Design of Elevator Comprehensive Back-to-Back Test System Based on Common DC Bus

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Abstract. As a new horizontal rotation loading device, elevator comprehensive back-to-back test system can simulate the energy status of in different elevator load. It makes the elevator or its components such as magnetorheological(MR) traction transmission device to meet the dynamic characteristics in practical test conditions. By analyzing the characteristics of elevator traction machine and the close relationship between frequency converter and traction machine, this paper derived a mathematical system model of elevator traction machine. An energy-feedback type traction machine back-to-back experimental system was proposed through establishing a common DC bus. And the functions, components, control and additional equipment of the experimental system was also introduced in this paper. The test system can realize actual testing and verification on various operating characteristic parameters of elevator products and its control mode, which offers a comprehensive and reliable performance test platform for elevator products, and ensures the quality of the finished product. The experimental results of MR traction transmission device in simulated condition showed that the system had easy operation, small structure size, large detection range, etc. Besides, it overcame the disadvantages of conducting MR traction transmission device type test in an entire elevator machine.

Introduction

With the rapid development of industrial automation technology, there come more new elevator control units and components. Therefore, elevator manufacturers urgently need to conduct performance testing on those new products and provide reference data and direction for product improvement and development, which requires a reliable elevator testing equipment. Meanwhile, they need to find out methods to more quickly and cost-effectively test the performances of elevators. So it becomes a worthy subject how to choose an effective test unit.

Type tests of the elevator transmission device or components in the elevator machine have many shortcomings of few test parameters, huge structure, inconvenient operation, small detection range, complex control and high cost [1]. The paper proposed an elevator comprehensive back-to-back test system based on the common DC bus. This system can not only test the properties and partial reliability of MR transmission device, but also the mechanical property, efficiency characteristics, torque control precision and temperature rise of traction machine or frequency converter. Furthermore, it is also an economical and energy-saving system.

Establishment of test platform mathematical model

Dynamic model of the drive motor is composed by voltage equation, flux equation, torque equation and motion equation [2-4].

(1) Voltage equation

The three-phase stator voltage equation can be expressed as:

$$u_x = i_x R_s + \frac{d\psi_x}{dt}, x = A, B, C \qquad （1）$$

Where U_A, U_B and U_C represent three phase voltage of the stator; i_A, i_B and i_C represent three-phase currents of the stator; ψ_A, ψ_B and ψ_C represent the three-phase stator winding flux; Rs represents the stator winding resistance of each phase.

Converting the three-phase stator winding to rotor side, we can obtain a new voltage equation:

$$u_y = i_y R_s + \frac{d\psi_y}{dt}, x = a, b, c \qquad （2）$$

Writing the voltage equation in the form of torque, and replacing the differential symbol with differential operator p, we can obtain an equation as flow:

$$\begin{bmatrix} u_A \\ u_B \\ u_C \\ u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 & 0 & 0 \\ 0 & 0 & R_s & 0 & 0 & 0 \\ 0 & 0 & 0 & R_r & 0 & 0 \\ 0 & 0 & 0 & 0 & R_r & 0 \\ 0 & 0 & 0 & 0 & 0 & R_r \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \\ i_a \\ i_b \\ i_c \end{bmatrix} + p \begin{bmatrix} \psi_A \\ \psi_B \\ \psi_C \\ \psi_a \\ \psi_b \\ \psi_c \end{bmatrix} \qquad (3)$$

(2) Flux equation

The flux of each winding motor is the sum of its own self-inductance flux and mutual flux of other windings. Therefore, the all six winding flux can be expressed as:

$$\begin{bmatrix} \psi_A \\ \psi_B \\ \psi_C \\ \psi_a \\ \psi_b \\ \psi_c \end{bmatrix} = \begin{bmatrix} L_{AA} & L_{AB} & L_{AC} & L_{Aa} & L_{Ab} & L_{Ac} \\ L_{BA} & L_{BB} & L_{BC} & L_{Ba} & L_{Bb} & L_{Bc} \\ L_{CA} & L_{CB} & L_{CC} & L_{Ca} & L_{Cb} & L_{Cc} \\ L_{aA} & L_{aB} & L_{aC} & L_{aa} & L_{ab} & L_{ac} \\ L_{bA} & L_{bB} & L_{bC} & L_{ba} & L_{bb} & L_{bc} \\ L_{cA} & L_{cB} & L_{cC} & L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \\ i_a \\ i_b \\ i_c \end{bmatrix}, \qquad (4)$$

where L is a 6×6 inductance matrix; the diagonal elements L_{AA}, L_{BB}, L_{CC}, L_{aa}, L_{bb} and L_{cc} are the self-inductance of the relevant winding, and the rest are the mutual inductance between the windings.

(3) Torque equation

According to electromechanical energy conversion principle, the torque equation in linear inductance of multi-winding motor condition is:

$$T_e = \frac{1}{2} n_p i^T \frac{\partial L}{\partial \theta} i \qquad (5)$$

where n_p represents the number of the pole pairs; θ represents the angular displacement.

(4) Equation of motion

In general condition, the equation of motion for constant torque electric drive system is:

$$T_e - T_l = \frac{J}{n_p} \frac{d\omega}{dt}, \omega = \frac{d\theta}{dt} \qquad (6)$$

where T_e is the electromagnetic torque; T_l is the load torque; ω is the motor mechanical angular velocity; J is the moment of inertia.

By integrating the voltage equation (3), flux equation (4), torque equation (5) and motion equation (6), this paper derived a multivariate nonlinear mathematical model of traction machine with constant torque load, as shown in Fig.1
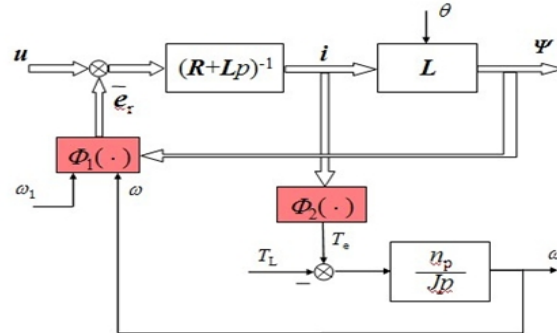

Fig.1 Multivariable nonlinear dynamic structure of traction machine

Test system principles

The common DC bus cross feed back-to-back test platform controls the speed and torque of test device and load device by utilizing high-performance vector control method. The test platform can simulate elevator's static and dynamic performance under various load conditions, and the diagram of the platform is shown in Fig.2. The system consists of four parts, namely the load traction machine and converter system (A), traction host–converter system (B), the torque and speed test system (T) and control and monitoring system (CM). The traction host and load are interconnected by MR traction transmission device and a coupling device; the load bus of two converters is connected by a controllable contactor; besides, motor torque and power of measured motor should be less than that of load motor [3-4].
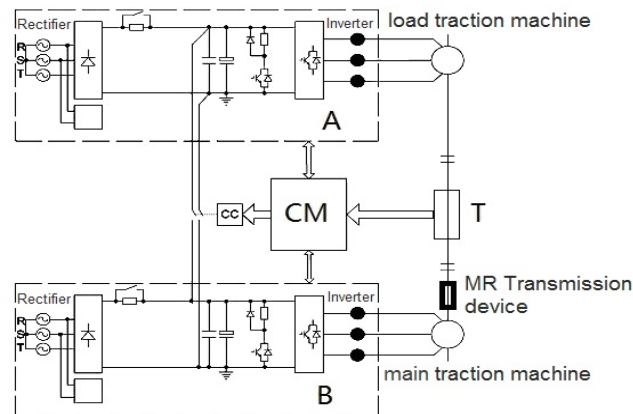

Fig.2 Common DC bus cross feed PMSM drag test platform

Three-phase power supply R, S and T separately electrify A and B system. If CM unit detects the power voltage of A and B system to be normal, then the contactor will be pulled in, and the system is in test state. Main traction machine and load traction machine are shaft-coupled. So during the test, if one motor is in electric mode, then the other operates in the power generation state. Host–converter system works in closed-loop speed control, state-controlling the rotational speed of the entire test platform. Load motor and converter system operates in closed-loop torque control state, changing the load torque by controlling the current of load motor. Load change of the host is stimulated to test the MR transmission device, so the cross feed drag test platform can realize flexible adjustment of speed and torque, completing a variety of functional tests.

CM unit can control and monitor the operation of the entire system. According to test requirements, it will issue control instructions to the converter through the serial bus and receive their operational data simultaneously. Meanwhile, the data will be saved, analyzed and displayed.

The two coaxial-connected motor drive systems have the same common DC bus, leading to their internal cross feed of energy. Energy consumption of the entire system just includes the motor losses, variable frequency driver loss, a small amount of line loss and magnetic rheologic zero-field lose, thus reducing the energy loss and greatly improving energy efficiency. This method uses low power supply to complete the high power transmission test, without power expansion transformation. The high-performance vector control is adopted for speed and torque control of traction and load motor, which can simulate a variety of static and dynamic performance under load. The platform can test MR traction transmission device, three-phase asynchronous (or synchronous) motor, load response performance of permanent magnet synchronous motor and a variety of control performance of variable frequency drivers on motors.

Design of back-to-back test system

The system consists of a traction machine test bench, electrical system and hoistway information simulation test bench. And the traction machine test bench connects two traction machines together through coupling shaft, forming the procedure of equivalent motor test: When the host inverter drives its traction machine to rotate, load motor will generate appropriate resistance moment to stop the rotation, achieving the simulation of the load conditions of converter and motor.

Traction machine test bench. The role of traction machine test bench is to ensure accurate and reliable coaxial connection of two traction machine. It makes the traction machine resist shake, displacement, strong torque and other risks in high-speed operation, and also makes the disassembly, replacement and repair of motors easier[5]. Basic structure of test bench is shown in Fig.3, the MR device can be other tested equipment.
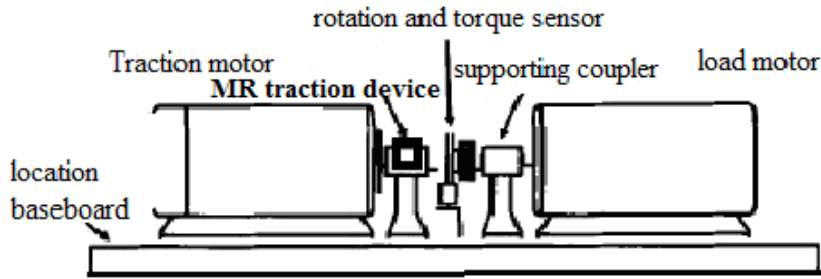
Fig.3 Test bench

Electrical system. The electrical system is composed by converter, traction machine, elevator electrical circuit and other components. When the test system works, the electrical energy will realize self-loop in the DC bus through the inverter, traction host, load traction machine and load inverter (or opposite path). The encoder can detect the operating state of the traction machine and transmit it to the controller to start rotation. Then, torque sensor detects the motor torque and transmits to the controller for torque control.

Hoistway information simulation test bench. The hoistway information simulation test platform consists of simulated hoistway, instruction button, call button, floor display, simulated gate machine, various switches, rotary encoders, programmable control panel and other components.

The back-to-back test system is shown in Fig.4, The test platform have flow functions: (1) The accuracy and reliability of signal control can be detected by through simply loading in MR traction transmission device. The brake logic instruction can be determined by whether the floor detection signal display of loop test is functioning properly;(2) It can detect whether the start, acceleration, deceleration, leveling and parking of MR traction transmission device and inverter is normal;(3) The wide range of configurations can test the quality and specifications of the elevator control system. Test platform evaluates the quality of control cabinet through comprehensive analysis on the configuration, function, operational reliability, electromagnetic compatibility, comfortability and other performance factors (noise, temperature, energy).
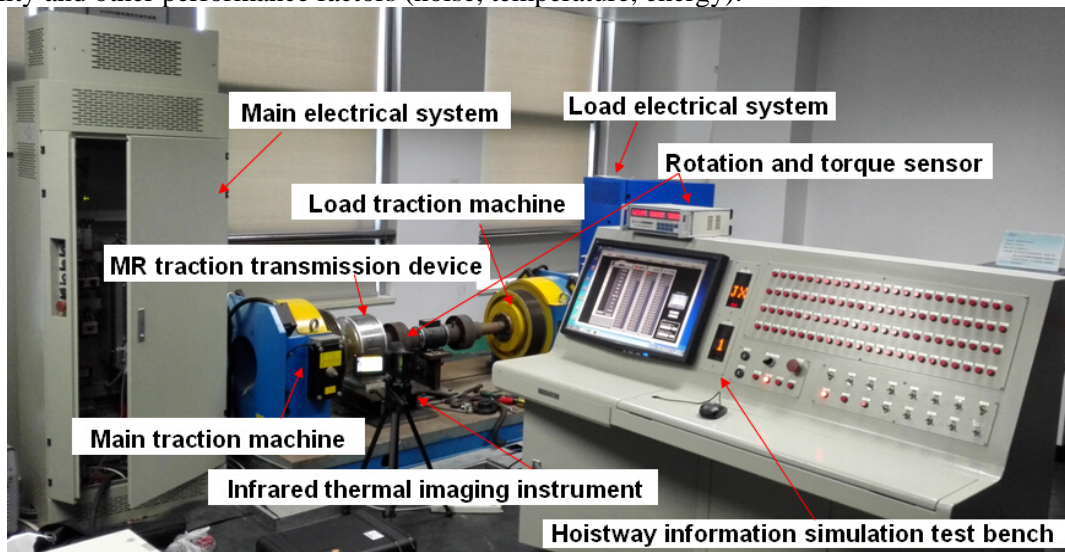

Fig.4 the back-to-back test system

Experimental analysis

According to European Standard EN81-1 "1998 Elevator Manufacturing and Installation Safety Norms" (Chinese Standard GB7588-2003 "Elevator Manufacturing and Installation Specifications"), this paper conducted experiments of dynamic load test and upward overspeed protection of new MR traction transmission device with the test bench [6-8].

Dynamic load test. The dynamic load test is that the car puts 125% rated load and runs down at rated speed, which is suddenly braked. Braking performance curve of the device is shown in Fig. 5(a).It can be seen that stopping distance and acceleration are 1.476m and 0.324m/ s^2, and the curve changes smoothly, indicating that there is no sudden change in velocity and the car stops more smoothly without abnormal vibration and shock. It can reflect the torque control performance of linear adjustable characteristics in the elevator traction transmission device which is developed based on MR technology.

Upward over-speed protection test. When the empty car runs at rated speed up, the braking performance curve of brake is shown in Fig. 5(b), With the torque control performance of linear adjustable characteristics based on MR technology, it can be seen that stopping distance and acceleration are 1.673m and 0.299m/s^2 which change smoothly, without the speed mutation, and there isn't abnormal vibration and shock.

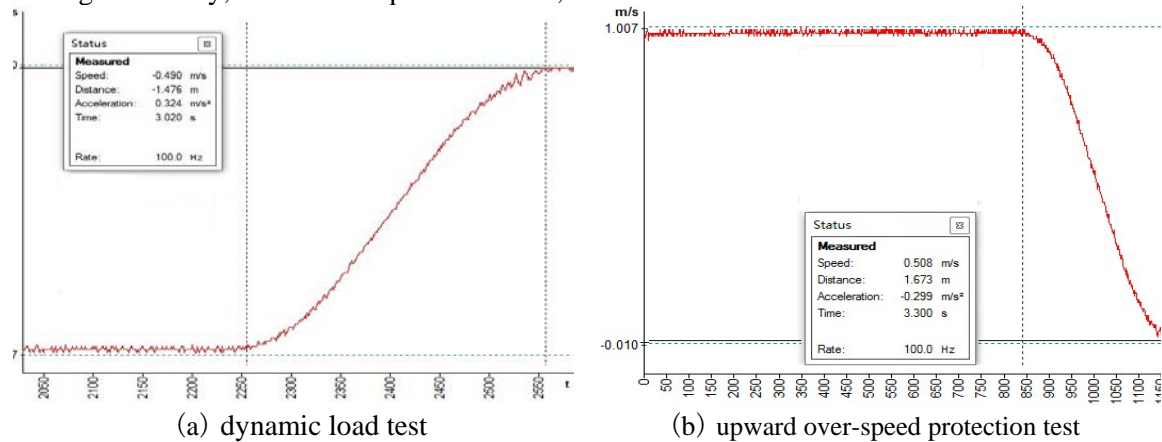(a) dynamic load test   (b) upward over-speed protection test

Fig.5 Braking speed curve

Summary

1) Elevator comprehensive back-to-back test system based on a common DC bus is charactered by simple operation, small structure size, wide detection range, etc., which overcomes the shortcomings of MR traction transmission device test in an entire elevator machine.

2) Elevator comprehensive back-to-back test system based on a common DC bus can realize accurate and efficient test on the MR traction transmission device, inverter and electric control methods, which provides reference data and orientation for further improvement and development of products.

Acknowledgments

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