A Study on the Development of Traction Motor for Electric Railway: Insulation System Design & Performance Test

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In this paper, design considerations and manufacturing procedure of 200 class insulation system with polyimide(Kapton) main insulation and silicone resin VPI process on the traction motor for EMU will be reviewed. The performance test and the long life evaluation test that prove stability and reliability of insulation system for traction motor will also be introduced.

Keywords : Traction motor, 200 class insulation system, Performance test, Long life evaluation.

1. INTRODUCTION

For the standard type traction motor of electric railway, 3-phase squirrel cage induction motor, which has advantages of its easy maintenance and handling process, and simple mechanism, is widely used in the railway rolling-stock[1]. Specification of traction motor is 200 kW of rated power, 1,100 V of rated voltage and 130 A of rated current, and is operated in the range of 0~200 kHz by VVVF control[2].

Accordingly, traction motor for electric railway has a constraint due to the need of producing much power in smaller space, and it should have heat-resistance against harmonic loss by inverter drive. The traction motor should have enough insulation strength against the occurrence of high-speed switching surge and the concentration of over-voltage stress and corona by superimposed driving current on the stator winding of traction motor. Also the construction of insulation system should be provided for mechanical strength against vibration, shock and electro-magnetic force and long life endurance against dust, metal particle and oil under the operating condition[3].

In this paper, standard specification requirements will be presented as considerations of insulation design for traction motor. Manufacturing process of C-class special insulation with vacuum pressure impregnation (VPI) will also be reviewed. Finally the result of the performance & long life evaluation test, which proves operation safety and long life reliability, will be introduced.

2. CONSIDERATIONS OF INSULATION DESIGN FOR TRACTION MOTOR

2.1. Standard specification requirements for traction motor[4]

Traction motor for electric railway should meet the following requirements and the standard specification is shown in the table. 1.

Table 1. Standard specification of traction motor for electric railway.

Rating	Input: 3-phase, 1,100 V AC Power: 200 kW Revolution velocity: 1,950 rpm or above Maximum torque: 2100 N.m or above
Efficiency	92 % or above
Maximum operating velocity	4,950 rpm or above
Insulation class	H class or above

1) Traction motor should endure bad conditions such as frequent start and stop, vibration and dust in the tunnel.
2) Cooling system should adopt self ventilation type, filter in the air inlet and structure which minimize the noise.
3) Stator and rotator should have structure which minimize the temperature increase and loss by harmonic current.

4) The type of bearing lubrication should be sealed type grease lubrication method with lubricator and prevent the electrical erosion by leakage current.
5) Maximum allowed revolution velocity in relation with the motor's mechanical strength is 120 % of maximum operating velocity.

2.2. Applying stress and insulation degradation factors

Major degradation factors that determine the life of insulation system for traction motor are temperature, operating time, frequency, voltage, and thickness of insulator, mechanical stress and environmental factors. These factor which interacts with electrical, mechanical, and thermal factor form the complex stress according to operating condition and environment[5].
1) Rising of temperature: reduces insulation resistance and breakdown strength, and increases dielectric loss
2) Higher frequency: increases dielectric loss, and reduces breakdown strength
3) Applying voltage: distorts voltage wave form(dv/dt), and repetitively accumulates voltage surge
4) Occurrence of corona: internal void of insulator(volume corona), surface corona
5) Electro-magnetic force on the stator windings: electro-magnetic force occurred by over current due to frequent start and stop. Fixed parts of end-turn receive significant shocks whenever phase revolution order changed at starting and braking.
6) electro-magnetic force in slot: each coil in the stator slot receives electro-magnetic force by flow of alternative current in operation. Therefore insulation system and firm tie-up which make it endure the electro-magnetic force under normal operation are needed. If coil side in the slot is movable, spacer which fills up the space is required to prevent the mechanical abrasion.
7) Heat-cycle stress: insulation system which can bear the differences of the thermal expansion of the various materials and the numerous repetitive cycle of heating and cooling is needed.
8) Contamination: since majority of insulation materials is organic compounds, conductivity increases and insulation resistance decreases, and breakdown probability rises by the chemical contamination and the humidity penetration.
9) Incursion of conducting object: ferromagnetic substance such as metal particle glued on the surface of insulator, end-turn part, and air-gap is affected by revolving magnetic field, and it penetrates the insulation and brings fault.

2.3. Limitation of temperature rising

Temperature rising depends on the total loss and cooling capability, and allowable limitation is determined by insulation class. In case of traction motor for electric railway, 200 class insulation system which composes of polyimide(Kapton) strand insulation and silicon resin are used for main material to endure the high temperature and the high electric stress[6].

2.4. Coil and winding structure

Considering the spacial constraint and the need for improvement of performance by reducing of leakage reactance and cooper wire resistivity, the length of stator winding end-turn for traction motor is designed shorter than the general industrial motors[7].

Connection of stator winding adopts parallel Y-connection structure which increases the number of turns and subdivides the number of strands to minimize the skin effect, which is caused by large quantity of harmonics when inverter drives[8].

3. COMPOSITION OF INSULATION SYSTEM FOR ELECTRIC RAILWAY TRACTION MOTOR

When traction motor is driven by inverter, surge voltage is concentrated on the first turn of winding. Therefore the insulation capacity which made up of inter-turn insulation, inter-phase insulation, and ground insulation should be based on the voltage across the first turn[9].

However, the thicker insulation material becomes, the more core and cooper wire are needed, and the temperature rising problem is also generated. Therefore 200 class insulation system which bear the high temperature and electric stress should be selected to improve the safety and to secure the higher reliability to prevent the unexpected fault.

3.1. Strand insulation

1) Used material: Adhesive Kapton Tape 0.05t + Teflon flourocarbon resin 0.013t
2) Work process: 1/2 Overlap × 1 time(0.25 mm)

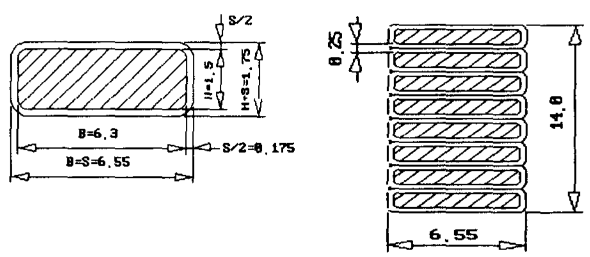


Fig. 1. Work process of strand insulation

Close adhesion between Kapton and cooper wire should be attained by the heat treatment in order to prevent the internal void remained and shelling of curved part of winding. Figure 1 shows the work process of strand.

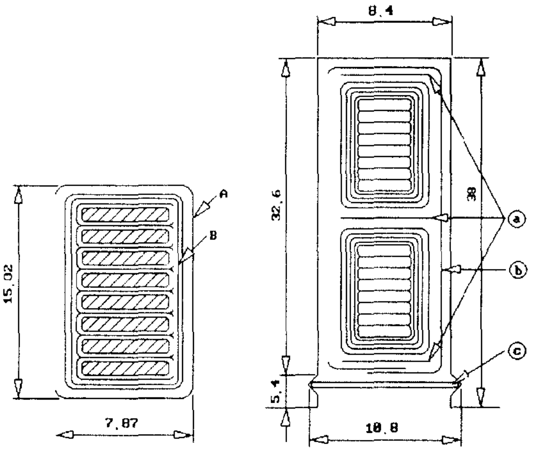
3.2. Main insulation(ground insulation)

1) 1st layer(ground insulation): B in Fig. 2(a)
- Used material: Glass Mica Tape for silicone resin impregnation 0.11t.
- Work process: 1/2 Overlap × 2 times(0.88 mm)

Reinforcing the anti-corona property and maintaining mechanical strength by using the Mica. Glass cloth used in the ground insulation should be compatible with silicon resin.

2) 2nd layer(sheathing insulation): B in Fig. 2(a)
- Used material: Glass Nomex Tape 0.11t.
- Work process: 1/2 Overlap × 1 time(0.44 mm)

Nomex(polyamid paper) has the function of absorbing the shock, preventing the shelling of Mica and allowing the silicone penetration.



(a) Main insulation (b) Slot insulation

Fig. 2. Work process of main insulation(ground insulation) and slot insulation

3.3. Slot insulation

1) Slot liner: "a" in Fig. 2(b)
- Used material: Nomex Polyimide Film 0.13t.
- Work process: 8 mm(width) × 230mm(length)

Safeguarding against the damage of winding insulation when it inserted in the core.

2) Slot cell: "b" in Fig. 2(b)
- Used material: Nomex(Aramid paper) 0.13t.
- Work process: 88 mm(width) × 230mm(length)

Preventing the vibration of winding by filling up the space of inter-layer and slot.

3) Slot wedge: "c" in Fig. 2(b)
- Used material: Non-conductive epoxy glassfibre laminate for high temperature 1.0t
- Work process: inserting 9.8 mm(width) × 220mm(length)

Preventing the breakaway of winding in the slot by crossbar.

4) Spacer : porous swellable rigid glass mat containing a few of binder expands 150 % when it contacts the impregnation resin above 60 ℃ and fills up the space with a pressure of 0.1 N/mm2.

3.4. Vacuum pressure impregnation(VPI) of silicone resin.

- Compound: modified methyl phenyl vinyl hydrogen poly siloxan
- Curing conditions: rotating curing for 16 hours in 200 ℃

200 class silicone resin(SI H62C) which is applicable for low viscosity, solvent free, single composition is used for impregnating the main insulation resin. It has advantage of long-term life, and good thermal and electric property.

Table 2 presents the electric properties of insulating material and Fig. 3. shows the form winding structure of traction motors used for development of traction motor.

Table 2. Electric properties of insulating material for traction motor.

Property / Materials	Relative permittivity ε '	Breakdown strength	Volume Resistance [Ω cm]
Silicone resin (after curing)	50 Hz~10 MHz 2.8 ~ 2.0	90 [kV/mm] at 23℃ 75 [kV/mm] at 200℃	2×10^{17} at 23 ℃
Kapton film	1 kHz 3.6 ~ 3.7	276 [V/μm] for 25 μm thickness 213 [V/μm] for 50 μm thickness 181 [V/μm] for 75 μm thickness	1×10^{17} for 25 μm 8×10^{16} for 50 μm 5×10^{16} for 75 μm
Nomex aramid paper	60 Hz 2.5 ~ 2.7	30 [kV/mm] at 23℃	5×10^{16}
Slot wedge	50 Hz~1 MHz 2.5	60 [kV/mm]	

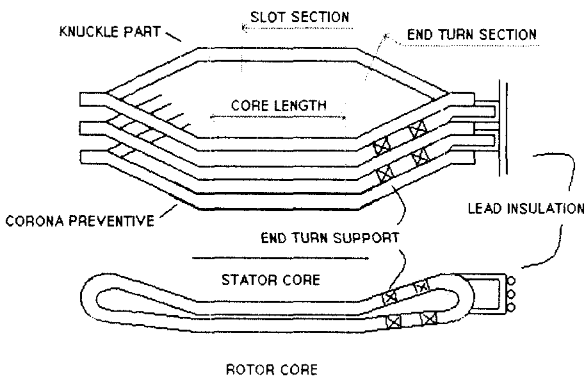


Fig. 3. Form winding structure of traction motors.

4. PERFORMANCE TEST AND RESULT CHARACTERISTICS

Developed standard traction motor was tested in accordance with the performance test criteria which is divided to type test and routine test. The result of the test is shown in the table 3. Type test is applied to first manufactured one to approve the rating and the performance characteristics. And routine test is applied to every manufactured ones to approve the exact assembling and reproduction of performance, and in this research the average of 4 motors of Fig. 4. was adopted as the standard characteristic. Also the combined test was performed in the inertia load test facility of 1C-4M to identify the performance in the real operating condition and evaluate the defined operating duty.

Table 3. Performance test result for traction motor.

No.	Test items	Performance criteria		Results
1	Continuous temperature rising test	Winding temperature : less than 160 K		118 K
2	One hour rating temperature rising test	Winding temperature : less than 160 K		122 K
3	Noise test	115 dBA or below at 4800 rpm		105.8dBA
4	Vibration test	5.25 mm/s or below		2.54
5	Overspeed test	5800 rpm for 2 minutes		O.K
6	Load test	Current	< 125A	123.1 A
		Efficiency	> 92%	94.4 %
		Power factor	> 88%	91.1 %
		Slip		1.55 %
7	Non-load test	Non-load current		31.2 A
8	Lock test	Lock voltage		202.8 V
9	Insulation resistance	more than 20 MΩ		2000 MΩ
10	Electrical endurance test	4500V for 1 minute		O.K

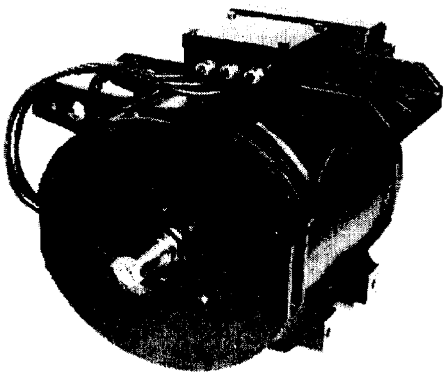


Fig. 4. Appearance of traction motor for electric railway. (rating power 200 kW, 1100 V, 125 A)

5. LONG LIFE RELIABILITY TEST OF INSULATION SYSTEM

The insulating system of traction motor for electric railway undergoes the accelerated thermal degradation test to guarantee the life span over 20 years and to verify operating reliability under severe operating condition and inverter driving stress. The accelerated thermal degradation test is performed under the procedures in Fig. 5. and conditions of the table 4 in the base of life time reduction by half with 10 ℃ of temperature rising[10].

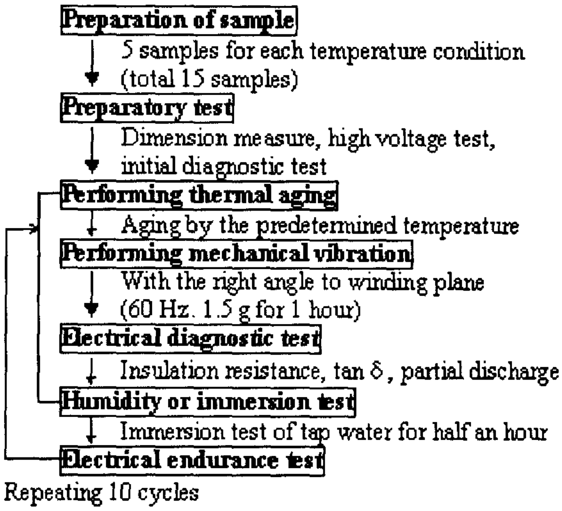


Fig. 5. Test procedure of accelerated thermal degradation for 200 Class insulation system .

Table 4. The condition of accelerated thermal degradation for 200 class insulation system.

Aging temperature	One cycle period for aging	Total aging period (10 cycle)
270 ℃	1.5 days	15 days
250 ℃	5 days	50 days
230 ℃	17.5 days	175 days

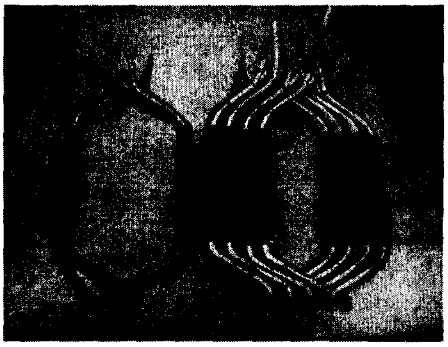


Fig. 6. Appearance of stator form coil used in accelerated thermal degradation test.

6. CONCLUSION

In this paper, design and manufacturing process of 200 class insulation system for the development of standard traction motor for electric railway are introduced considering inverter drive stress and high temperature operation.

Developed standard traction motor was tested in accordance with the performance test and the combined test in the inertia load test facility, and the result of the test demonstrates that the performance characteristics meet the standard criteria for railway application.

Also it confirms that the accelerated thermal degradation test on the stator winding insulating system guarantees the life span over 20 years and verifies the operating reliability under severe operating condition and inverter driving stress.

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