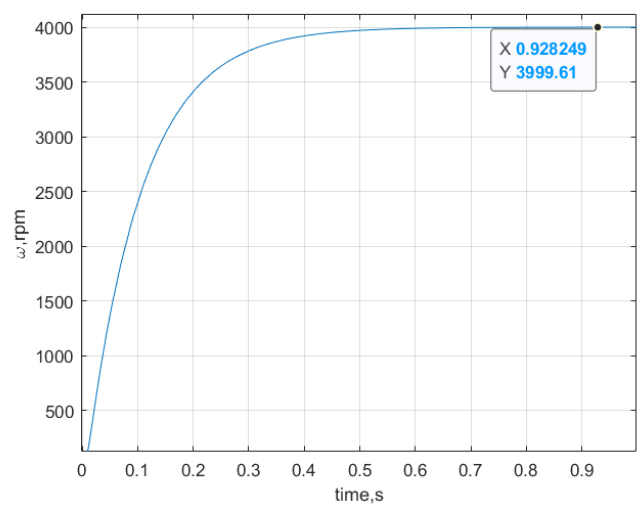


Fig. 3.8. Measured velocity

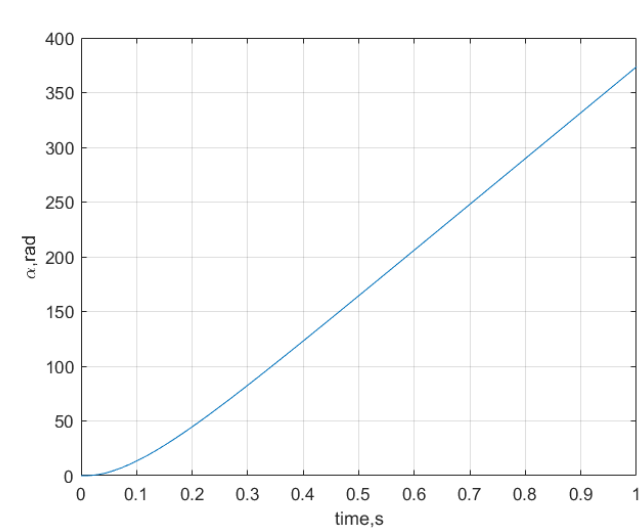


Fig. 3.9. Measured angle of rotation

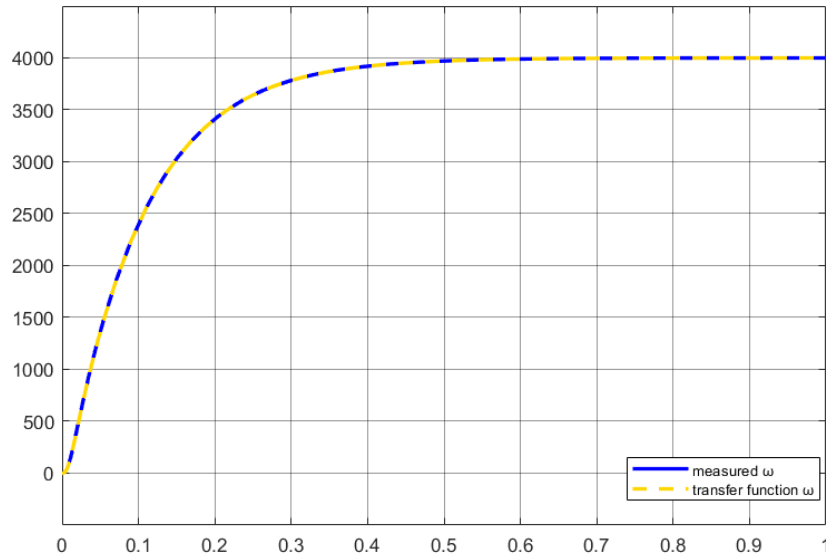


Fig. 3.10. Transfer function output comparison

From Fig.3.4-Fig.3.8 above, it can be seen that $\omega_r = 4000rpm$ in the experimental value is the same as the rated speed ($4000rpm$). However, the stable value of I ($13.7133A$) and the stable value of W_E ($0.8640Nm$) are different from the peak current ($11.5 A$) and peak torque ($0.7 Nm$) in the motor passport.

§3.6 Error Analysis & Simulation Verification

Analyze the causes of errors, it may be for the following reasons :

- 1) In real life motors have losses, and in the manufacturer write values with some losses
- 2) in the passport the manufacturer don't write non-integer value, So there might be some rounding in the motor passport data

So I simulated the range of rated torque as $\omega_r \sim \omega_r + 300(rpm)$ as shown in Fig.3.1-Fig.3.16:

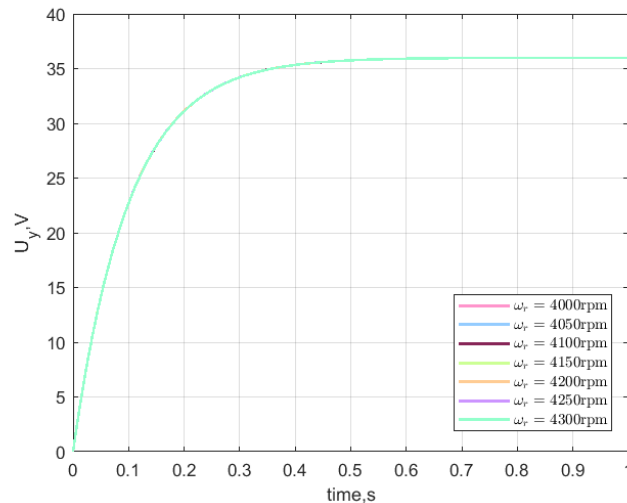


Fig. 3.11. Measured voltage

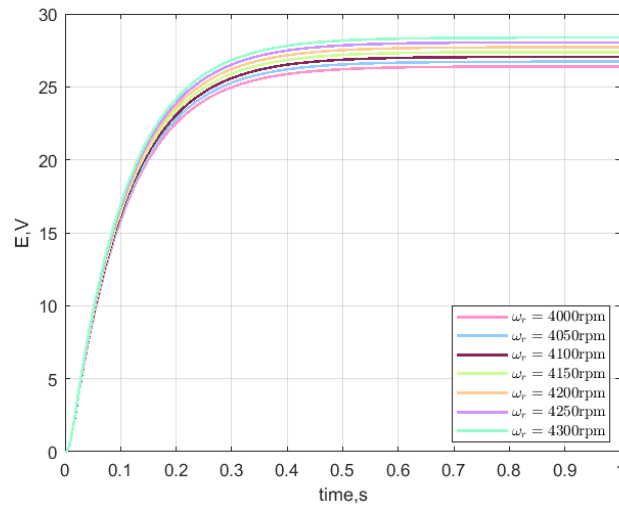


Fig. 3.12. Measured counter electromotive force(EMF)

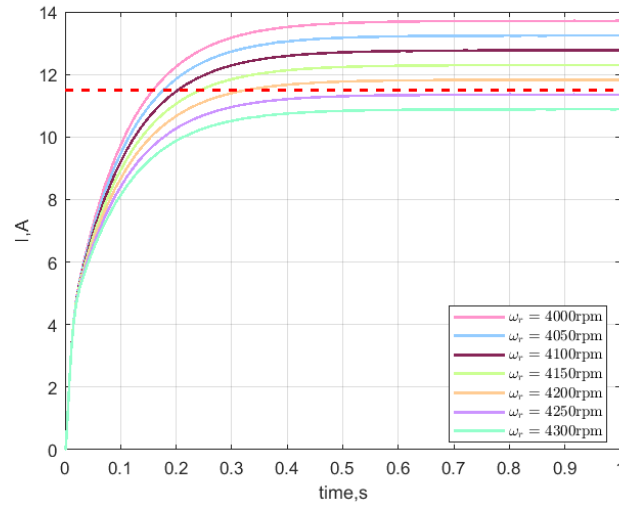


Fig. 3.13. Measured Current

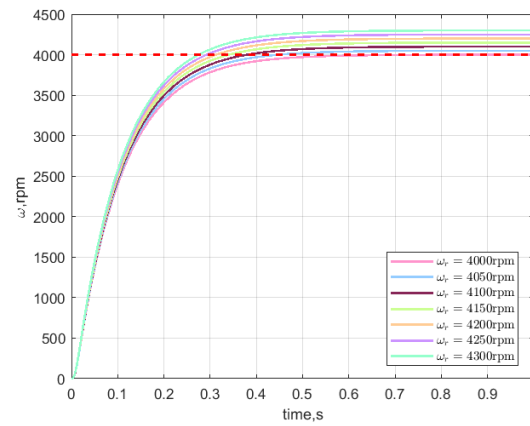


Fig. 3.15. Measured velocity

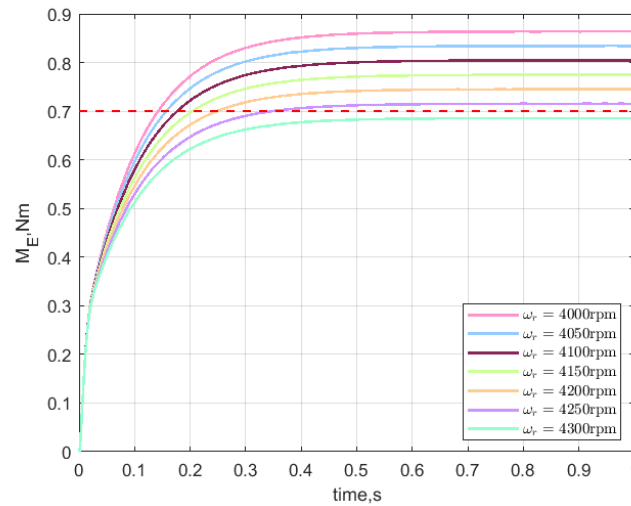


Fig. 3.14. Measured engine torque

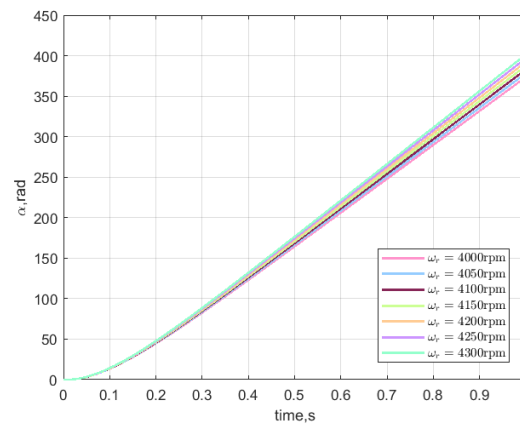


Fig. 3.16. Measured angle of rotation

§3.7 Conclusion

If the motor does not consider other friction or losses during operation, the rated torque is about $4200 \sim 4300 \text{ rpm}$, the peak current is about $10 \sim 11.9(A)$, the peak torque is about $0.68 \sim 0.73(N \cdot m)$, which may be different from the value of on the motor passport(rated torque : 4000 rpm , peak current : $11.5A$, peak torque : $0.7N \cdot m$). There may be many reasons for this phenomenon :

1. The motor is running with other losses that reduce the speed measured by the manufacturer
2. There are some roundings in actual measurements
3. The manufacturer takes the loss in practical application into account, and the value on the motor passport has some reduction to accommodate this loss
4. and so on

I

Appendix

A Complete source code

parameter

```
1 clear all
2 %motor parameter
3 k_M = 0.063;k_E = 6.6*30/pi*10^(-3);
4 R = 0.7;L = 2.16*10^(-3);
5 K_M = 1/R;T_r = L/R;
6 U_H = 36;U_m = 10;
7 K_y = U_H/U_m;T_y = 1/U_m;
8 K_U = 1;K_I = 1;K_omega = 30/pi;K_alpha = 1;i_p = 1;
9 omega_rated = 4000*pi/30;
10 I_rated = K_M*(U_H - k_E * omega_rated);
11 M_r = I_rated*k_M;
12 k = M_r/omega_rated;
13 J_sum = 119*10^(-7)+4.5*10^(-5);
14 I_p = 11.5;
15 M_r = I_p * k_M;
```

simulation

```
1 sim('pra3.slx');
2 time = ans.tout;
3 omega = ans.omega(:,2);
4 Uy = ans.Uy(:,2);
5 M_E = ans.M_E(:,2);
6 I = ans.I(:,2);
7 E = ans.E(:,2);
8 alpha = ans.alpha(:,2);
9
10 figure
11 plot(time,E);
12 hold on
13 grid on
14 xlabel('time,s')
15 ylabel('E,V')
16 figure
17 plot(time,Uy);
18 hold on
19 grid on
20 xlabel('time,s')
21 ylabel('U_y,V')
22 figure
23 plot(time,I);
24 hold on
25 grid on
26 xlabel('time,s')
27 ylabel('I,A')
28 figure
```



```

29 plot(time,M_E);
30 hold on
31 grid on
32 xlabel('time,s')
33 ylabel('M_E,Nm')
34 figure
35 plot(time,omega);
36 hold on
37 grid on
38 xlabel('time,s')
39 ylabel('\omega,rpm')
40 figure
41 plot(time,alpha);
42 hold on
43 grid on
44 xlabel('time,s')
45 ylabel('\alpha,rad')

```

Simulation Verification

```

1 clear all
2 %motor parameter
3 k_M = 0.063;k_E = 6.6*30/pi*10^(-3);
4 R = 0.7;L = 2.16*10^(-3);
5 K_M = 1/R;T_r = L/R;
6 U_H = 36;U_m = 10;
7 K_y = U_H/U_m;T_y = 1/U_m;
8 K_U = 1;K_I = 1;K_omega = 30/pi;K_alpha = 1;i_p = 1;
9 J_sum = 119*10^(-7)+4.5*10^(-5);
10 I_p = 11.5;
11 M_r = I_p * k_M;
12
13 n = 4000;
14 omega_rated = n*pi/30;
15 I_rated = K_M*(U_H - k_E * omega_rated);
16 M_r = I_rated*k_M;
17 k = M_r/omega_rated;
18 sim('pra3.slx');
19 time = ans.tout;
20 omega = ans.omega(:,2);
21 Uy = ans.Uy(:,2);
22 M_E = ans.M_E(:,2);
23 I = ans.I(:,2);
24 E = ans.E(:,2);
25 alpha = ans.alpha(:,2);
26
27 n = 4050;
28 omega_rated = n*pi/30;
29 I_rated = K_M*(U_H - k_E * omega_rated);
30 M_r = I_rated*k_M;
31 k = M_r/omega_rated;
32 sim('pra3.slx');
33 time0 = ans.tout;
34 omega0 = ans.omega(:,2);

```

```

35 Uy0 = ans.Uy(:,2);
36 M_E0 = ans.M_E(:,2);
37 I0 = ans.I(:,2);
38 E0 = ans.E(:,2);
39 alpha0 = ans.alpha(:,2);
40
41 n = 4100;
42 omega_rated = n*pi/30;
43 I_rated = K_M*(U_H - k_E * omega_rated);
44 M_r = I_rated*k_M;
45 k = M_r/omega_rated;
46 sim('pra3.slx');
47 time1 = ans.tout;
48 omega1 = ans.omega(:,2);
49 Uy1 = ans.Uy(:,2);
50 M_E1 = ans.M_E(:,2);
51 I1 = ans.I(:,2);
52 E1 = ans.E(:,2);
53 alpha1 = ans.alpha(:,2);
54
55 n = 4150;
56 omega_rated = n*pi/30;
57 I_rated = K_M*(U_H - k_E * omega_rated);
58 M_r = I_rated*k_M;
59 k = M_r/omega_rated;
60 sim('pra3.slx');
61 time2 = ans.tout;
62 omega2 = ans.omega(:,2);
63 Uy2 = ans.Uy(:,2);
64 M_E2 = ans.M_E(:,2);
65 I2 = ans.I(:,2);
66 E2 = ans.E(:,2);
67 alpha2 = ans.alpha(:,2);
68
69 n = 4200;
70 omega_rated = n*pi/30;
71 I_rated = K_M*(U_H - k_E * omega_rated);
72 M_r = I_rated*k_M;
73 k = M_r/omega_rated;
74 sim('pra3.slx');
75 time3 = ans.tout;
76 omega3 = ans.omega(:,2);
77 Uy3 = ans.Uy(:,2);
78 M_E3 = ans.M_E(:,2);
79 I3 = ans.I(:,2);
80 E3 = ans.E(:,2);
81 alpha3 = ans.alpha(:,2);
82
83 n = 4250;
84 omega_rated = n*pi/30;
85 I_rated = K_M*(U_H - k_E * omega_rated);
86 M_r = I_rated*k_M;
87 k = M_r/omega_rated;

```

```

88 sim('pra3.slx');
89 time4 = ans.tout;
90 omega4 = ans.omega(:,2);
91 Uy4 = ans.Uy(:,2);
92 M_E4 = ans.M_E(:,2);
93 I4 = ans.I(:,2);
94 E4 = ans.E(:,2);
95 alpha4 = ans.alpha(:,2);
96
97 n = 4300;
98 omega_rated = n*pi/30;
99 I_rated = K_M*(U_H - k_E * omega_rated);
100 M_r = I_rated*k_M;
101 k = M_r/omega_rated;
102 sim('pra3.slx');
103 time5 = ans.tout;
104 omega5 = ans.omega(:,2);
105 Uy5 = ans.Uy(:,2);
106 M_E5 = ans.M_E(:,2);
107 I5 = ans.I(:,2);
108 E5 = ans.E(:,2);
109 alpha5 = ans.alpha(:,2);
110
111
112 figure(1)
113 plot(time,E,'Color',[1,0.58,0.8],'LineWidth',1.5);
114 hold on
115 plot(time0,E0,'Color',[0.58,0.8,1],'LineWidth',1.5);
116 hold on
117 plot(time1,E1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
118 hold on
119 plot(time2,E2,'Color',[0.8,1,0.58],'LineWidth',1.5);
120 hold on
121 plot(time3,E3,'Color',[1,0.8,0.58],'LineWidth',1.5);
122 hold on
123 plot(time4,E4,'Color',[0.8,0.58,1],'LineWidth',1.5);
124 hold on
125 plot(time5,E5,'Color',[0.58,1,0.8],'LineWidth',1.5);
126 hold on
127 grid on
128 h = legend('$\omega_r = 4000 \mathrm{rpm}$ ', '$\omega_r = 4050 \mathrm{rpm}$ ', '$\omega_r = 4100 \mathrm{rpm}$ ', '$\omega_r = 4150 \mathrm{rpm}$ ', '$\omega_r = 4200 \mathrm{rpm}$ ', '$\omega_r = 4250 \mathrm{rpm}$ ', '$\omega_r = 4300 \mathrm{rpm}$ ');
129 set(h,'Interpreter','latex','Location','SouthOutside')
130 xlabel('time,s')
131 ylabel('E,V')
132
133 figure(2)
134 plot(time,Uy,'Color',[1,0.58,0.8],'LineWidth',1.5);
135 hold on
136 plot(time0,Uy0,'Color',[0.58,0.8,1],'LineWidth',1.5);
137 hold on

```

```

138 plot(time1,Uy1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
139 hold on
140 plot(time2,Uy2,'Color',[0.8,1,0.58],'LineWidth',1.5);
141 hold on
142 plot(time3,Uy3,'Color',[1,0.8,0.58],'LineWidth',1.5);
143 hold on
144 plot(time4,Uy4,'Color',[0.8,0.58,1],'LineWidth',1.5);
145 hold on
146 plot(time5,Uy5,'Color',[0.58,1,0.8],'LineWidth',1.5);
147 hold on
148 grid on
149 h = legend('$\omega_r = 4000 \mathrm{rpm}$ ', '$\omega_r = 4050 \mathrm{rpm}$ ', '$\omega_r = 4100 \mathrm{rpm}$ ', '$\omega_r = 4150 \mathrm{rpm}$ ', '$\omega_r = 4200 \mathrm{rpm}$ ', '$\omega_r = 4250 \mathrm{rpm}$ ', '$\omega_r = 4300 \mathrm{rpm}$ ');
150 set(h,'Interpreter','latex','Location','SouthOutside')
151 xlabel('time,s')
152 ylabel('U_y,V')
153
154 figure(3)
155 plot(time,I,'Color',[1,0.58,0.8],'LineWidth',1.5);
156 hold on
157 plot(time0,I0,'Color',[0.58,0.8,1],'LineWidth',1.5);
158 hold on
159 plot(time1,I1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
160 hold on
161 plot(time2,I2,'Color',[0.8,1,0.58],'LineWidth',1.5);
162 hold on
163 plot(time3,I3,'Color',[1,0.8,0.58],'LineWidth',1.5);
164 hold on
165 plot(time4,I4,'Color',[0.8,0.58,1],'LineWidth',1.5);
166 hold on
167 plot(time5,I5,'Color',[0.58,1,0.8],'LineWidth',1.5);
168 hold on
169 line([0,1],[11.5,11.5],'Color','red','LineStyle','--','LineWidth',1.5);
170 hold on
171 grid on
172 h = legend('$\omega_r = 4000 \mathrm{rpm}$ ', '$\omega_r = 4050 \mathrm{rpm}$ ', '$\omega_r = 4100 \mathrm{rpm}$ ', '$\omega_r = 4150 \mathrm{rpm}$ ', '$\omega_r = 4200 \mathrm{rpm}$ ', '$\omega_r = 4250 \mathrm{rpm}$ ', '$\omega_r = 4300 \mathrm{rpm}$ ');
173 set(h,'Interpreter','latex','Location','SouthOutside')
174 xlabel('time,s')
175 ylabel('I,A')
176
177 figure(4)
178 plot(time,M_E,'Color',[1,0.58,0.8],'LineWidth',1.5);
179 hold on
180 plot(time0,M_E0,'Color',[0.58,0.8,1],'LineWidth',1.5);
181 hold on
182 plot(time1,M_E1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
183 hold on

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184 plot(time2,M_E2,'Color',[0.8,1,0.58],'LineWidth',1.5);
185 hold on
186 plot(time3,M_E3,'Color',[1,0.8,0.58],'LineWidth',1.5);
187 hold on
188 plot(time4,M_E4,'Color',[0.8,0.58,1],'LineWidth',1.5);
189 hold on
190 plot(time5,M_E5,'Color',[0.58,1,0.8],'LineWidth',1.5);
191 hold on
192 line([0,1],[0.7,0.7],'Color','red','LineStyle','--','LineWidth',1.5)
193 hold on
194 grid on
195 h = legend('$\omega_r = 4000 \mathrm{rpm}$ ', '$\omega_r = 4050 \mathrm{rpm}$ ', '$\omega_r = 4100 \mathrm{rpm}$ ', '$\omega_r = 4150 \mathrm{rpm}$ ', '$\omega_r = 4200 \mathrm{rpm}$ ', '$\omega_r = 4250 \mathrm{rpm}$ ', '$\omega_r = 4300 \mathrm{rpm}$ ');
196 set(h,'Interpreter','latex','Location','SouthOutside')
197 xlabel('time,s')
198 ylabel('M_E,Nm')
199
200 figure(5)
201 plot(time,omega,'Color',[1,0.58,0.8],'LineWidth',1.5);
202 hold on
203 plot(time0,omega0,'Color',[0.58,0.8,1],'LineWidth',1.5);
204 hold on
205 plot(time1,omega1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
206 hold on
207 plot(time2,omega2,'Color',[0.8,1,0.58],'LineWidth',1.5);
208 hold on
209 plot(time3,omega3,'Color',[1,0.8,0.58],'LineWidth',1.5);
210 hold on
211 plot(time4,omega4,'Color',[0.8,0.58,1],'LineWidth',1.5);
212 hold on
213 plot(time5,omega5,'Color',[0.58,1,0.8],'LineWidth',1.5);
214 hold on
215 line([0,1],[4000,4000],'Color','red','LineStyle','--','LineWidth',1.5)
216 hold on
217 grid on
218 h = legend('$\omega_r = 4000 \mathrm{rpm}$ ', '$\omega_r = 4050 \mathrm{rpm}$ ', '$\omega_r = 4100 \mathrm{rpm}$ ', '$\omega_r = 4150 \mathrm{rpm}$ ', '$\omega_r = 4200 \mathrm{rpm}$ ', '$\omega_r = 4250 \mathrm{rpm}$ ', '$\omega_r = 4300 \mathrm{rpm}$ ');
219 set(h,'Interpreter','latex','Location','SouthOutside')
220 xlabel('time,s')
221 ylabel('\omega,rpm')
222
223 figure
224 plot(time,alpha,'Color',[1,0.58,0.8],'LineWidth',1.5);
225 hold on
226 plot(time0,alpha0,'Color',[0.58,0.8,1],'LineWidth',1.5);
227 hold on
228 plot(time1,alpha1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
229 hold on

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230 plot(time2,alpha2,'Color',[0.8,1,0.58],'LineWidth',1.5);
231 hold on
232 plot(time3,alpha3,'Color',[1,0.8,0.58],'LineWidth',1.5);
233 hold on
234 plot(time4,alpha4,'Color',[0.8,0.58,1],'LineWidth',1.5);
235 hold on
236 plot(time5,alpha5,'Color',[0.58,1,0.8],'LineWidth',1.5);
237 hold on
238 grid on
239 h = legend('$\omega_r = 4000 \mathrm{rpm}$ ', '$\omega_r = 4050 \mathrm{rpm}$ ', '$\omega_r = 4100 \mathrm{rpm}$ ', '$\omega_r = 4150 \mathrm{rpm}$ ', '$\omega_r = 4200 \mathrm{rpm}$ ', '$\omega_r = 4250 \mathrm{rpm}$ ', '$\omega_r = 4300 \mathrm{rpm}$ ');
240 set(h,'Interpreter','latex','Location','SouthOutside')
241 xlabel('time,s')
242 ylabel('\alpha,rad')
```