DURABILITY VERIFICATION OF THE PRACTICAL GROUND COIL FOR PROPULSION

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Abstract

A huge number of ground coils will be required for outdoor use over an extended period of time. The verification of the durability of coils on the assumption of actual service conditions is really important in securing the total reliability of the Magnetically Levitated transportation (MAGLEV) system. We examined the durability using the improved single layer coil for propulsion, which were laid on a part of the Yamanashi Test Line. The durability under the specified performance was confirmed for a simulated 30-year service. As a result, we could confirm the normality of the electric insulation functions and found no mechanical damages such as cracking on the molded resin.

1. Introduction

Recently, the railway system is in the spotlight again as a mass transport system that has a lesser environmental impact. Furthermore, the linear motor train system, which enables extreme high-speed transport operation has become a great hope as a new transport system for the 21st century. The Railway Technical Research Institute and JR Central constructed an experimental line in the Yamanashi Prefecture and have been performing running tests by vehicles for practical use since April 1997. In 1999, a manned train achieved a speed of 552 km/h. Running tests are smoothly progressing and is now into the high speed running stage to confirm the reliability of the system. In regard to the ground coils, which are important equipment of this system, this paper describes an outline of the improved single layer coil for propulsion and the results of durability verification tests.

2. Basic Configuration of Durability Verifications

The durability of ground coil has been studied with the test configuration shown in Figure 1.

In this Figure, an allowable performance evaluation test targeting improved ground coils is being enforced as a part of the verification test for actual coils. We have evaluated the coil after accelerating specified types of load, which are equivalent to the loads during the period of actual life in service by means of the allowable performance evaluation test.

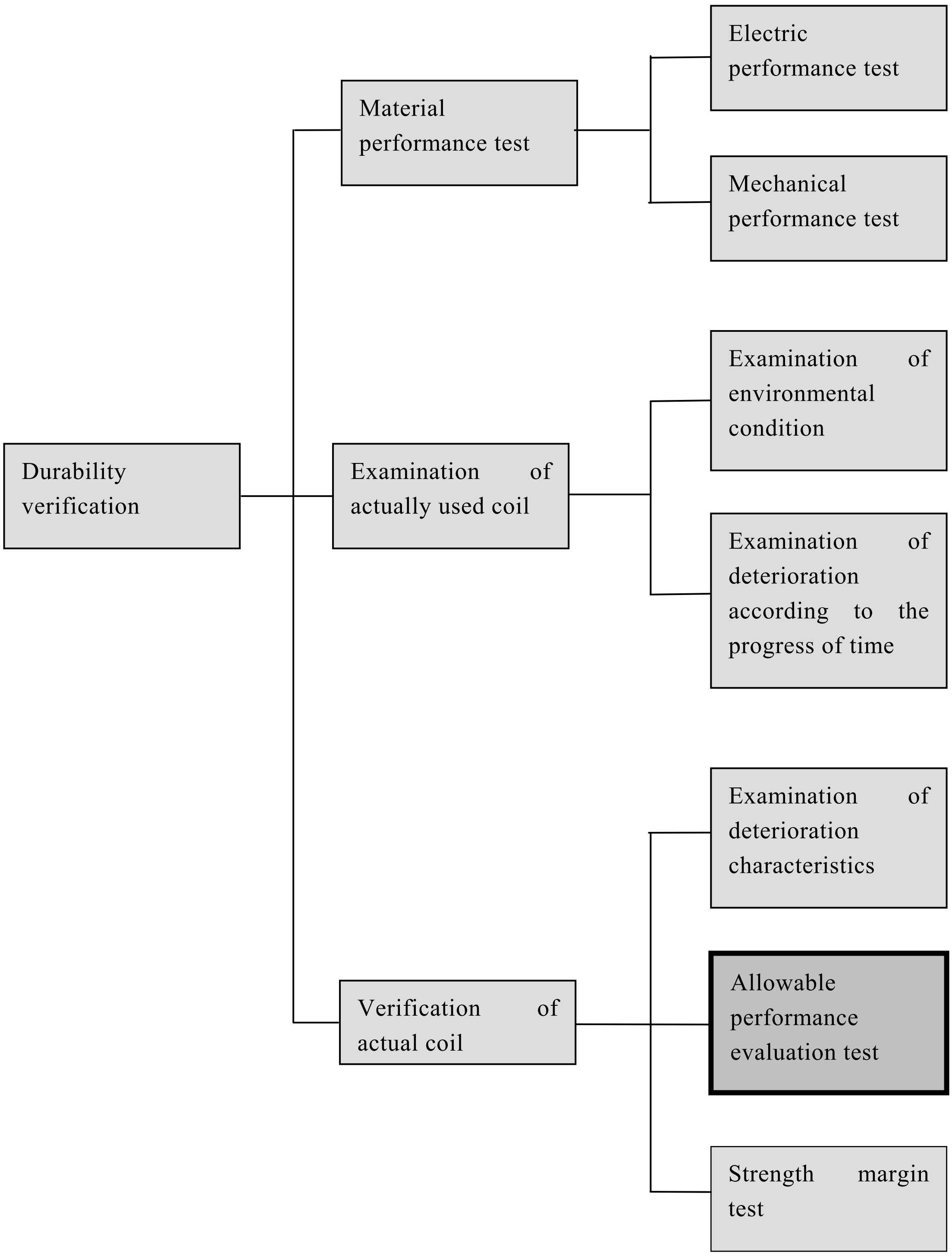

Fig. 1 Basic configuration of the durability verification test

3. Accelerating Deterioration Process

3.1 Chemical Deterioration

It is generally accepted that the relation between the reaction temperature of material and the reaction speed follows the empirical formula of Arrhenius. The formula of the reaction speed against the deterioration of material is described as follows.

$$\frac{dC}{dt} = Kf(C) \qquad \cdots\cdots\cdots \quad (1)$$

where, C is the characteristic value of material; t is time; and K is the reaction speed constant. The correlation between the reaction speed constant and the temperature according to Arrhenius is described as follows.

$$K = A exp\left[-\frac{\Delta E}{RT} \right] \qquad \cdots\cdots\cdots \quad (2)$$

where, A is the frequency factor; ΔE is the activation energy; R is the gas constant; T is the absolute temperature. The following speed equation is derived from (1) and (2) above.

$$\frac{dC}{dt} = A exp\left[-\frac{\Delta E}{RT} \right] f(C) \qquad \cdots\cdots\cdots \quad (3)$$

Integration of the above equation (3) under the conditions where time t_e has elapsed and the material characteristics have changed from C_0 to C_e leads to

$$\int_{C_0}^{C_e} \frac{dC}{f(C)} = A \int_{t_0}^{t_e} exp\left[-\frac{\Delta E}{RT} \right] dt \qquad \cdots\cdots\cdots \quad (4)$$

As the left side of the above equation is also correlated with C, it can be substituted by the function G(C).

$$G(C_e) - G(C_0) = A \int_{t_0}^{t_e} exp\left[-\frac{\Delta E}{RT} \right] dt \qquad \cdots\cdots\cdots \quad (5)$$

When C_0 and C_e are defined as constant values, the left side of the above equation (5) is a constant. The left side can be expressed as the constant value $A\theta$.

$$A\theta = A \int_{t_0}^{t_e} exp\left[-\frac{\Delta E}{RT} \right] dt \qquad \cdots\cdots\cdots \quad (6)$$

The equation (7) is derived from the formula (6) under the condition of constant temperature.

$$A\theta = A exp\left[-\frac{\Delta E}{RT} \right] (t_e - t_0) \qquad \cdots\cdots\cdots \quad (7)$$

where, t_e - t_0 is the time for the initial characteristics C_0 to reach C_e. This value is substituted by t_L. The following formula is obtained by logarithmic conversion of both sides of the above equation and by canceling the constants of the equation.

$$\ln t_L = \ln \theta + \frac{\Delta E}{RT} \quad \cdots\cdots\cdots \quad (8)$$

Substituting $\ln t_L$ by Y, $\Delta E/R$ by a, 1/T by x, and $\ln \theta$ by b leads to

$$Y = aX + b \quad \cdots\cdots\cdots \quad (9)$$

A linear correlation is obtained between the reciprocal number of the absolute temperature and the logarithm of elapsed time.

We applied the above formula to verify the correlation between the time for molding epoxy resin to reach the specified water absorption ratio and the water temperature for immersing the resin. Figure 2 shows the Arrhenius plots between the time for reaching the specified water absorption ratio and the immersion temperature. In this verification test, block-shaped resin samples were used. This graph shows a virtually linear correlation between them [1].

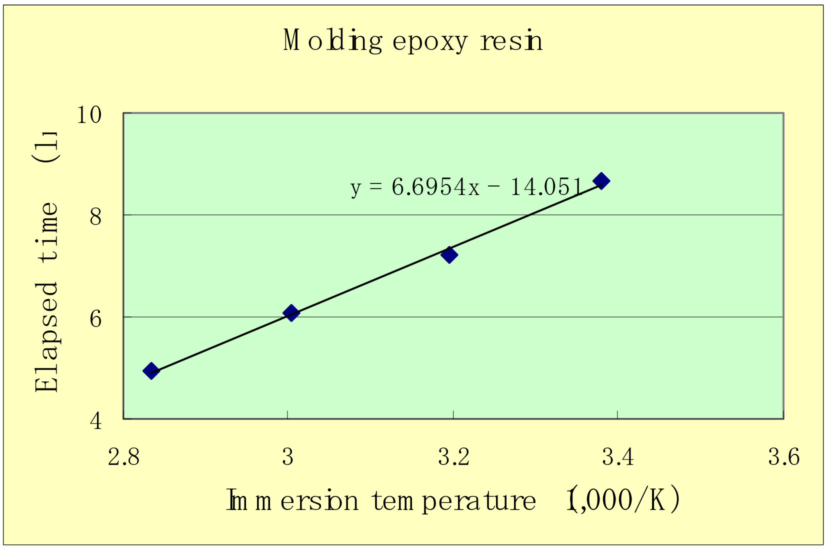

Fig. 2 Example of Arrhenius plots

3.2 Mechanical Deterioration

The S-N curve is obtained from fatigue test results of the material at each test temperature.

$$N_1 = \left(\frac{S_2}{S_1}\right)^n \times N_2 \quad \cdots\cdots\cdots (10)$$

After that, the multiplier for acceleration of the load is derived from the S - N curve and the formula (10).

This sets the loading conditions for the test. In the equation (10), S_1 is the stress during the test; N_1 is the number of applications of load; S_2 is the generated stress during actual service; N_2 is the accumulated loading times over 30 years; and n is the acceleration multiplier.

3.3 Electrical Deterioration

The multiplier for acceleration of the electrical load is derived from the V - t curve for alternating current insulation break - down conditions and the formula (11).

$$t_1 = \left(\frac{V_2}{V_1} \right)^n \times t_2 \qquad \cdots\cdots\cdots \quad (11)$$

This sets the loading conditions for the test. In the equation (11), V_1 is the applied voltage to the test coil; t_1 is the total hours of electrified as the load; V_2 is the voltage applied during actual service; t_2 is the accumulated hours of electrified over 30 years; and n is the acceleration multiplier.

4. Durability Tests of the Actual Coil

4.1 Outline of the Test Coil

The improved single layer model for propulsion, for which aluminum coil winding is molded with epoxy resin, was used as the test coil. This coil has increased resin strength and reduced eddy current loss due to a thinner wire diameter. Figure 3 shows an external view of the test coil.

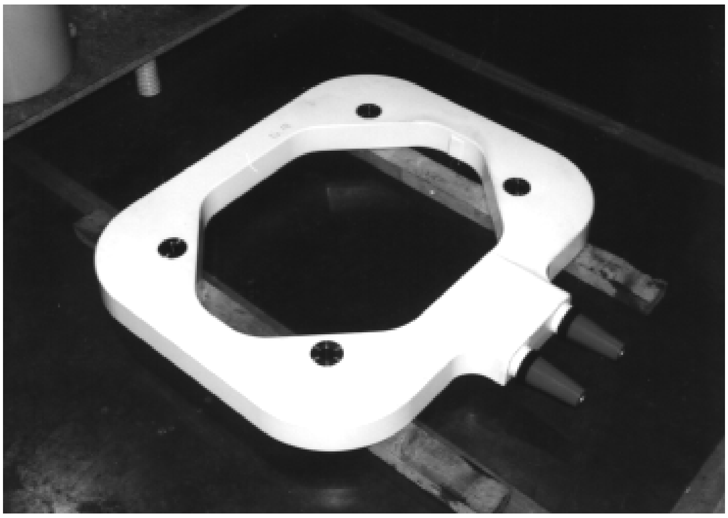

Fig. 3 Exterior of the test coil

4.2 Test Procedure

Two cycles of 15-year equivalent complex loads are applied to the test coil to simulate the long-term outdoor use. This verified that the coil is durable for 30 years for practical use [2]. Figure 4 shows the test configuration. In the test, a specified environmental load was initially applied, after which both repeated mechanical loads and electrical load were applied to the sample.

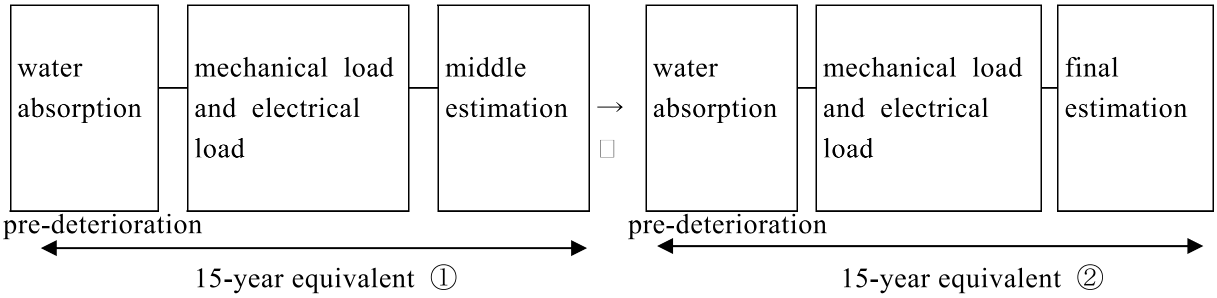

Fig. 4 Test configuration of the allowable performance evaluation

4.3 Load Condition

We set up each acceleration deterioration condition considering equivalency to the actual conditions.

4.3.1 Deterioration due to water absorption

The 30-year equivalent rainfall data was derived for the specified area from the actual weather reports. After that, data on water absorption deterioration was derived based on the temperature characteristics and absorption ratio obtained from the material test. The test coil was dipped in a 70 ℃ hot bath for 40 days (2×20 days) to simulate a rainfall period of 30 years.

4.3.2 Mechanical deterioration

The sample coil was installed in the chamber of the durability test equipment of the Institute, and the environment temperature was kept at 60℃ to repeated tests under the maximum electromagnetic force of car passing (2×7.7 millions times).[*1] In order to shorten the test period, the stress was multiplied by 1.2 times by considering the S - N characteristics of the material. Figure 5 shows the loading condition for the mechanical deterioration test.

*1: The maximum electromagnetic force indicates the maximum lateral force per coil, where the relative displacement to the super conducting magnet was 0 mm (vertical) and 20 mm (lateral), and the phase shift of the LSM current was 40 degrees.

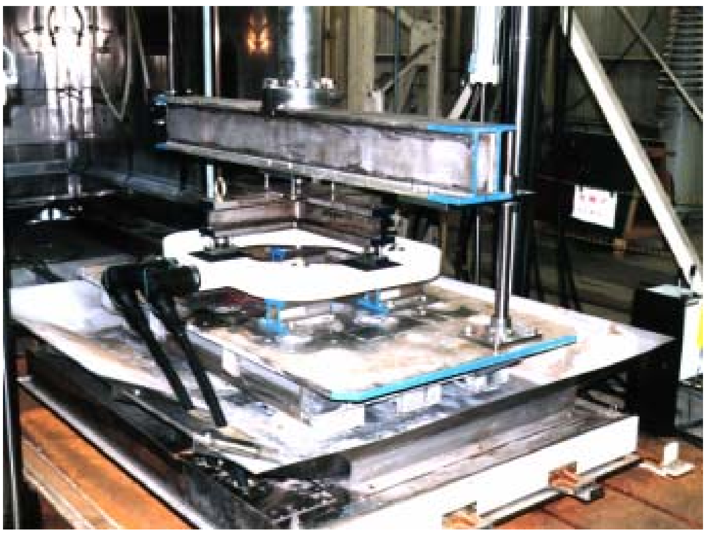

Fig. 5 Loading condition for the mechanical deterioration test

4.3.3 Deterioration due to electricity

The mechanical load and the voltage were applied to the sample coil at the same time. The AC voltage was continuously applied between conductor and the ground, while effecting a 30-year insulation loss by an accelerating test. To consider the combined load, the voltage application period was synchronized to that of the mechanical load as far as possible. The applied voltage was derived in the following manner. The deterioration coefficient (1.4) by the n'th power was derived from the V - t characteristics. The maximum r.m.s. value of the fundamental voltage (19 kV to the ground level) was multiplied by the deterioration coefficient. This multiplied value (26.6 kV) was used as the test voltage.

4.4 Durability test at the actual site

Prototype coils of the practical type have already been installed in a part of the open sections of Yamanashi Test Line based upon various bench test results, and subjected to a durability examination test under the actual conditions of high speed levitation runs. The test has continued three years since the installation and no troubles have occurred. Figure 6 shows the actual installation of the test coil.

Fig. 6 Actual installation of the test coils

5. Results of the Durability Test

5.1 External Conditions

No cracks or any other damages were observed in the test coils after completion of the bench tests or durability tests at the actual site.

5.2 Electrical Conditions

When a voltage was applied to the test coils, the insulation characteristics of tan δ and partial discharge did not deteriorate any test coils. As a result, we could confirm the normality of the electric insulation functions.

6. Summary

This study performed 30-year equivalent durability tests of the improved ground coil single layer model and evaluation tests. No mechanical damages such as cracking on the molded resin or electrical damage such as insufficient insulation were observed after equivalent complex loads were applied to the test coils. The test coils maintained their specified performance.

7. Acknowledgments

Above, we outlined the durability verification of the practical ground coil for propulsion. Our research and tests have been funded in part by the Ministry of Land, Infrastructure and Transport, of the Japanese government.

Finally, we offer our deep thanks for the cooperation of the Toshiba Corporation and all other individuals who contributed their time and help toward our success.

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