Special edition paper

Development of high performance main electrical circuit system


Yoshitaka Yasui*, **Ryosuke Furuta****

Increasing of the Shinkansen speed requires increased output, size reduction, weight reduction, and reduced noise generation of the power equipment. 3 types of power equipment have been developed for the type E954 Shinkansen high speed test train. These are: a type characterized by a main power converter cooled by ram air cooled water, a type characterized by self-ventilated synchronous motor driving, and a type characterized by a power transformer cooled by ram air. Through tests, in order to confirm the function and performance of each type, reliability evaluation, durability evaluation, and maintenance evaluation will be performed. This paper introduces these 3 types of main electrical circuit systems that have been developed.

• **Keywords:** Main electrical circuit, ram air cooling, water cooling, synchronous motor

1 Introduction

Increasing of the Shinkansen speed requires increased output, size reduction, weight reduction, and reduced noise generation of the power equipment. The development goals have been set at power output providing the equilibrium speed of 400 km/h or higher (grade of 3/1000) for a 6M2T group of train cars, 11.6 tons per unit weight, and for noise, the noise level of the power equipment by itself at or below 90 dB (C). Furthermore, in order to increase redundancy of the power equipment and control torque for the group of cars, control is being performed on an individual bogie basis.

In order to realize this goal, 3 types of power equipment have been developed. These are a type that is characterized by a main power converter that circulates water utilizing ram air which does not need a motor-driven blower, a type characterized by a small and low noise main power converter that utilizes ram air, and a type that is characterized by a self-ventilated permanent magnet synchronous motor. These will be introduced below.

2 Main electrical circuit performance

2.1 Powering performance

For the speed-tractive effort characteristics, the standard was set at achieving the equilibrium speed of 360 km/h at 9 notch characteristic (assumed final notch for commercial train cars) for open sections with a grade of 10%.

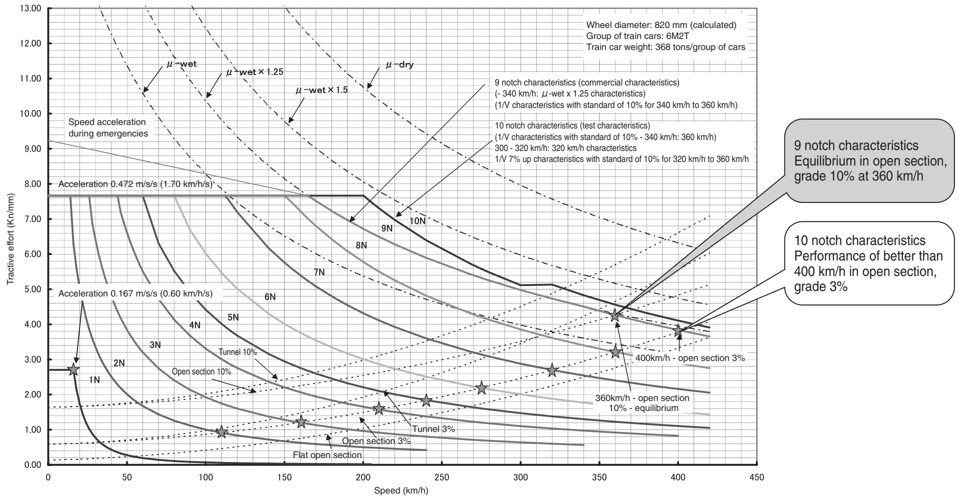


Fig.1: Speed-tractive effort curves

* Mito branch office Transport department (Former Advanced Railway System Development Center)
** Advanced Railway System Development Center, Research and Development Center of JR East Group

The start up acceleration was set at 0.472 m/s/s (1.7 km/h/s). Furthermore, for the test train car, performance was set at greater than 400 km/h for notch 10 in an open section with a grade of 3%. In addition, settings have been prepared for the overload characteristics in order to control torque for the group of cars at notch 10. Fig. 1 shows speed-tractive effort curves.

For high speed traveling cars, the number of driving wheels (M number) and notch characteristics depend on the area of adhesion performance. For the type E954, because adherence characteristics for the M car, the last car of the group, can be ensured through 1.25 times the adhesion plan equation μ-wet (1) and torque control for the group of cars is effective, notch 9 and 10 were set in areas above μ-wet characteristics.

$$\mu\text{-wet} = \frac{13.6}{85+V} \cdots\cdots\cdots (1)$$

V: Speed (km/h)

2.2 Regenerative braking performance

Speed-regenerative braking force characteristics use the full capacity of the main electrical circuit systems to carry the burden of the T car to the extent possible (for lower than B5 notch, full burden, for B6 notch and above, supplement with air brakes).

Effective use of adhesion characteristics based on the position of the group of cars (group of cars braking force control) was performed, and this was used to set the regenerative braking force level.

3 Main electrical circuit systems

For the main electrical circuit systems of the E954 type, 3 types that have equivalent tractive performance and regenerative braking characteristics were developed.

Power equipment characteristics and specifications are shown in Table 1.

Table 1: Power equipment characteristics and specifications

		First unit	Second unit	Third unit
Characteristics		A main electrical circuit system where **size and noise reduction have been achieved for the main power converter** through using a water cooling system cooled by ram air for the main power converter. ◯Reduction of noise through ram air cooling and elimination of blowers ◯Size reduction enabled through use of water cooling that has high cooling efficiency	A main electrical circuit system where **high efficiency, weight reduction, and noise reduction have been achieved for the traction motor** through use of a self ventilated permanent magnet synchronous motor. ◯Utilization of a permanent magnet synchronous motor achieving high efficiency and weight reduction ◯Based on self-ventilation, the MM blower is no longer needed and this leads to noise reduction ◯Through utilization of a synchronous motor, control becomes 1 inverter-1 motor ◯This is larger than the induction motor type due to the built-in open contactor; however, this size increase is offset by the removal of the MM blower	A main electrical circuit system where **weight and noise reductions have been achieved for the main power converter** through use of ram air and fan forced cooling for the main power converter. ◯Weight reduction through utilization of ram air and fan forcible cooling ◯Blower noise reduction through utilization of ram air cooling
Power transformer	Method	Fan forcible cooling	Fan forcible cooling	Ram air + fan forcible cooling
	Rated power output	3650 kVA	3600 kVA	3600 kVA
	External dimensions	L 2742 x W 2569 x H 650 mm	L 2593 x W 2215 x H 650 mm	L 2740 x W 2287 x H 650 mm
	Weight	3255 kg	3280 kg	3195 kg
Main power converter	Method	Ram air cooled water cooling	Ebullient cooling by fan forcible cooling	Fan forcibly cooled water cooling
	Converter circuit	3 level PWM type	3 level PWM type	3 level PWM type
	Inverter circuit	3 level PWM type	2 level PWM type	2 level PWM type
	External dimensions	L 2900 X x W 2030 x H 650 mm	L 3200 x W 2400 x H 650 mm	L 3000 x W 2400 x H 650 mm
	Weight	1650 kg	1820 kg	2084 kg
Traction motor	Method	Fan forcible cooling induction motor	Self-ventilated permanent magnet synchronous motor	Fan forcible cooling induction motor
	Rated power output	370 kW	355 kW	350 kW
	External dimensions	Φ480-L 597.5 mm	Φ490-L 595.5 mm	Φ470-L 599.5 mm
	Weight	453 kg	440 kg	444 kg
Unit overall weight (pantograph, support insulator, including special high speed devices)		10.9 tons	11.2 tons	11.7 tons

3.1 Main power converter with ram air cooled water cooling

3.1.1 Ram air cooling

Heat is generated by controlling activities performed by the main power converter that controls the traction motor. The motor-driven blower used to remove this heat enlarges the device, increases its weight, and generates noise.

Therefore, this type utilizes ram air for cooling making the motor-driven blower unnecessary; reducing size and noise. Furthermore, through utilizing a water cooling method that has high cooling efficiency, size reduction is realized.

Fig. 2 shows an illustration with respect to capture of ram air.

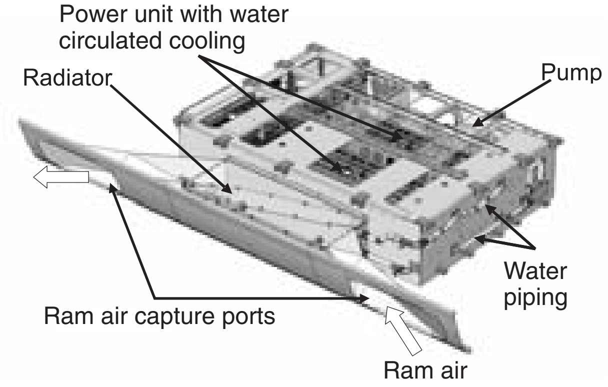


Fig.2: Ram air capture diagram

3.1.2 Water cooling

Fig. 3 shows an illustration of the cooling configuration.

Water circulation connects the heat generating area (power unit mounting area) and the heat release area (radiator) in order to use ram air captured from the side of the train car.

Furthermore, in the type E954, continuous operation at low speeds is expected and this will make it difficult to obtain sufficient cooling performance. Therefore a configuration where the exhaust air from the continuous ventilation equipment can be used for supplemental cooling air was adopted.

A comparison of conventional ebullient cooling method and water cooling method is shown in Table 2.

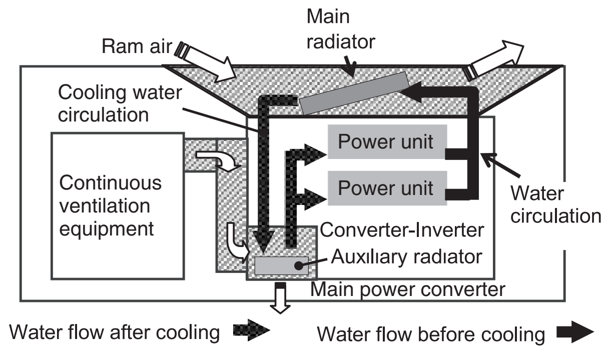
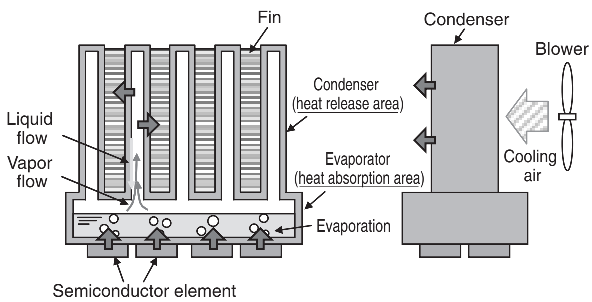
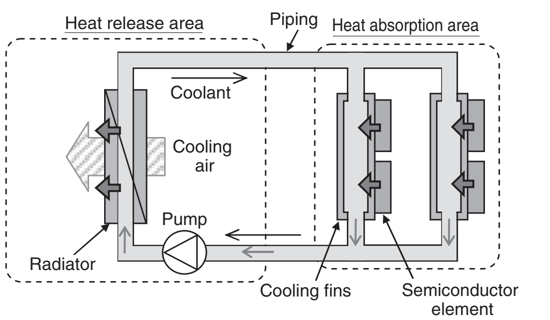


Fig.3: Illustration of cooling configuration

Table 2: Comparison of ebullient cooling and water cooling

Method	Ebullient cooling method (applied to E2 model)	Water cooling method (applied to type E954)
Principle of operation	Evaporation of refrigerant (Fluorinert) using the heat generated by a semiconductor element and absorption of the heat from the element in the evaporator. The vapor derived from evaporation moves to the condenser, is cooled by the fins on the condenser, where it is liquefied and the heat is released to the atmosphere. The liquefied refrigerant is then returned to the evaporator using gravity. 	Through forcibly circulating the coolant (water) using a pump, heat is removed from the semiconductor element by the water cooling fins and the heat is moved to the radiator by the coolant where the heat is released through fan forcible cooling (same as the cooling method used in an automotive engine). 
Characteristics	· Integrated configuration of evaporator and condenser · Does not impede cold starts · Position of condenser is limited · Most size reduction for mid-range capacity cooling systems	· Freedom with placing of the unit · Size reduction of the equipment is feasible for large-capacity cooling · Burden on the environment is low · Pump and piping are necessary

3.2 Synchronous motor

The traction motor for conventional Shinkansen is an induction motor where the rotor rotates based on the reciprocal electromagnetic induction effect of current induced in the rotor by a rotating magnetic field of the stators.

On the other hand, a synchronous motor rotates based on a permanent magnet embedded in the rotor that directly pulls and repels against the rotating magnetic field of the rotor. (Fig. 4)

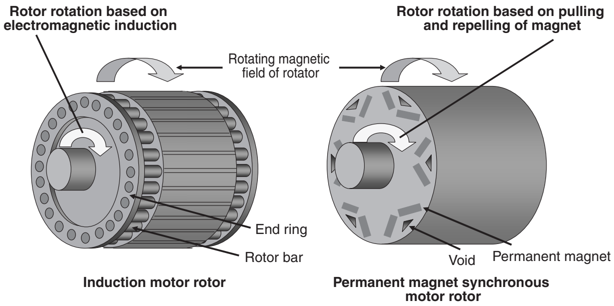


Fig.4: Principle of induction motor and synchronous motor operation

Because a permanent magnet synchronous motor does not have induction current losses generated in the rotor, it has higher efficiency and less heat generation compared to an induction motor.

As a result of measuring efficiency through bench testing, it has been confirmed that the efficiency at rated output reached 97%. Compared with conventional induction motors, an approximately 3% improvement in efficiency is anticipated.

Fig. 5 shows the external appearance of the synchronous motor and rotor.

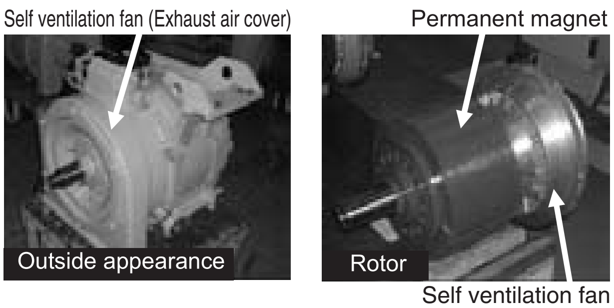


Fig.5: External appearance of synchronous motor and rotor

3.3 Ram air cooled power transformer

An increase in the output power of the main electrical circuit and in the amount of cooling for the power transformer are required for increasing speed. For this system, increase in cooling capacity causes increase in weight. Therefore, in order to suppress increase in size, cooling fins were mounted on the bottom of the main unit tank to utilize ram air.

Cooling capacity from ram air is expected to be approximately 10% of the total. As this will enable suppression of the amount of air provided by the motor-driven blower, it enables reduction of mass, weight savings, and reduction of noise.

Fig. 6 shows the external appearance of the ram air cooled power transformer and cooling fins.

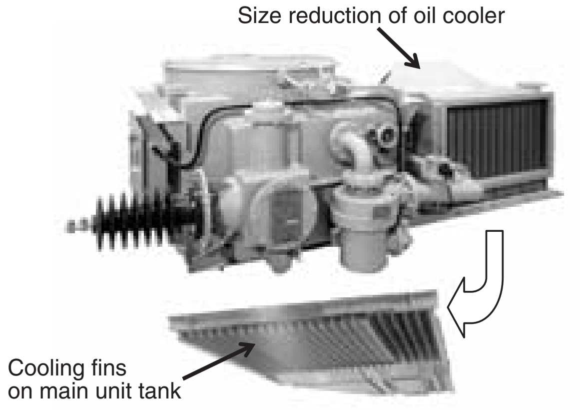


Fig.6: External appearance of ram air cooled power transformer and cooling fins

4 Conclusion

At this time the 3 types of main electrical circuit systems have been developed for the type E954 Shinkansen high speed test train car.

In the future, the functions and performance of these types will be evaluated through the on-track tests. Also, reliability evaluation, durability evaluation, and maintenance evaluation will be performed to establish the optimum design of the main electrical circuit system for a world class Shinkansen.

References

1) Ryosuke Furuta, Yoshitaka Yasui, Satoshi Sagawa, Hideo Kitabayashi; Development of main power converter with a water circulation cooling method that utilizes ram air - a first for the Shinkansen. 14th Transportation and Logistics Conference (TRANSLOG 2005), December, 2005

2) Ryosuke Furuta, Yoshitaka Yasui, Shigetoshi Shiraishi, Atsushi Yajima, Hajime Yamamoto; System development of permanent magnet synchronous motor that first achieved 400 km/h, 14th Transportation and Logistics Conference (TRANSLOG 2005), December, 2005