A Study of Dynamic Electric Dynamometer Based on Separate-excited DC Generator

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Abstract

Eddy dynamometer is widely used in drive motor and ICE's character testing, in which it can't be loaded large torque under lower speed, and can't drag testing motor, and its dynamic response is weak .Also it changes mechanical energy to heat energy, which wastes energy resource. In this paper, a new kind of electric dynamometer based on separate-excited DC generator is introduced to overcome these shortcomings, which realizes large load torque under lower speed, and can measure motor's characters in four quadrants, and has quick dynamic response ability. The electric dynamometer can work in steady speed mode, steady torque mode and steady power mode. It can not only measure motor steady character, but also dynamic character. In this paper, the whole system hardware framework and software will be introduced. DC motor's control method is introduced in detail. At last, experiment results will be shown on.

Keywords

electric dynamometer, separate-excited DC generator, dynamic response

1. INTRODUCTION

Eddy dynamometer is widely used in drive motor and ICE's character testing, in which it can't be loaded large torque under lower speed, and can't drag testing motor, and its dynamic response is weak. Also it changes mechanical energy to heat energy, which wastes energy resource. With the development of technology, electric dynamometer is more and more generally used, which can act as not only generator, but also electromotor. As a generator, it can generate power to produce electromagnetism torque. As a electromotor, it can simulate vehicle's braking to drag testing motor to measure feedback brake. Electric dynamometer's key part is the control of load motor. Load motor often uses DC or AC motor. In comparison to AC motor, DC motor is easily to be controlled, and has good dynamic response. The DC motor can be easily switched in four quadrants and generate large torque in low speed. Besides it can measure motor static state: power, torque, speed and efficiency, our electric dynamometer also can simulate vehicle's working condition to carry through motor's dynamic character testing. In this paper, DC motor's control arithmetic, software framework, data acquisition system will be introduced in detail. At last, ac motor dynamic testing results are shown on.

2. DC DYNAMOMETER'S PRINCIPLE

The electric dynamometer is a generator in fact, it can change testing motor's mechanical energy to electricity energy. Through measuring reserve direction's electromagnetism torque, ICE (motor)'s torque and power can be get. DC electric dynamometer's working character is decided by dc motor's control character. The electric dynamometer consists of DC motor, armature and excitation's control circuit, load circuit, torque/speed sensor, power analyzer, and signal sampling and processing system.

When DC motor is in generating electricity mode, as Figure 1 shows, DC motor electromotive force equation is:

$$E = C_e \phi n \qquad (1)$$

where C_e -constant relative to motor's structure; ϕ -magnetic pole's magnetic flux, Wb; n -motor's revolution, rpm.

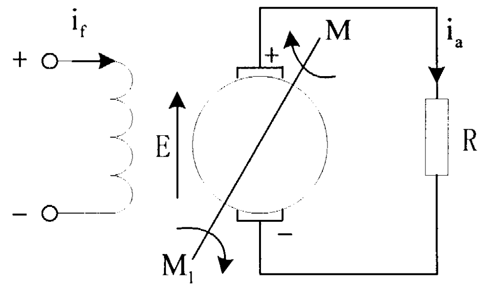

Fig. 1 DC motor generating electricity mode

And, its armature voltage function is

$$E = U + I_a R_a = I_a (R_a + R) \qquad (2)$$

where I_a -armature current, A; Ra-armature resistance, Ω;

Electromagnetism torque function is:

$$M = C_m \phi I_a \quad (3)$$

where C_m -constant relative to motor's structure;

When dynamometer is in steady rotate speed, ICE's output torque M_l is equal to electromagnetism torque M adding non- load spoilage torque(friction torque) M_0, $M_l = M + M_0$.

In fact, friction torque (M_0) is little, so $M_l = M + M_0 \approx M$.

From equ. (2) and (1),we can get

$$I_a = \frac{E}{R + R_a} = \frac{C_e \phi n}{R + R_a} \quad (4)$$

Inserting equ. (4) into (3), we can get

$$M = C_m \phi I_a = \frac{C_m C_e \phi^2 n}{R + R_a} \quad (5)$$

From equ. (5), electromagnetism torque can be changed through adjusting excitation current i_f, reserve electromotive force E and load resistor R. In fact, load resistor often adopts active load, which can generate resistance torque through feedback to power. For DC motor's power is limited, electromagnetism torque's maximum value M_{max} is not unlimited. Figure 2 is DC dynamometer M-n Curve,when decreasing R, torque will increase.

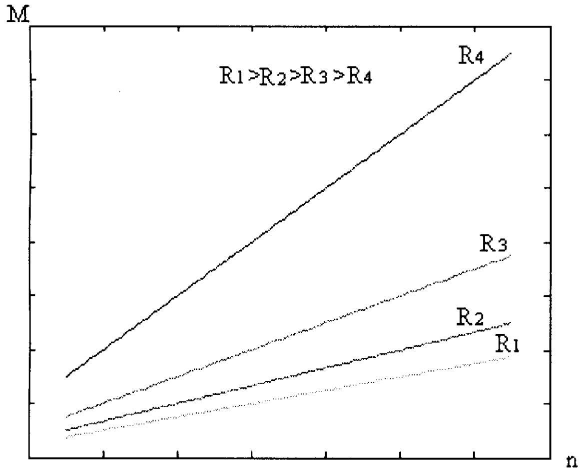

Fig. 2 DC dynamometer M-n curve

Basing on dynamometer requirements, DC motor has two kinds of control modes: speed closed -circle control and torque closed -circle control, which can be switched freely. The main circuit adopts two bridges reversing thyristors, which can generate electricity and feed back to power, and DC motor can run in four quadrants. The whole DC motor control framework is as Figure 3 shows. There are two closed-circle: current circle and speed circle. If dynamometer works on steady torque mode, it only needs current circle.

DC motor adopts separated-excited flux, like AC motor's vector control, it needs weaken field. As Figure 4 shows,

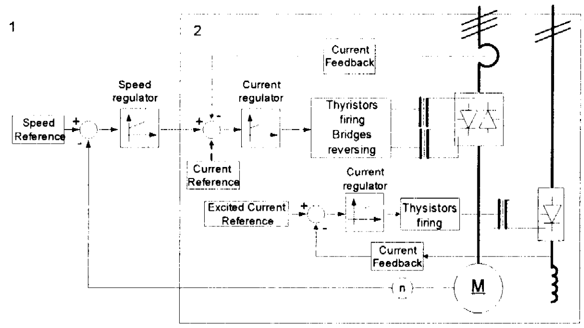

Fig. 3 DC motor control framework

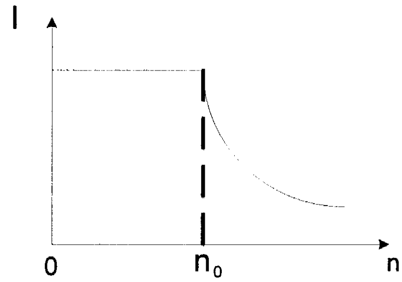

Fig. 4 Excited current-speed curve

below rated rotated speed, excited current sustains, above rated speed, it is inverse proportion to rotated speed.

In dynamometer system, DC motor works in steady speed closed circle control mode, and testing motor or ICE works in steady torque closed- circle control mode. When measuring motor's Torque-Speed (steady) character, it is through adjusting resistor, when measuring motor's dynamic situation, it is through computer's D/A card output.

3. THE FRAMEWORK OF SEPARATED-EXCITED DC MOTOR ELECTRIC DYNAMOMETER

The whole system consists of machine system, electric control equipment and signal sampling and process system. The machine system includes testing motor ,gear box, and DC generator; electric equipments mainly include switch cabinet, isolate transformer, rectifier, load DC generator and inverter, in which the isolate transformer is charge of raising and isolating input power voltage ,and decrease interference to the power; the rectifier provides DC voltage for motor controller and DC generator and inverter can generate electricity to the power.

The measure system includes torque and speed sensor, industrial computer, operating platform and power analyzer. The measure software is based on Labview, which is charge of data sampling card, data analyzer, data storage and display. The torque/speed sensor adopts HBM T10F, which is high precise and quick response. The testing motor control strategy is torque closed circle

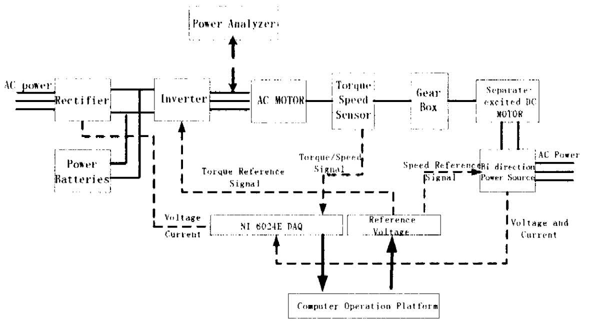

Fig. 5 The framework of electric dynamometer

control and load DC generator is speed closed circle control, where torque and rotor speed's reference voltage are can be respectively given by resistor and computer. The whole framework is as Figure 5 shows.
For DC motor's rotated speed is far slowly than AC motor's, there is a two-band gear box. If testing motor works in high speed range, lower band is used. NI 6024E DAQ, 6126D/A card are used to be charge of data gathering.

4. SOFTWARE STRUCTURE

Software is mainly charge of torque/speed sensor's communication and converter's voltage and current's reading. Torque and speed's signal is through CAN bus, and voltage and current's signal is through D/A card (NI 6024E DAQ). The whole software includes four parts: HBM MP60 CAN bus communication program, steady state measuring program, dynamic measuring program and data display program. The software is designed by Labviews. Figure 6 is system operation diagram. Figure 7 is dynamic testing diagram. Figure 8 is human-computer interaction interface.

5. EXPERIMENT RESULTS

(1) The given work situation dynamic testing
Figure 9 (a) is the given work situation test. The data sampling period is 0.25s. Figure9 (b) is generator's speed response curve, Figure 9 (c) is the testing ac motor's torque response curve, Figure 9 (d) is the ac motor power output curve, where the rotor speed average response time is about 1 second, and rotor speed average overtune is about 2%.
(2) Sudden torque change in different speed testing
As Figure 10 shows, speed reference voltage is given as Figure 10 (a), AC motor's torque reference is given as Figure 10 (c). The dynamometer speed response curve is Figure 10 (b), and torque response voltage curve is Figure 10 (d).
(3) Steady character testing
Fixing torque reference given at some value, speed reference value is changed. From this testing, we

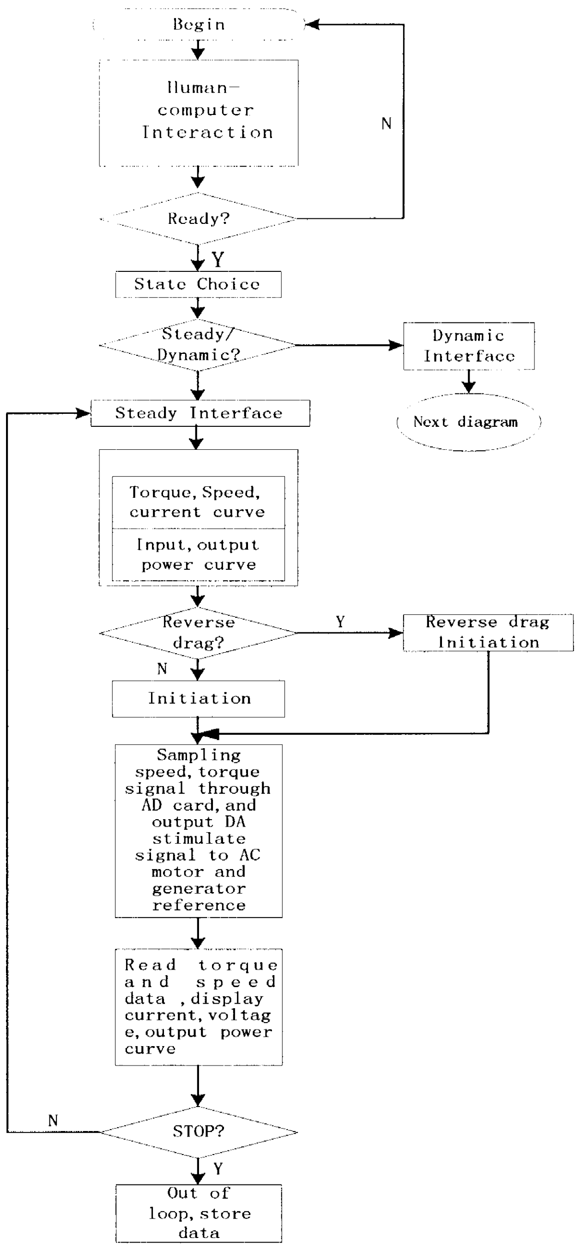

Fig. 6 System operation diagram

can receive dynamometer speed control's precision. From Table 2, steady speed's maximum absolute error rate is 0.8%, which is satisfied with measuring precision requirement.

6. CONCLUSIONS

DC dynamometer has excellent steady and dynamic character, which is fit for ice or drive motor's testing need. DC motor is easy to be controlled and its maintenance cost is cheap, which is widely used. For equipment of advanced torque sensor, it has upper measuring precision.

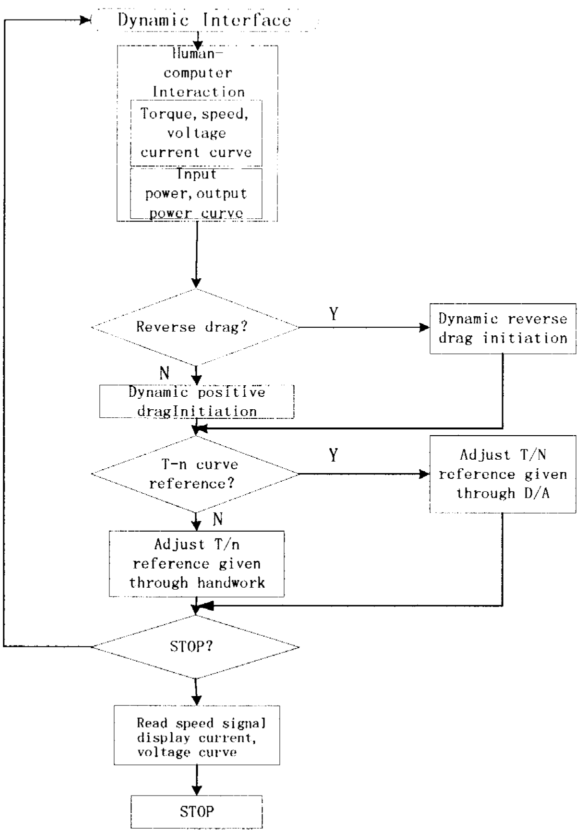

Fig. 7 Dynamic testing diagram

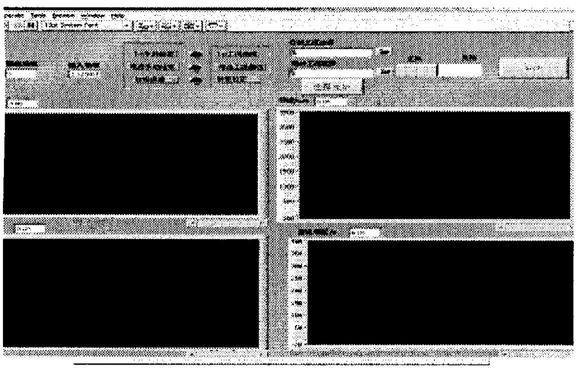

Fig. 8 Human-computer interaction

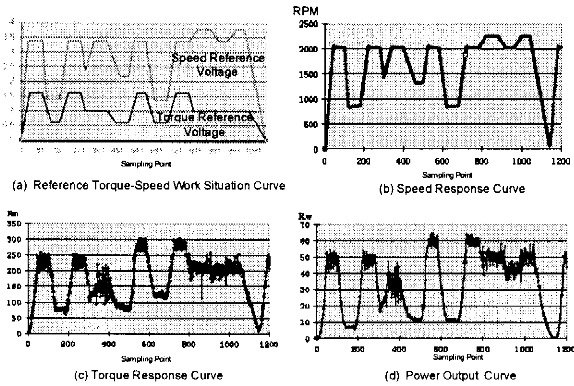

Fig. 9 Standard work situation test

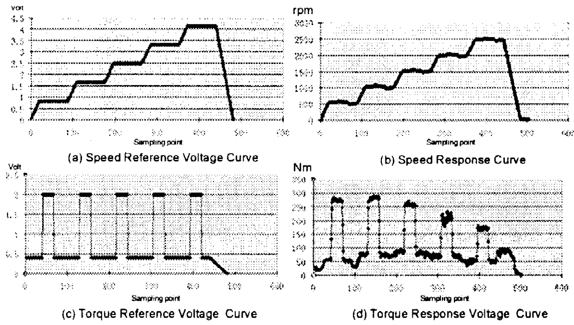

Fig. 10 Sudden torque response test

Table 1 The response of sudden changing torque reference voltage

To increase 300% torque				To decrease 300% torque			
Reference speed(rpm)	Max speed (rpm)	Response Time (s)	Overtune	Reference Speed(rpm)	Min. Speed (rpm)	Response Time (s)	overtune
550	602	6.0	9.5%	550	498	5.0	9.5%
1035	1088	6.5	5.1%	1035	981	5.8	5.2%
1518	1569	5.4	3.4%	1522	1471	4.4	3.4%
1999	2043	4.8	2.2%	2004	1956	5.5	2.4%
2487	2530	3.5	1.7%	2490	2442	4.5	1.9%

Table 2 Steady character testing

Torque (Nm)	Maximum speed (rpm)	Minimum speed (rpm)	Difference speed (rpm)	Absolute Error rate (%)
48	549	546	3	0.5
100	1483	1479	4	0.3
150	554	551	3	0.5
200	2459	2451	8	0.3
200	2011	2007	4	0.2
200	549	545	4	0.7
250	549	546	3	0.5
250	1056	1048	8	0.8
250	2011	2006	5	0.2

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