Practice # 3

Motor model construction.

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Contents

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	Reted 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	gcm²	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:

$$T_y \frac{dU_y}{dt} + U_y = k_y U \tag{3.1}$$

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

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

§3.1.ii Electric Motor Model

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

$$U_y = E + IR + L \frac{dI}{dt} \tag{3.3}$$

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

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

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

$$M_E - M_\tau = J_\Sigma \frac{d\omega}{dt} \tag{3.5}$$

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:

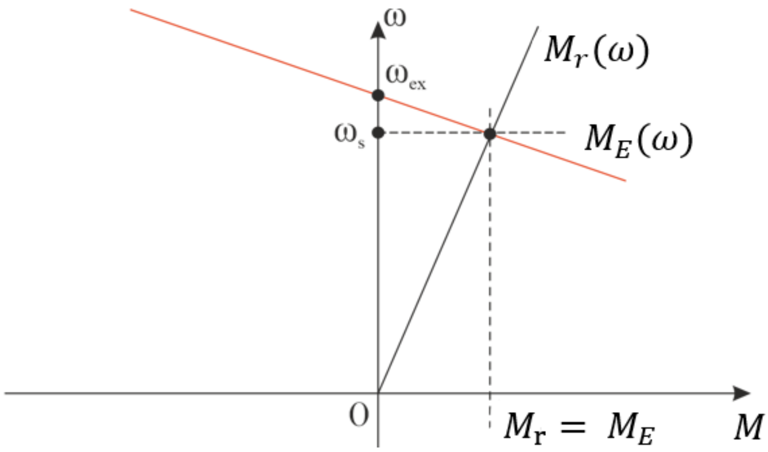

Fig. 3.1. Motor Torque-Angular Velocity Characteristics

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

$$M_r = k \cdot \omega \tag{3.6}$$

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

$$J_\Sigma = J_M + J_A \tag{3.7}$$

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

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

§3.1.iii Mearsuring 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.

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

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

$$\begin{cases} \hat{U}_y = K_v U_y \\ \hat{I} = K_I I \\ \hat{\omega} = K_\omega \omega \\ \hat{\alpha}_M = K_\alpha \alpha_M \end{cases} \tag{3.10}$$

§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	Reted 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	gcm²	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:

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

§3.2.ii Known Parameters

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

$$\begin{cases} U = 10 \text{ V} \\ J_A = 4.5 \times 10^{-5} \text{ kg} \cdot \text{m}^2 \\ K_U = 1; K_I = 1 \\ K_I = 1; K_\alpha = 1 \end{cases} \tag{3.12}$$

§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

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

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

$$I_r = K_M \left(U_y - k_E \omega_r\right) \approx 11.2629 \tag{3.14}$$

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

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

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

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

Then we can get the scale factor k:

$$k = \frac{M_r^{rated}}{\omega_r} \approx 0.0016 \tag{3.17}$$

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

The differential equation for the motor part is shown below:

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

Simplifying it we can get:

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

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

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

Computationally simplifying (3.20) we can get:

$$W(s) = \frac{\omega(s)}{U_y(s)} = \frac{K_M \cdot k_M}{(J_\Sigma \cdot s + k)(T_r \cdot s + 1) + K_M \cdot k_M \cdot k_E} \approx \frac{0.09}{1.7558 \times 10^{-7} s^2 + 6.1808 \times 10^{-5} s + 0.0073} \tag{3.21}$$

§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:

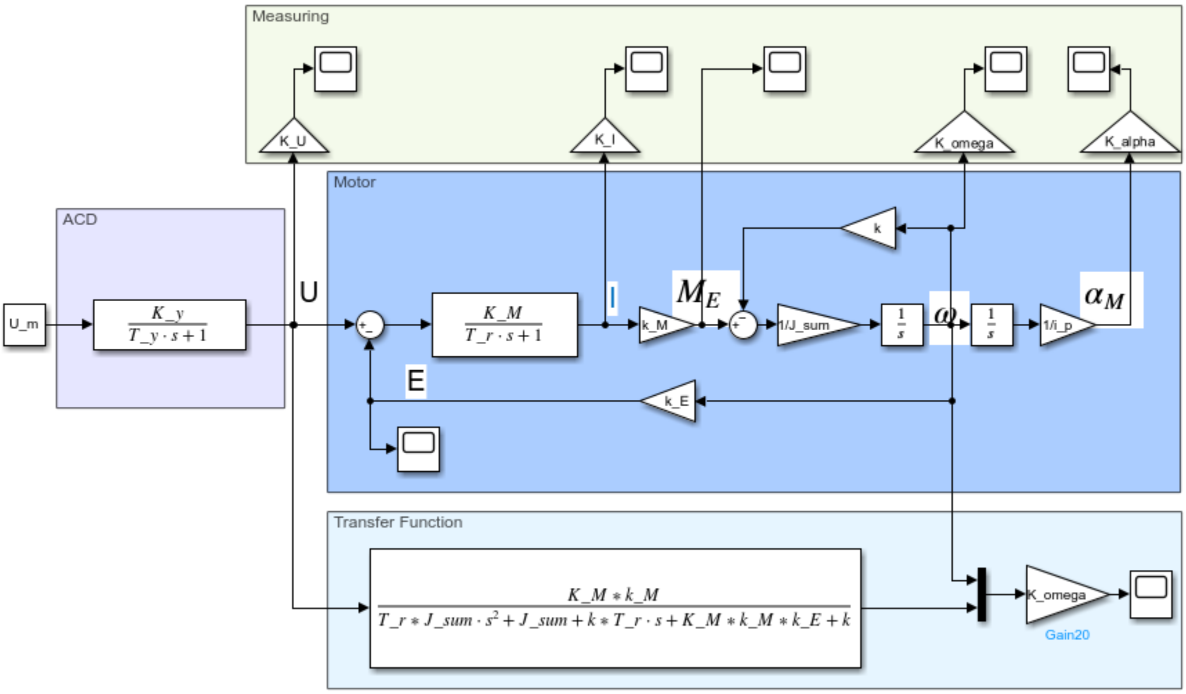

Fig. 3.3. Block Diagram of the Model

§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 :

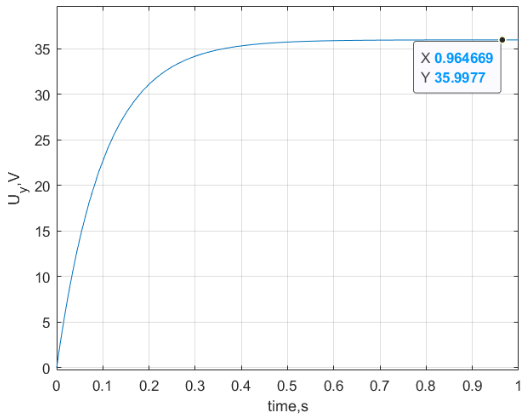

Fig. 3.4. Measured voltage

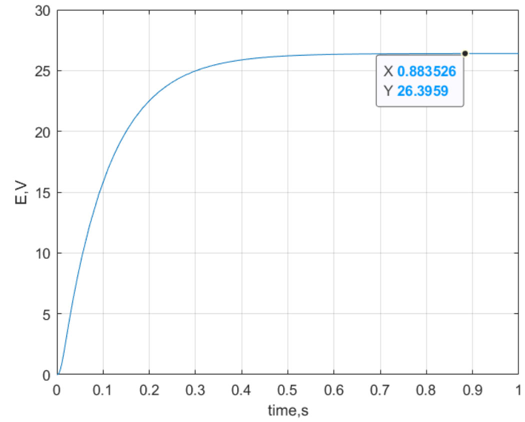

Fig. 3.5. Measured counter electromotive force(EMF)

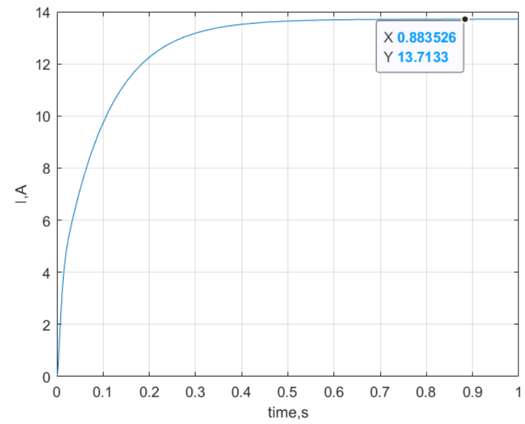

Fig. 3.6. Measured Current

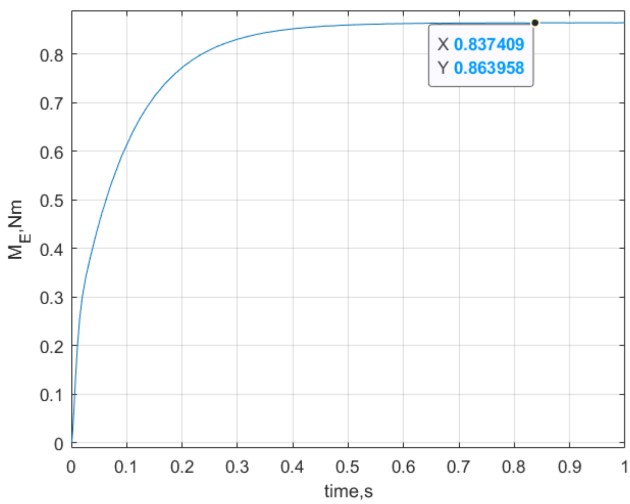

Fig. 3.7. Measured engine torque

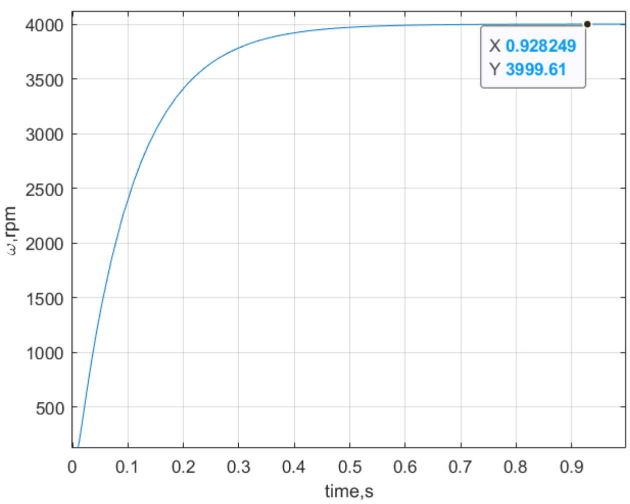

Fig. 3.8. Measured velocity

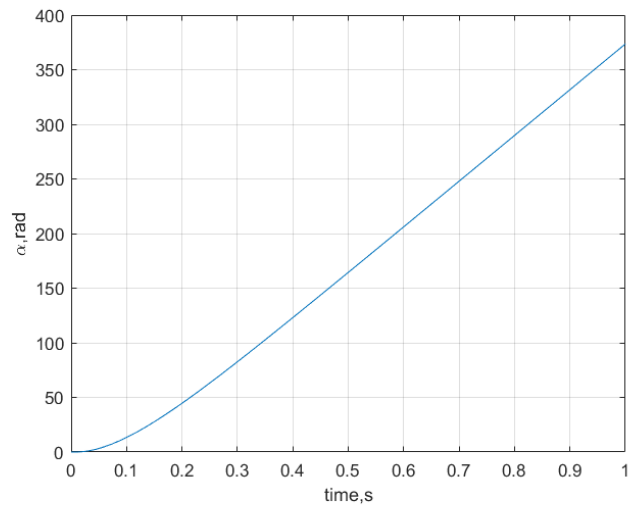

Fig. 3.9. Measured angle of rotation

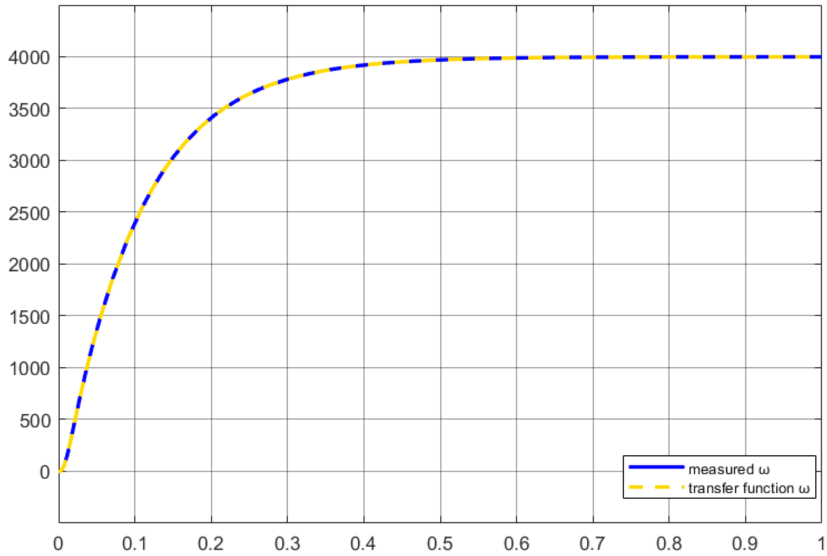

Fig. 3.10. Transfer function output comparison

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:

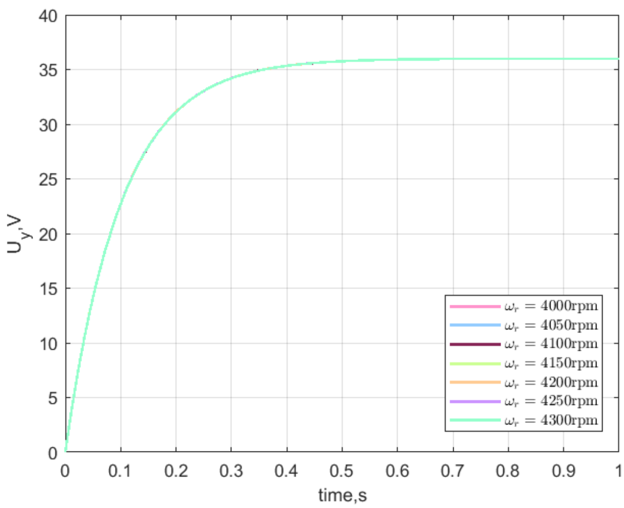

Fig. 3.11. Measured voltage

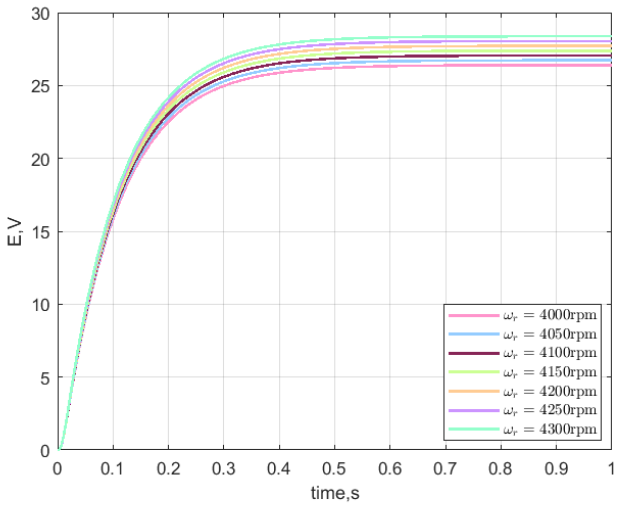

Fig. 3.12. Measured counter electromotive force(EMF)

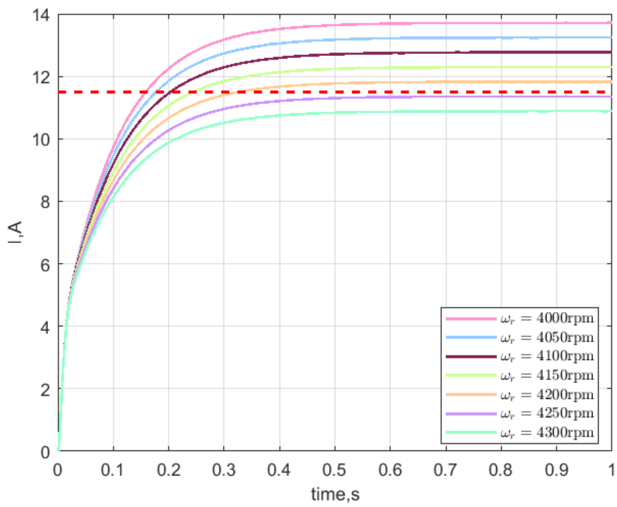

Fig. 3.13. Measured Current

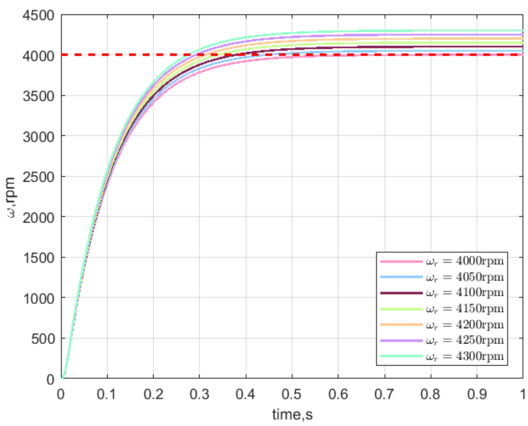

Fig. 3.15. Measured velocity

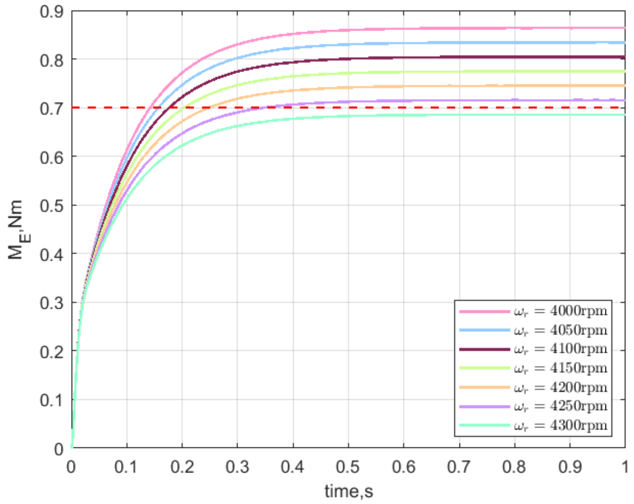

Fig. 3.14. Measured engine torque

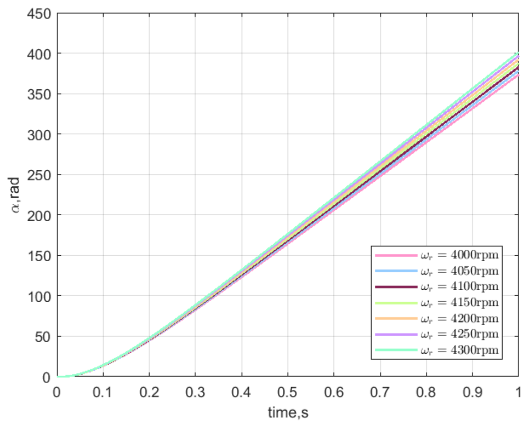

Fig. 3.16. Measured angle of rotation

§3.7 Conclusion

If the motor does not consider other friction or losses during operation, the rated torque is about $4200 \sim 4300rpm$,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 : $4000rpm$,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

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Appendix

A Complete source code

parameter

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

simulation

```
sim('pra3.slx');
time = ans.tout;
omega = ans.omega(:,2);
Uy = ans.Uy(:,2);
M_E = ans.M_E(:,2);
I = ans.I(:,2);
E = ans.E(:,2);
alpha = ans.alpha(:,2);

figure
plot(time,E);
hold on
grid on
xlabel('time,s')
ylabel('E,V')
figure
plot(time,Uy);
hold on
grid on
xlabel('time,s')
ylabel('U_y,V')
figure
plot(time,I);
hold on
grid on
xlabel('time,s')
ylabel('I,A')
figure
```

```
plot(time,M_E);
hold on
grid on
xlabel('time,s')
ylabel('M_E,Nm')
figure
plot(time,omega);
hold on
grid on
xlabel('time,s')
ylabel('\omega,rpm')
figure
plot(time,alpha);
hold on
grid on
xlabel('time,s')
ylabel('\alpha,rad')
```

Simulation Verification

```
clear all
%motor parameter
k_M = 0.063;k_E = 6.6*30/pi*10^(-3);
R = 0.7;L = 2.16*10^(-3);
K_M = 1/R;T_r = L/R;
U_H = 36;U_m = 10;
K_y = U_H/U_m;T_y = 1/U_m;
K_U = 1;K_I = 1;K_omega = 30/pi;K_alpha = 1;i_p = 1;
J_sum = 119*10^(-7)+4.5*10^(-5);
I_p = 11.5;
M_r = I_p * k_M;

n = 4000;
omega_rated = n*pi/30;
I_rated = K_M*(U_H - k_E * omega_rated);
M_r = I_rated*k_M;
k = M_r/omega_rated;
sim('pra3.slx');
time = ans.tout;
omega = ans.omega(:,2);
Uy = ans.Uy(:,2);
M_E = ans.M_E(:,2);
I = ans.I(:,2);
E = ans.E(:,2);
alpha = ans.alpha(:,2);

n = 4050;
omega_rated = n*pi/30;
I_rated = K_M*(U_H - k_E * omega_rated);
M_r = I_rated*k_M;
k = M_r/omega_rated;
sim('pra3.slx');
time0 = ans.tout;
omega0 = ans.omega(:,2);
```

```
Uy0 = ans.Uy(:,2);
M_E0 = ans.M_E(:,2);
I0 = ans.I(:,2);
E0 = ans.E(:,2);
alpha0 = ans.alpha(:,2);

n = 4100;
omega_rated = n*pi/30;
I_rated = K_M*(U_H - k_E * omega_rated);
M_r = I_rated*k_M;
k = M_r/omega_rated;
sim('pra3.slx');
time1 = ans.tout;
omega1 = ans.omega(:,2);
Uy1 = ans.Uy(:,2);
M_E1 = ans.M_E(:,2);
I1 = ans.I(:,2);
E1 = ans.E(:,2);
alpha1 = ans.alpha(:,2);

n = 4150;
omega_rated = n*pi/30;
I_rated = K_M*(U_H - k_E * omega_rated);
M_r = I_rated*k_M;
k = M_r/omega_rated;
sim('pra3.slx');
time2 = ans.tout;
omega2 = ans.omega(:,2);
Uy2 = ans.Uy(:,2);
M_E2 = ans.M_E(:,2);
I2 = ans.I(:,2);
E2 = ans.E(:,2);
alpha2 = ans.alpha(:,2);

n = 4200;
omega_rated = n*pi/30;
I_rated = K_M*(U_H - k_E * omega_rated);
M_r = I_rated*k_M;
k = M_r/omega_rated;
sim('pra3.slx');
time3 = ans.tout;
omega3 = ans.omega(:,2);
Uy3 = ans.Uy(:,2);
M_E3 = ans.M_E(:,2);
I3 = ans.I(:,2);
E3 = ans.E(:,2);
alpha3 = ans.alpha(:,2);

n = 4250;
omega_rated = n*pi/30;
I_rated = K_M*(U_H - k_E * omega_rated);
M_r = I_rated*k_M;
k = M_r/omega_rated;
```

```
sim('pra3.slx');
time4 = ans.tout;
omega4 = ans.omega(:,2);
Uy4 = ans.Uy(:,2);
M_E4 = ans.M_E(:,2);
I4 = ans.I(:,2);
E4 = ans.E(:,2);
alpha4 = ans.alpha(:,2);

n = 4300;
omega_rated = n*pi/30;
I_rated = K_M*(U_H - k_E * omega_rated);
M_r = I_rated*k_M;
k = M_r/omega_rated;
sim('pra3.slx');
time5 = ans.tout;
omega5 = ans.omega(:,2);
Uy5 = ans.Uy(:,2);
M_E5 = ans.M_E(:,2);
I5 = ans.I(:,2);
E5 = ans.E(:,2);
alpha5 = ans.alpha(:,2);


figure(1)
plot(time,E,'Color',[1,0.58,0.8],'LineWidth',1.5);
hold on
plot(time0,E0,'Color',[0.58,0.8,1],'LineWidth',1.5);
hold on
plot(time1,E1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
hold on
plot(time2,E2,'Color',[0.8,1,0.58],'LineWidth',1.5);
hold on
plot(time3,E3,'Color',[1,0.8,0.58],'LineWidth',1.5);
hold on
plot(time4,E4,'Color',[0.8,0.58,1],'LineWidth',1.5);
hold on
plot(time5,E5,'Color',[0.58,1,0.8],'LineWidth',1.5);
hold on
grid on
h = legend('$\omega_r = 4000 \mathrm{rpm}$ ','$\omega_r = 4050 \
    mathrm{rpm}$ ','$\omega_r = 4100 \mathrm{rpm}$ ','$\omega_r =
    4150 \mathrm{rpm}$ ','$\omega_r = 4200 \mathrm{rpm}$ ','$\omega_r
     = 4250 \mathrm{rpm}$ ','$\omega_r = 4300 \mathrm{rpm}$ ');
set(h,'Interpreter','latex','Location','SouthOutside')
xlabel('time,s')
ylabel('E,V')

figure(2)
plot(time,Uy,'Color',[1,0.58,0.8],'LineWidth',1.5);
hold on
plot(time0,Uy0,'Color',[0.58,0.8,1],'LineWidth',1.5);
hold on
```

```
plot(time1,Uy1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
hold on
plot(time2,Uy2,'Color',[0.8,1,0.58],'LineWidth',1.5);
hold on
plot(time3,Uy3,'Color',[1,0.8,0.58],'LineWidth',1.5);
hold on
plot(time4,Uy4,'Color',[0.8,0.58,1],'LineWidth',1.5);
hold on
plot(time5,Uy5,'Color',[0.58,1,0.8],'LineWidth',1.5);
hold on
grid on
h = legend('$\omega_r = 4000 \mathrm{rpm}$ ','$\omega_r = 4050 \mathrm{rpm}$ ','$\omega_r = 4100 \mathrm{rpm}$ ','$\omega_r = 4150 \mathrm{rpm}$ ','$\omega_r = 4200 \mathrm{rpm}$ ','$\omega_r = 4250 \mathrm{rpm}$ ','$\omega_r = 4300 \mathrm{rpm}$ ');
set(h,'Interpreter','latex','Location','SouthOutside')
xlabel('time,s')
ylabel('U_y,V')

figure(3)
plot(time,I,'Color',[1,0.58,0.8],'LineWidth',1.5);
hold on
plot(time0,I0,'Color',[0.58,0.8,1],'LineWidth',1.5);
hold on
plot(time1,I1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
hold on
plot(time2,I2,'Color',[0.8,1,0.58],'LineWidth',1.5);
hold on
plot(time3,I3,'Color',[1,0.8,0.58],'LineWidth',1.5);
hold on
plot(time4,I4,'Color',[0.8,0.58,1],'LineWidth',1.5);
hold on
plot(time5,I5,'Color',[0.58,1,0.8],'LineWidth',1.5);
hold on
line([0,1],[11.5,11.5],'Color','red','LineStyle','--','LineWidth',1.5)
hold on
grid on
h = legend('$\omega_r = 4000 \mathrm{rpm}$ ','$\omega_r = 4050 \mathrm{rpm}$ ','$\omega_r = 4100 \mathrm{rpm}$ ','$\omega_r = 4150 \mathrm{rpm}$ ','$\omega_r = 4200 \mathrm{rpm}$ ','$\omega_r = 4250 \mathrm{rpm}$ ','$\omega_r = 4300 \mathrm{rpm}$ ');
set(h,'Interpreter','latex','Location','SouthOutside')
xlabel('time,s')
ylabel('I,A')

figure(4)
plot(time,M_E,'Color',[1,0.58,0.8],'LineWidth',1.5);
hold on
plot(time0,M_E0,'Color',[0.58,0.8,1],'LineWidth',1.5);
hold on
plot(time1,M_E1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
hold on
```

```
plot(time2,M_E2,'Color',[0.8,1,0.58],'LineWidth',1.5);
hold on
plot(time3,M_E3,'Color',[1,0.8,0.58],'LineWidth',1.5);
hold on
plot(time4,M_E4,'Color',[0.8,0.58,1],'LineWidth',1.5);
hold on
plot(time5,M_E5,'Color',[0.58,1,0.8],'LineWidth',1.5);
hold on
line([0,1],[0.7,0.7],'Color','red','LineStyle','--','LineWidth',1.5)
hold on
grid on
h = legend('$\omega_r = 4000 \mathrm{rpm}$ ','$\omega_r = 4050 \
    mathrm{rpm}$ ','$\omega_r = 4100 \mathrm{rpm}$ ','$\omega_r =
    4150 \mathrm{rpm}$ ','$\omega_r = 4200 \mathrm{rpm}$ ','$\omega_r
     = 4250 \mathrm{rpm}$ ','$\omega_r = 4300 \mathrm{rpm}$ ');
set(h,'Interpreter','latex','Location','SouthOutside')
xlabel('time,s')
ylabel('M_E,Nm')

figure(5)
plot(time,omega,'Color',[1,0.58,0.8],'LineWidth',1.5);
hold on
plot(time0,omega0,'Color',[0.58,0.8,1],'LineWidth',1.5);
hold on
plot(time1,omega1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
hold on
plot(time2,omega2,'Color',[0.8,1,0.58],'LineWidth',1.5);
hold on
plot(time3,omega3,'Color',[1,0.8,0.58],'LineWidth',1.5);
hold on
plot(time4,omega4,'Color',[0.8,0.58,1],'LineWidth',1.5);
hold on
plot(time5,omega5,'Color',[0.58,1,0.8],'LineWidth',1.5);
hold on
line([0,1],[4000,4000],'Color','red','LineStyle','--','LineWidth'
    ,1.5)
hold on
grid on
h = legend('$\omega_r = 4000 \mathrm{rpm}$ ','$\omega_r = 4050 \
    mathrm{rpm}$ ','$\omega_r = 4100 \mathrm{rpm}$ ','$\omega_r =
    4150 \mathrm{rpm}$ ','$\omega_r = 4200 \mathrm{rpm}$ ','$\omega_r
     = 4250 \mathrm{rpm}$ ','$\omega_r = 4300 \mathrm{rpm}$ ');
set(h,'Interpreter','latex','Location','SouthOutside')
xlabel('time,s')
ylabel('\omega,rpm')

figure
plot(time,alpha,'Color',[1,0.58,0.8],'LineWidth',1.5);
hold on
plot(time0,alpha0,'Color',[0.58,0.8,1],'LineWidth',1.5);
hold on
plot(time1,alpha1,'Color',[0.53,0.15,0.34],'LineWidth',1.5);
hold on
```

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