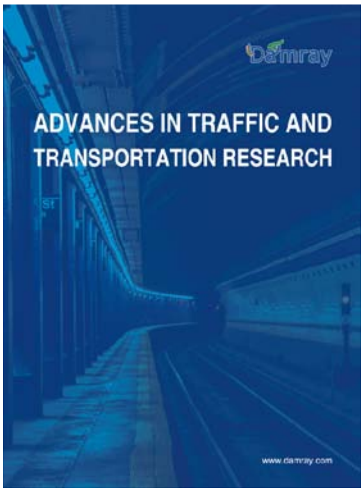
Analysis of Permanent Magnet Traction System Technology for Urban Rail Transit



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Abstract

With the acceleration of urban life rhythm, higher requirements are put forward for urban rail transit in areas such as large cities with large passenger flow. Quick start and quick stop, energy saving and consumption reduction, and high efficiency have become the development trends of urban rail transit traction systems. Existing asynchronous motors have been unable to meet the more severe demands of traction systems. Therefore, the permanent magnet traction system came into being. This paper analyzes and compares the permanent magnet traction system, and studies the influence of the permanent magnet traction system on the development of urban rail transit.

Keywords

Urban Rail, Traffic Vehicle, Permanent Magnet Traction

1. Introduction

Traction systems based on permanent magnet motors have been widely used in many industries such as rail transit, wind power generation, electric vehicles, air conditioners, and ship propulsion. Foreign-based permanent magnet motor traction systems have been researched and applied in the field of rail transit since the 1990s, and are now in the stage of commercialization. Permanent magnet motor traction systems have been successfully applied in various models of foreign rail transit, such as French AGV, Japan E954, etc. China has started the basic research work on the permanent magnet motor traction system for rail transit since the 21st century, and in 2014, it was successfully applied to the new generation of high-speed EMUs.

2. Introduction of permanent magnet traction motor

The permanent magnet traction system consists of a traction transformer, a traction converter and a permanent magnet traction motor. The traction transformer is completely consistent with the asynchronous traction system, and the traction converter and the permanent magnet traction motor are different from the asynchronous traction system.

2.1. Structure

The permanent magnet motor is composed of stator, rotor, base and other components. The stator and base are the same as the asynchronous motor. The permanent magnet traction motor rotor is composed of iron core and permanent magnet. A resolver is set at the non-transmission end to measure the position of the permanent magnet. The rotor can be made in solid form or it can be extruded from laminations with permanent magnet material on it.

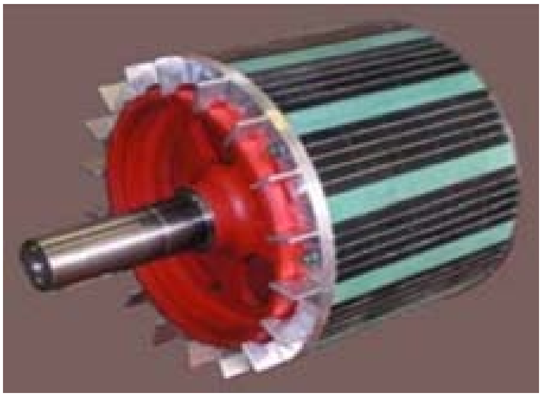

Figure 1. Permanent magnet motor rotor.

2.2. Principle

The three-phase inverter supplies power to the three-phase winding of the motor stator, and the rotating magnetic field synthesized by the three-phase symmetrical current interacts with the magnetic field generated by the rotor permanent magnet to produce torque, which in turn drags the rotor to rotate synchronously. When the air-gap synthesized magnetic field lags behind the main rotor magnetic field, the electromagnetic torque generated is opposite to the rotor rotation direction, and the motor is in the power generation state.

2.3. Advantages

Permanent magnet traction motor uses permanent magnet excitation, no excitation current, no copper consumption in the rotor, relatively small copper consumption in the stator, high motor efficiency, compared with asynchronous motors, efficiency increased by about 3% ~ 5%. High power density, low noise, light weight, energy saving and consumption reduction, high low torque output capability, easy to start the vehicle at low speed.

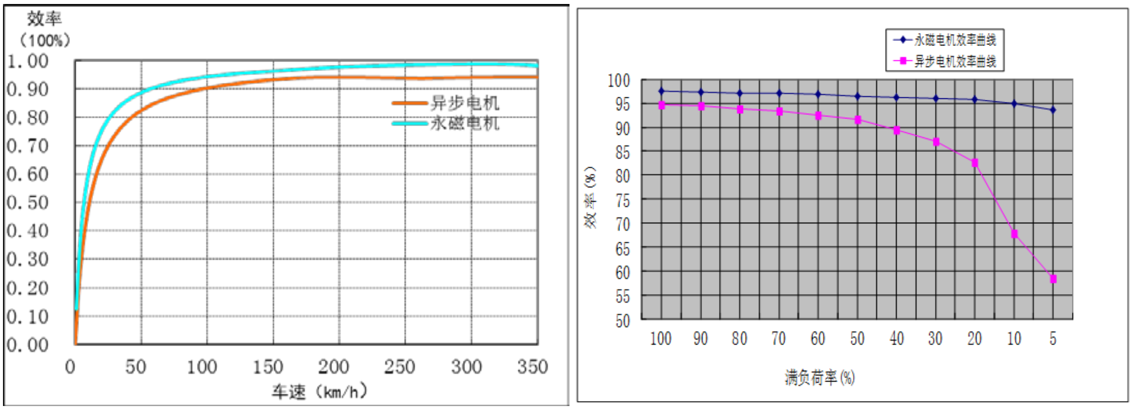

Figure 2. Comparison of the efficiency of permanent magnet motor and asynchronous motor.

2.4. Key technologies

To meet the requirements of high efficiency and energy saving, high power density, high speed, high torque, high reliability and low noise of the traction motor, the key technologies facing the permanent magnet motor are.

2.4.1. Electromagnetic design technology

In order to meet the synchronous variable frequency speed control of permanent magnet motor, it is necessary to obtain the parameters of motor cross and straight axis inductance and no-load leakage magnetism in the whole working speed range, and establish the motor electromagnetic model simulation analysis by using ANSOFT electromagnetic field finite element.

2.4.2. Anti-demagnetization technology

The factors that cause irreversible demagnetization of permanent magnets are mainly mechanical vibration shock, inrush current and high temperature. Different magnetic circuit structures and different permanent magnet materials are selected to verify the anti-demagnetization performance of permanent magnets, and finally complete the vibration shock test, short-circuit current test and temperature rise test.

2.4.3. Temperature rise control technology

Different magnet materials will fail at different temperatures. Reasonable allocation of controlling motor iron consumption and copper consumption, motor air path guiding design are the key technologies for permanent magnet motors.

2.4.4. Permanent magnet motor control technology

The permanent magnet motor faces control difficulties such as weak magnetic control, belt speed rethrow control, etc. The control strategy is improved by continuously optimizing the control software.

2.5. Protection measures

Temperature protection: setting the stator temperature sensor to monitor the traction motor temperature in real time.

Rotational speed monitoring: set the resolver to monitor the rotor speed and remove the motor when the sensor fails.

Prevention of counter-electromotive force: set isolation contactor to disconnect the isolation contactor to prevent counter-electromotive force from impacting the IGBT module when the inverter stops operating or when there is a fault.

3. The comparison analysis of permanent magnet traction system and asynchronous traction system

There are differences between the converter and motor of permanent magnet traction system and asynchronous traction system, but the requirements for transformer are the same, compare and analyze the differences between converter and traction motor scheme.

3.1. Asynchronous traction converter and permanent magnet traction converter

3.1.1. Asynchronous traction converter scheme

Asynchronous traction converter adopts the integrated design of main and auxiliary charger, including two rectification and two inverters, sharing the middle DC circuit, and the traction motor is vehicle-controlled or rack-controlled. The single converter contains charging unit, four-quadrant pulse rectifier, intermediate DC link, VVVF inverter, overvoltage chopper unit, auxiliary inverter, auxiliary filter transformer, DC110V charger, etc.

3.1.2. Permanent magnet traction converter

The permanent magnet traction converter adopts the integrated design of main and auxiliary chargers, including two rectifiers and four inverters, all sharing the intermediate DC circuit, and the traction motor is shaft-controlled. The single converter contains charging unit, four-quadrant pulse rectifier, intermediate DC link, VVVF inverter, isolated contactor, overvoltage chopper unit, auxiliary inverter, auxiliary filter transformer, DC110V charger, etc.

3.1.3. Technical Analysis

The differences between asynchronous traction converters and permanent magnet traction converters are analyzed from the perspective of circuit structure, equipment size and weight, and cost, and the differences in the comparison schemes are shown below.

Compared to the asynchronous traction converter, the permanent magnet traction converter scheme has the following changes:

The addition of two internal inverter modules and four isolation contactors and other components.
Case dimensions to be calibrated and an increase in weight of 200 kg.
The manufacturing and acquisition costs of the equipment will be significantly higher if the PMDC is used.

Table 1. Comparison analysis of asynchronous converter and permanent magnet converter

Parameter	Asynchronous converter scheme	Corresponding Permanent Magnet Converter Requirements
Main circuit structure	Rack control	Axis control
	Double rectification and double inverter	Double rectification and quadruple inverter
	None	4 isolated contactors
Size and weight	4290mm×2340mm×650mm	4290mm×2340mm×650mm
	≤3200kg	≤3400kg
Cost factor	Double inverter	Adopt quadruple inverter, and add IGBT, distribution board, drive board and voltage sensor
	Rack control scheme	Adopt axis control scheme
	None	Four isolation contactors are added to the main circuit;
	Direct torque control	Vector control technology and weak field control technology;

3.2. The analysis of inter-turn faults occurring in permanent magnet traction motors is as follows.

Table 2. inter-turn faults occurring in permanent magnet motors and asynchronous motors

Short circuit between turns	Asynchronous traction motors	Similarities and differences with asynchronous motors
Probability of occurrence	Low probability	Same
System protection measures	Seal pulse	Seal pulse and break isolated contactor
Impact on vehicle operation	The loss of a single frame with two motors power operation of the train does not affect the operation.	The loss of single motor power operation of the train does not affect the operation.
Motor damage	After the system protection action, the fault damage will not be further expanded.	Due to the existence of rotor magnetic field, the stator coil fault point damage expands after the system protection action until it burns out. The stator coil insulation of the traction motor is made of flame retardant material, so that the motor will not catch fire during the burnout process and affect the safety of the traffic.
Processing measures	Motor replacement	Same

4. Inspection and maintenance

Operation and maintenance, permanent magnet traction system also has obvious advantages, according to the repair process comparison analysis into the following.

Table 3. permanent magnet traction system and asynchronous traction system maintenance and repair comparison analysis table

No	Repair process	Description of the differences in the content of the inspection	Note
1	First level repair	Same	
2	Secondary Level Repair	Same	
3	Third level repair	1. Permanent magnet motors do not require rotor inspection. 2. Permanent magnet motors reduce the blocking test, no-load test, and speed sensor factory inspection test.	Adding items. 1. The permanent magnet motor adds the insulation performance test of the resolver, the measurement of the zero angle between the resolver and the permanent magnet motor, the no-load counter-potential test, and the steady-state short-circuit test. 2. The work related to speed sensor inspection is replaced by the work related to resolver inspection. 3. The need to avoid electromagnetic radiation and interference from the rotor to the outside after the motor is disassembled.
4	Fourth level repair	1. Permanent magnet motors do not require rotor inspection. 2. Permanent magnet motors reduce the blocking test, no-load test, and speed sensor factory inspection test.	
5	Fifth level repair	1. Permanent magnet motors do not require rotor dust cleaning and rotor guide end ring inspection. 2. Permanent magnet motors reduce the blocking test, no-load test, and speed sensor factory inspection test.	Adding items: 1. Permanent magnet motor with the addition of insulation performance test of the resolver, zero angle measurement between the resolver and the permanent magnet motor, no-load counter potential test and steady-state short circuit test. 2. The work related to speed sensor inspection is replaced by the work related to resolver inspection. 3. The need to avoid electromagnetic radiation and interference from the rotor to the outside after the motor is disassembled.

5. Conclusion

In this paper, the main circuit structure, permanent magnet synchronous motor structure, key technologies, protection measures and operation and maintenance have been specifically analyzed for permanent magnet synchronous traction system. As the third generation of rail transit traction technology, permanent magnet traction system high power density has obvious advantages, if SiC traction converter is used, the size and weight of converter box will be reduced, the weight of motor will be reduced and self-ventilation will be adopted. Actively promote the promotion of the batch application of permanent magnet traction system in urban rail transit vehicles, which will help the development of energy-saving and emission reduction technology in rail transit industry.

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