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Analysis of the Result for the Accelerated Life Cycle Test of the Motor for Washing Machine by Using Acceleration Factor

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***Abstract*—**Accelerated life cycle test is applied to various products or components in order to reduce the time of life cycle test in industry. It must be considered for many test conditions according to the product characteristics for the test and the selection of acceleration parameter is especially very important. We have carried out the general life cycle test and the accelerated life cycle test by applying the acceleration factor (AF) considering the characteristics of brushless DC (BLDC) motor for washing machine. The final purpose of this study is to verify the validity by analyzing the results of the general life cycle test and the accelerated life cycle test. It will make it possible to reduce the life test time through the reasonable accelerated life cycle test.

***Keywords*—**Accelerated life cycle test, reliability test, motor for washing machine, brushless dc motor test.

I. Introduction

THE development of new products or components takes several months to verify the reliability of failure and life prediction. This has been a major challenge in supplying new products to the market.

If the accelerated life test method is applied under severe conditions than the normal conditions, the failure can be induced within a short time, and the life of the product can be quickly predicted [1]. However, inappropriate accelerated life test models can lead to erroneous conclusions, so the accelerated life test model should be verified within the stress range. The test period should be shortened to the required level, but the stress level should be close to the operating range of the possible items. The high stress level should not exceed the operating limits. By setting the low stress level closer to the operation limit or overlapping, it is possible to develop a precise acceleration test model and to apply the empirical stress model. During the test, one will be able to obtain better modeling information if a lot of measurements and monitoring are executed. In addition, the failure mode and the mechanism of the use condition and the acceleration condition should be the same. The influence of other factors, exclusive of the acceleration factor, should be kept constant and the test product should be the same as the final development or production product.

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In order to apply the accelerated life test as above, various requirements must be satisfied.

We establish the accelerated life test method considering the characteristics of the motor for washing machine and analyzed the results through experiments.

II. Accelerated Life Cycle Test Method Modeling

A representative model for applying on the accelerated life test method is as follows [2].

A. Arrhenius Model

Acceleration models where temperature has a significant effect.

$$T_{50} = AF \cdot e^{\frac{\Delta H}{kT}}$$
$$AF = \frac{A\,e^{\frac{\Delta H}{kT_1}}}{A\,e^{\frac{\Delta H}{kT_2}}} = e^{\frac{\Delta H}{k}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)} \quad (1)$$

T_{50}: 50% failure time; k: Boltzmann constant; H: Unknown constant; $T1$: Lifetime at normal conditions; $T2$: Lifetime at accelerated conditions

B. Eyring Model

Model that temperature stress includes other stresses.

$$T_{50} = AF \cdot e^{\frac{\Delta H}{kT}} \cdot V^{-B}$$
$$AF = e^{\frac{\Delta H}{k}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)} \quad (2)$$

C. 10℃ Rule

Increasing 10 ℃ above normal temperature, life reduces by half.

$$\theta_a = \frac{\theta_n}{2^{\alpha}}$$
$$AF = 2^{\frac{\Delta T}{10}} \quad (3)$$

θa: Lifetime at accelerated temperature; θn: Lifetime at normal temperature; α: Number of temperature differences per 10℃

D. α-Square Law

When using pressure or voltage as an acceleration factor.

$$V = \frac{V_n}{V_a}$$
$$AF = V^{\alpha} = \left(\frac{V_n}{V_A}\right)^{\alpha} \quad (4)$$

V_A: Normal stress; V_n: Accelerated stress. Equations (3) and (4) were adopted for the application of the accelerated life cycle test of the motor for washing machine.

The final accelerated life equation is as follows.

$$AF = 2^{\frac{\Delta T}{10}} \cdot \left(\frac{V_n}{V_A}\right)^{\alpha} \quad (5)$$

However, the actual acceleration level depends on the structure, operating characteristics, and physical properties of the accelerated life test product. Therefore, the value of 10 ℃ rule or α-square must be adjusted through experiments.

The flow chart which is utilized in order to apply the accelerated life test is as shown in Fig. 1 [3].

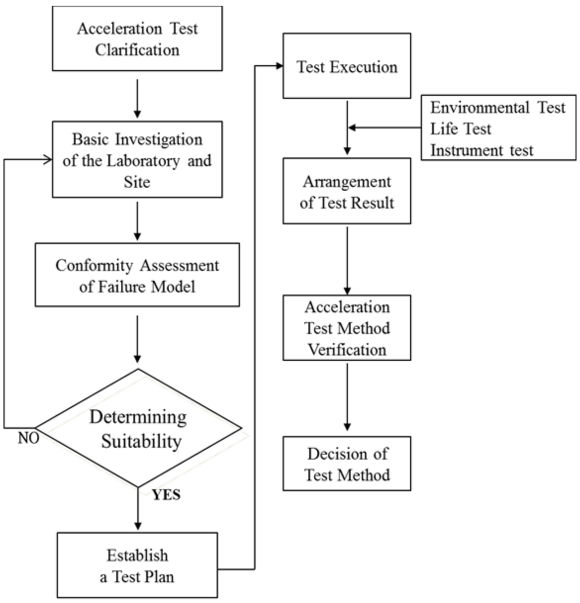

Fig. 1 Flow chart for accelerated life cycle test

For home appliances such as washing machines, the lifetime warranty must be at least 10-years. The 10-year driving time calculation formula of the washing machine is as follows

$$\begin{aligned} 10\,years\ life\ cycle\ time &= 2hr \times 360\,day \times 10\,year \\ &= 7200hr(300day) \end{aligned} \quad (6)$$

One cycle operation process of washing machine is as shown in Fig. 2. Generally, most of the power consumption of the washing machine occurs in the laundry board and dehydration mode. Therefore, the load was applied by using a motor load tester to minimize the life test time, and the load mode was classified into the washing mode and the dehydration mode, and then continuous test was applied to each mode.

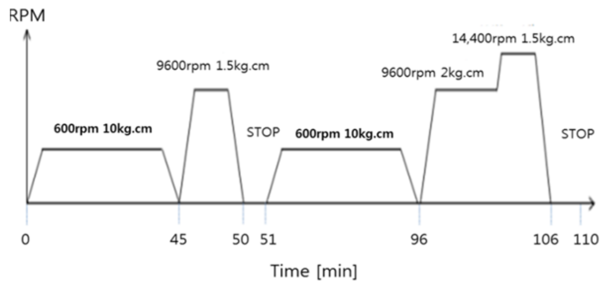

Fig. 2 The operating cycle profile of washing machine

Acceleration factor was set to 3, acceleration parameter was selected by using ambient temperature and load, and acceleration condition was determined by using (3) and (4). The assigned accelerated life cycle test model is as:

$$AF = 2^{\frac{\Delta T}{10}} \cdot \left(\frac{V_n}{V_A}\right)^{\alpha} = 2^{\frac{11}{10}} \cdot (1.2)^2 \approx 3 \quad (7)$$

* In the field of electrical machinery, α is normally applied as 2.

The acceleration factor 3 was set by increasing the load (stress) by 20% and the ambient temperature of 11℃.

When setting the acceleration factor as 3, the 10 ℃ rule and the α-square law are applied as above, but the level acceleration depends on the type and characteristics of the test object. Thus, we will calculate the acceleration factor by analyzing the results of the accelerated life test and we will modify the 10 ℃ rule and the α-square law to match the motor for the washing machine.

The general life test and the accelerated life test time required to ensure the 10-year quality of the washing machine are shown as Table I.

TABLE I
COMPARISON OF LIFE TEST TIME

Operating Type	Normal Life Cycle Test	Accelerated Life Cycle Test
Washing Mode Test Time [h]	1800	600
Dehydration Mode Test Time [h]	900	300
Total Test Time [h]	2700	900

* 1 cycle Motor operation time of washing mode: 30 minutes

III. Execution of the Accelerated Life Cycle Test

There are some factors to consider when carrying out the accelerated life test. In general, chambers are used for accelerated tests due to environmental temperature rise. However, when the sample itself generates heat by itself, it is difficult to raise in the accurate environmental temperature by using the chamber. Therefore, to increase the accuracy of the test, the temperature reference was selected as the surface temperature of the motor rather than the ambient temperature.

The test conditions for the analysis of the results on the general life test and the accelerated life test are shown in Table II.

TABLE II
TEST CONDITIONS

Test Condition	Normal Life Cycle Test	Accelerated Life Cycle Test
Torque_Washing mode [kg·cm]	10	12
Speed_Washing mode [r/min]	600	600
Torque_ Dehydration mode [kg·cm]	2.0	2.4
Speed_ Dehydration mode [r/min]	9600	9600
Surface Temp of Motor [°C]	Saturation Temp	Saturation Temp + 11°C

Fig. 3 Environmental (temperature) chamber used for the test

Fig. 4 Motor setting up using dynamo load tester in chamber

Fig. 5 Measurement of test temperature and load condition

In the case of motors, the stress was selected as the load because the factor that directly affects the stress is the load [4].

When the temperature rise was applied, the surface temperature of the steady state was measured, and the surface temperature was adjusted to rise by 11 °C compared to the steady state. Since the load was increased by 20% under the condition that the surface temperature was increased, the temperature rise has occurred twice in total.

The test condition for the normal life cycle test and the accelerated life cycle test is shown in Figs. 3-5.

IV. COMPARISON OF TEST RESULTS

Tables III and IV show the results of the normal life cycle test and the accelerated life cycle test with an increase in Environmental temperature of 11°C and a load of 20%.

TABLE III
TEST RESULT OF NORMAL LIFE CYCLE TEST

Item	Before the Test	After the test	Rate
Insulation Resistance [Ω] (DC 500 V)	99.9 G	62.5 G	-37 %
Leakage Current [A] (Dielectric AC 1.5 kV)	296 μ	317 μ	+7.1 %
Leakage Current [A] (Dielectric DC 2.5 kV)	2.0 μ	3.0 μ	+50 %
No-load Current [A] [@600 rpm]	0.257	0.235	-8.5%

Results of test analysis showed that the accelerated life cycle test reduced the rate of change by 29.5% compared to normal life cycle test. This means that the acceleration factor 3 is not applied. Therefore, in order to apply the accelerated life test of the motor, the acceleration life method modeling should be modified as follows.

$$AF = 2^{\frac{\Delta T}{10}} \cdot \left(\frac{V_n}{V_A}\right)^{\alpha} = 2^{\frac{11}{10}} \cdot \left(1.2\right)^2 \Rightarrow\ 2^{\frac{11}{14}} \cdot \left(1.2\right)^{1.4} \approx 2.2 \quad (8)$$

TABLE IV
TEST RESULT OF ACCELERATED LIFE CYCLE TEST

Item	Before the Test	After the Test	Rate
Insulation Resistance [Ω] (DC 500 V)	99.9 G	78.4 G	-26 %
Leakage Current [A] (Dielectric AC 1.5 kV)	254 μ	267 μ	+5.1 %
Leakage Current [A] (Dielectric DC 2.5 kV)	2.0 μ	2.7 μ	+35 %
No-load Current [A] [@600 rpm]	0.484	0.460	-5.0%

V. CONCLUSION

Accelerated life cycle test shall be calculated differently depending on the characteristics of the test subject and the type of stress applied. In this paper, it is found that the test is different from the actual acceleration life cycle test model when the 10 °C rule and the α-Square Law are applied to the motor. Since the accelerated life cycle test at the first depends on the theoretical values, it is necessary to obtain a sufficient database through test.

If the values of the parameters for the accelerated life cycle test are correctly calculated and applied to the industry, it is expected to be very useful for reducing the time and cost on the reliability verification [5].

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