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A Study on the Accelerated Life Cycle Test Method of the Motor for Home Appliances by Using Acceleration Factor

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***Abstract*—**This paper deals with the accelerated life cycle test method of the motor for home appliances that demand high reliability. Life Cycle of parts in home appliances also should be 10 years because life cycle of the home appliances such as washing machine, refrigerator, TV is at least 10 years. In case of washing machine, the life cycle test method of motor is advanced for 3000 cycle test (1cycle = 2hours). However, 3000 cycle test incurs loss for the time and cost. Objectives of this study are to reduce the life cycle test time and the number of test samples, which could be realized by using acceleration factor for the test time and reduction factor for the number of sample.

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

I. Introduction

NOWADAYS, the universal motor inserted in washing machine is replaced with the permanent magnet synchronous motor (PMSM) used permanent magnet because of the synergy effect on energy efficiency and increasing on the market demand for low noise. PMSM has many advantages such as high torque density, high power density [1]. Advances in PMSM manufacturing and technology are primarily responsible for lowering the cost and increasing the applications of PMSMs. If the magnet is mounted on the surface of the rotor, it is called surface mount permanent magnet synchronous motor (SPMSM), and if the magnet is placed inside the rotor, it is called interior permanent magnet synchronous motor (IPMSM). Because the magnets of the IPMSMs are embedded inside the rotor, magnets are protected from flying away out the rotor surface from the rotational force [2]. So IPMSM has been used in wide field and is on the increase in use. For the next five years, IPM will be expected to capture on the market up to 50 percent. IPM motor is important to secure reliability for the application to washing machine, due to different form of structure, existing on the universal motor.

Generally, the life cycle of the washing machine seems to be same as the life cycle of motor, which is very important factor to decide for the life cycle of the washing machine. The life cycle test on driving motor of the washing machine has been proceeding under operation test for the number of operating (3600 cycle) of the washing machine. It brings on much loss in terms of cost and time. In order to reduce the loss as mentioned earlier, the life cycle test on driving motor of the washing machine which needs to apply to accelerated life cycle test is suggested that shorten time for the life cycle test.

From the modeling results, it will be confirmed that the proposed accelerated life cycle test is useful method for the washing machine motor.

TABLE I
Reliability Accident (Comp & Motor)

	G company	M company
Product	Household Refrigerator	
Unit	Rotary Comp & motor	
Production Date	1986.3	1985.1
Issued data	1987.7	1991.10
Failed Cost	450Million $	560Million $
Failed Amount	1.1Million	1Million`
Failure Mechanism	Abnormal Wear Out (Sintered Iron) Oil Reaction/ Sludge Imbedding	Wear Out (Lubrication at High T) Oil Reaction Sludge Imbedding
User Disaster	Worst Case	Worst Case

II. The Worldwide Market Trends of the Washing Machine

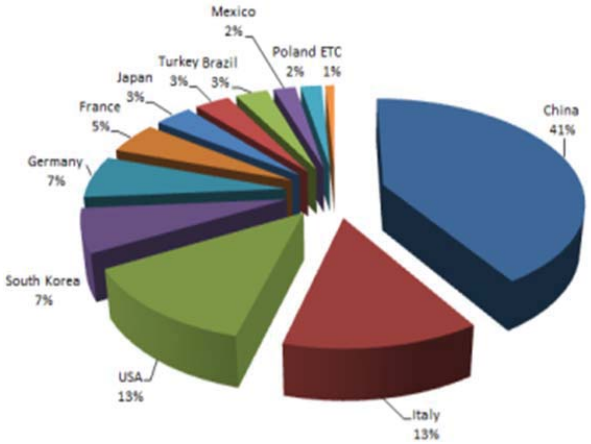

Fig. 1 Regional output of washing machine

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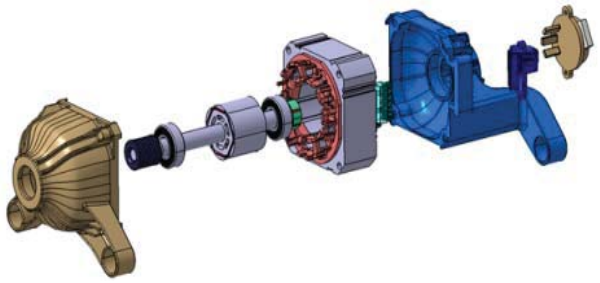

Fig. 2 Structure of BLDC Motor for Washing machine

Recently, the washing machine of the belt type drum accounts around 80 percent of whole washing machine, and almost manufactures have been replacing the universal motor with the IPM motor.

III. The Life Cycle Test on the Driving Motor of the Washing Machine

The life cycle test of driving motor of the washing machine is carried out as shown in (1).

$$10\,years\,life\,cycle\,time = 2hr \times 360\,day \times 10\,year = 7200hr(300day) \quad (1)$$

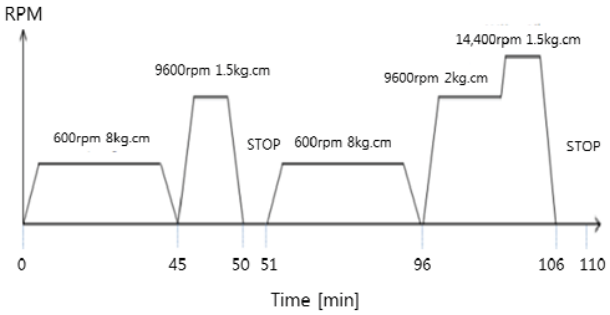

Fig. 3 The operating cycle profile of washing machine

Also, the selection on the number of sample, which is computed by BX-LIFE Table II, should be conducted for the reliability data.

TABLE II
Reliability Index: BX Life

Category	Washing Machine	Motor Vehicle
Reliability Target of Finished Product (20% /10 Year)	B20 Life 10Y	B20 Life 10Y
Number of components	1,000	20,000
Required cumulative failure rate of component till lifetime	0.02%	0.001%
BX life, 10 years, of component	B0.02	B0.001
Number of units (Assume that each unit has 100 comp.)	10	200
Required cumulative failure rate of unit till lifetime	2%	0.1%
BX life, 10years, of unit	B2 Life 10Y	B0.1 Life 10Y

In the motor as a unit, the fraction defective for 10 years is required to be less than 2 percent. To ensure that the fraction defective is less than 2 percent, a sample of 50 tests is needed [3]. The previous life cycle test used to take 300 days, operating 24 hours per day, as above.

The manufacture will be much more charged as a result of the increasing at expense for the test and the delay in delivery.

IV. Modeling for Accelerated Life Cycle Test of the Motor

This paper performs modeling of accelerated life cycle test of the motor in normal life cycle conditions as shown in (2). The accelerated life cycle test of motor can be drawn by using Acceleration Factor (AF). AF indicates acceleration ratio for the normal life cycle condition as below [4]-[6].

$$AF = \left(\frac{S}{S_o}\right)^n \cdot \exp\left[\frac{E_a}{k}\left(\frac{1}{T_o} - \frac{1}{T}\right)\right] \quad (2)$$

S: Stress; T: Ambient temperature; Ea: Boltzmann constant; k: Energy coefficient.

In accordance with the specification as above,

1) Temperature (T) makes degradation to occur quickly.
- As the temperature increases about 10 degree, the life cycle of the 1/2 portion shall decrease, and increase twice as many failures as.
2) Stress (S) makes damage to accumulate fast.
- As the stress is doubled, the life cycle shall be decreased, failure shall be increased as the portion.
- As the stress is bigger than 1.2, failure rate will be increased by 1.44 times.
3) Activation energy (Ea) is about 0.5 ~ 0.6 eV
4) The verification shall be required "n" and "Ea" by multi-level test.

A. Application to Accelerated Life Cycle Test of the Motor

If the accelerated life cycle test is carried out on the motor, Parameter T can be ambient temperature and Parameter S can be applied current.

In case of applied to T (ambient temperature) = 15 °C, S (current I) = 20 %, likewise, AF can be derived as in (3):

$$AF = \left(\frac{S}{S_o}\right)^n \cdot \exp\left[\frac{E_a}{k}\left(\frac{1}{T_o} - \frac{1}{T}\right)\right] = \left(\frac{I}{I_o}\right)^2 \cdot e^{\frac{Ea}{k}\left(\frac{1}{T_o} - \frac{1}{T}\right)} = \left(\frac{1.2}{1}\right) \cdot \left(2^{\frac{15}{10}}\right) = 4.3 \quad (3)$$

By the application to AF, (4) indicates that the test time can be shortened from 200 days to 70 days.

$$\therefore\ 7200hr / 4.3 \cong 1670hr(70days) \quad (4)$$

B. The Number of Sample

According to the strict test conditions for the accelerated life cycle test, it is difficult for the test with a lot of samples. Therefore, it is necessary to reduce the number of samples by increasing the accelerated life cycle test time. The number of

samples can be reduced by reduction factor as in (5):

$$RF = \left(\frac{L_{BX}}{AF \cdot h_a} \right)^{\beta} \quad (5)$$

AF: Acceleration Factor; ha: Acceleration Time Increasing ratio; LBX: Normal life cycle time; β: Shape Parameter. Here, Shape Parameter (β) defined as each part of experience point and statistics will be able to adapt as shown in Table III [3].

TABLE III
SHAPE PARAMETER β

Item	Beta Value		
	Low	Typical	High
Ball bearing	0.7	1.3	3.5
Roller bearing	0.7	1.3	3.5
Sleeve bearing	0.5	1	3
Belts, drive	0.5	1.2	2.8
Bellows, hydraulic	0.5	1.3	3
Bolts	0.5	3	10
Clutches, friction	0.8	1.4	3
Clutches, magnetic	0.8	1	1.6
Couplings	0.8	2	6
Couplings, gear	1	2.5	4
Cylinders, hydraulic	0.5	2	3.8
Diaphragm, metal	0.5	3	6
Diaphragm, rubber	0.5	1.1	1.4
Gaskets, hydraulics	0.5	1.1	1.4
Filter, oil	0.5	1.1	1.4
Gears	0.5	2	6
Impellers, pumps	0.5	2.5	6
Joints, mechanical	0.5	1.2	6
Knife edges, fulcrum	0.5	1	6
Liner, recip. Comp. cyl.	0.5	1.8	3

Shape Parameter (β) of a certain component would be invariable. Therefore, shape parameter will be estimated and then will be confirmed after the test.

1) High Temperature, high pressure, high stress: $2.5 < \beta < 10$
- Low cycle fatigue: Depend on cycle time
- disk, shaft, turbine.

2) Low temperature, low pressure, low stress: $0.7 < \beta < 10$
- Degradation: Depend on use time
- electrical appliance, pump, fuel control value

Shape parameter indicates the intensity of wear-out failure and represents the grade of structure precision and material homogeneity.

As shown in (6), reduction factor can be obtained through applying 3 in shape parameter (β) factor and 2 in accelerated time ratio (ha).

$$RF = \left(\frac{L_{BX}}{AF \cdot h_a} \right)^{\beta} = \left(\frac{7200}{4.3 \cdot 1670 \cdot 2} \right)^{3} = 0.125 \quad (6)$$

If (6) is applied to the derived reduction factor,

$$\therefore \; 50\,EA \times 0.125 \cong 6\,EA \quad (7)$$

With respect to reduction factor, the time for the accelerated life cycle test is increased by twice (1,670 hours x 2) whereas the number of samples can be decreased 50 samples to 6 samples. At the final, accelerated life cycle test method which is applied AF and reduction factor indicates as shown in Table IV, which is compared with normal life cycle test method.

TABLE IV
COMPARISON OF LIFE CYCLE TEST METHODS

Item	BLDC Motor for Washing machine	
	Normal Life Cycle Test	Accelerated Life Cycle Test
Life Cycle Test Time	7200 hr	3340 hr
The Number of Sample	50 EA	6 EA
Current (Stress)	100 %	120%
Ambient Temperature (T)	Room Temperature	Room Temperature + 15 °C

Applying accelerated life cycle condition increasing current by 20 percent, along with increasing ambient temperature by 15 degree, it is possible to reduce the life cycle test time by half and the number of sample by the portion of 1/6.

V. CONCLUSION

This paper proposes the accelerated life cycle test method to reduce life cycle test time and the number of test samples for washing machine motor. When parameter value is chosen for the application to accelerated life cycle test, it has to consider the environmental factors such as characteristic of component, quality of material and operating condition. Chosen parameter value should be verified via many times of multilevel test. In addition, securement of reliable database is vital in accelerated test. The accelerated life cycle condition as derived before will be applied and will be used to analyze the property change of the motor, before and after the test.

The comparison factor of the motor will consist of mechanical loss, dielectric strength, insulation resistance and rated current. Hence, the validity of the accelerated life cycle test should be confirmed and we are going to suggest a new alternative for life cycle test of the motor [7].

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REFERENCES

[1] T. J. E. Miller and J. R. Hendershot Jr., "Brushless Permanent Magnet and Reluctance Motor Drives," Oxford, U.K., 1989.
[2] G. R. Slemon and X. Liu, "Modeling and design optimization of permanent magnet motors," Elect. Mach. Power syst., Vol. 101 pp. 71-92, 1992.
[3] D. S. Ryu, "Improving Reliability and Quality for Product Success," Taylor & Francis Group CRC Press, May. 2012.

[4] William Q. Meeker, "A Comparison of Accelerated Life Test Plans for Weibull and Lognormal Distributions and Type I Censoring," Technomertics, vol. 26, issue. 2, pp. 157-171, 1984.
[5] Mohamed T. madi, "Multiple step-stress accelerated life test: the tampered failure rate model." Communications in Statistics - Theory and Methods, vol. 22, issue. 9, pp. 295-306, 1993.
[6] K. P. Yeo, L. C. Tang, "Planning step-stress life-test with a target acceleration-factor." *Reliability IEEE Transactions on*, vol. 48, no. 1, pp. 61-67, 1999.
[7] J. M. Seo, "Analysis of Home Appliance Permanent-magnet Machine for Energy Saving," *Korean society for new and renewable energy*, pp.140, June. 2015.