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DEVELOPMENT OF AN ACCELERATED LIFE TEST PROCEDURE FOR COOLING FAN MOTORS

W. G. SHIN[1),2)]*, S. H. LEE[1)] and Y. S. SONG[2)]

[1)]School of Mechanical Engineering, Yonsei University, Seoul 120-749, Korea
[2)]Electronic Module Reliability Team, Reliability Division, Korea Automotive Technology Institute, 74 Yongjung-ri, Pungse-myeon, Cheonan-si, Chungnam 330-912, Korea

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ABSTRACT–Reliability of automotive parts has been one of the most interesting fields in the automotive industry. Especially, a small DC motor was issued because of the increasing adoption for passengers' safety and convenience. For several years, small DC motors have been studied and some problems of a life test method were found out. The field condition was not considered enough in the old life test method. It also needed a lot of test time. For precise life estimation and accelerated life test, new life test procedure was developed based on measured field condition. The vibration condition on vehicle and latent force on fan motor shaft were measured and correlated with each other. We converted the acceleration data into the load data and calculated the equivalent load from integrated value. We found the relationship which can be used for accelerated life test without changing the severity by using different loading factors.

KEY WORDS : Fan motor, Reliability, Life test procedure, Vibration condition, Bearing load, Acceleration life test, Brushless DC motor, Field condition

1. INTRODUCTION

Today, to help resolve any possible trade barrier issues emerged with the launch of World Trade Organization (WTO), we need to put the highest priority on developing new products using advanced technology and improving the reliability and quality of products to ensure prolonged service life. Recently, consumers' understanding of and interest in the product quality have been significantly increased. However it still entails quite a lot of difficulty to evaluate the life distribution and long-term performance of high reliability products. An accelerated life test (Nelson, 1990) which forces product to fail in a shorter period of time than it would have under normal use condition is required (Rabinowicz *et al.*, 1970; Bolla, 2002).

The purpose of accelerated life test is to quickly produce the analysis data and the information related to the life or performance of the product by adopting appropriate models. This requirement is also quite important in the automotive industry. It is needed to develop a accelerated life test for high reliability to meet the customers' requirements for safety and convenience of their vehicles (Lu *et al.*, 2003; Krasich, 2004).

As modern vehicles incorporate ever increasing number of electric and electronic components (Chin and Soulard, 2003), the number of failure of those parts is also getting higher compared to the other parts. Small DC motors used for vehicles are also on line with this trend. Therefore, in this study, we would like to develop an accelerated life test procedure for cooling fan motor which drives cooling fan to remove heat from the radiator installed inside the engine bay of motor vehicle. The previous life test method for DC motors used powder brake to produce wear on the brush of motor by applying constant load at the centre of motor shaft. The disadvantages of this old method are that the brush is forced to wear and eventually fail without taking into account of the field conditions, and the test duration is considerably long (Toliyat and Kliman, 2004; Humphrey *et al.*, 2002; Hu *et al.*, 1993; Hu, 1994).

The failure mode of the motors includes brush wear-out, bearing damage, burnt coil, etc. However, we will only focus on the damage of bearing due to the eccentric load acting on the brushless DC motors. And to accomplish this, we will measure the vibration condition of actual vehicle driven on the real road, and the inherent load of fan motor shaft. And we obtain the equivalent load, which is then applied to the accelerated life test. The main objective of this thesis is to develop the life test procedure for cooling fan motor as summed up above.

**Corresponding author.* e-mail: wgshin@katech.re.kr

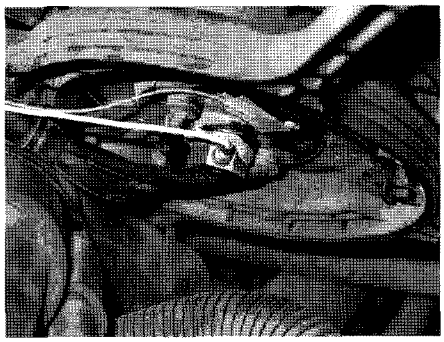
2. THE ACCELERATED LIFE TEST METHOD FOR COOLING FAN MOTORS

The failure mode of small DC (direct-current) motor includes brush wear-out, bearing damage, coil burnout, etc. But, in the case of BL (brushless) DC motors, brush wear-out cannot happen because of its unique structural characteristic, and the coil will not be burnt unless there is an electrical overload which is usually caused by external electrical problem and thus cannot be considered as a subsequent failure from mechanical damage. Therefore, we studied the bearing damage by the load applied to the motor (Kim *et al.*, 2004; Zhang *et al.*, 2002; Toliyat and Kliman, 2004).

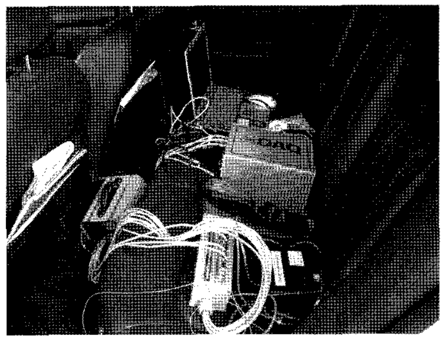
Radial load and thrust load are the major loads which cause failure of motor bearing. These loads are generated when the mass of the cooling fan driven by the motor is subjected to the acceleration from the vibration of driving vehicle. Meanwhile, the effect of thrust load on the bearing can be deemed insignificantly as the motor is designed to allow relative movement in axial direction between the main shaft with cooling fan and the bearing which supports the shaft, and also because there is a spring at the end of the shaft which absorbs impact. However, the radial load will be directly transferred to the bearing. Remember the bearing is there to provide firm support to the shaft (Lee and Han, 2000; Korea Machinery Co., 1988). Therefore it can be concluded that the main factor related to the failure of motor bearing is the load applied in perpendicular direction to the shaft among the loads developed by the mass to the shaft. The accelerated life test procedure proposed in this paper will be based on the above observation.

2.1. Measurement of Acceleration of Driving Road at Cooling Fan Motor

Firstly we have measured the load under actual mounting condition so that we can setup the load condition needed for the accelerated life test. The load applied to the motor shaft can be directly measured if we mount a strain gage onto the shaft, but in practice, the direct measurement is very difficult as there is no sufficient space inside the actual vehicle. To overcome this difficulty, we attached accelerometer at cooling fan motor and drove the vehicle to perform indirect measurement as shown in Figure 1. Table 1 (KATECH, 2002; Noh *et al.*, 2002) and Figure 2 represent the road driving condition and the resulting data respectively.



(a) The measuring position of field load test



(b) Data acquisition system

Figure 1. The measurement of acceleration at cooling fan motor.

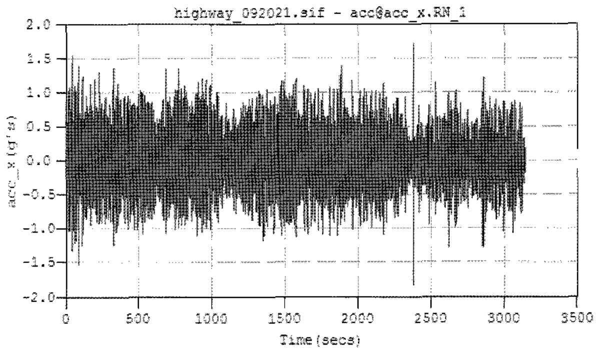


Figure 2. The measured data of acceleration at the field condition.

Table 1. Operating profile for driving vehicle.

Road type		profile(%)
Highway		22
Rough road		2
City road		50
Country	Good	18
	Bad	8

2.2. Measurement of Bending Load at Motor Shaft

In order to convert the measured acceleration into the load, we attached strain gage on the actual motor shaft and measured the bending load which causes the radial

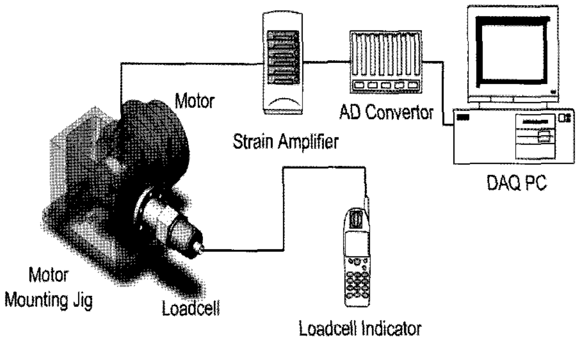


Figure 3. The schematic diagram of motor load measuring system.

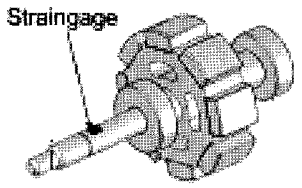


Figure 4. The position of straingage on the motor shaft.

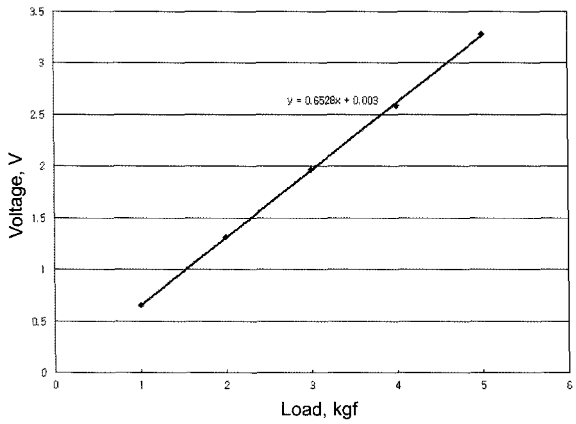


Figure 5. The Load vs. output Voltage graph obtained from motor loading test.

load on the bearing.

Figure 3 shows the schematic diagram of the connection of this test equipment. Strain gage on the motor shaft is in a bridge circuit to monitor the bending load as shown in Figure 4, and the load is applied at the center of mass of cooling fan using screw type loading device. We mounted the spring with the suitable coefficient of elasticity in the screw type loading device in order to minimize the change value with the various load.

We have measured the output voltage while changing the load in steps from 1 kgf to 5 kgf. Figure 5 is the load vs. output voltage graph obtained from the test.

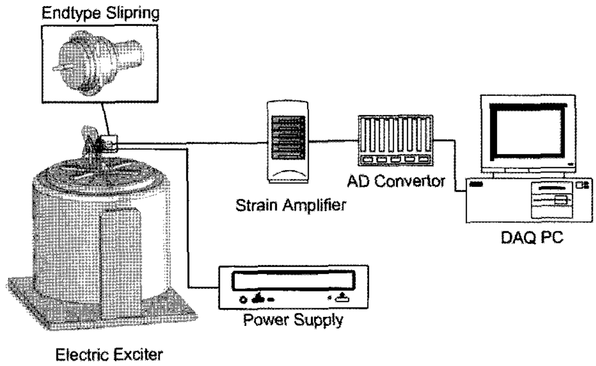


Figure 6. The measuring diagram of vibration excitation for cooling fan motor.

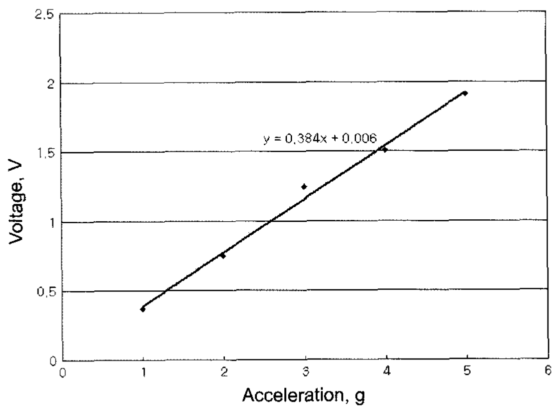


Figure 7. The Acceleration vs. output voltage graph obtained from vibration test for motor.

2.3. Vibration Test on an Exciter

In addition, we performed excitation test in order to convert the acceleration data obtained from road driving into the load data. As illustrated in Figure 6, we installed slip ring at the end of the motor where the strain gage is mounted on the shaft, and devised a zig to install on the table of exciter, so that we can measure the load while the motor is rotating. The vibration excitation is applied in steps from 1G to 5G, and the output voltage is measured using strain gage. The result is given in Figure 7.

2.4. Conversion to Equivalent Load

The obtained data represents the load applied to the motor while the vehicle is running, but it is a load experienced by the shaft and not by the bearing, hence it should be converted to the bearing load as shown in Figure 8. Both bearings of motor are standardized with the 608zz as the deep groove ball bearing. The diameter of the bearing is 22 mm.

As summarized in Figure 9, we converted the acceleration data from actual vehicle test into the load data,

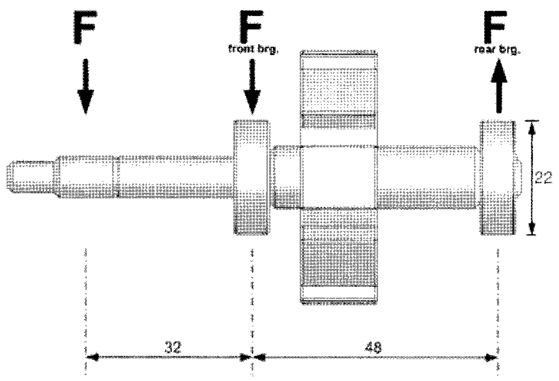


Figure 8. Dynamic equivalent load for bearing of motor.

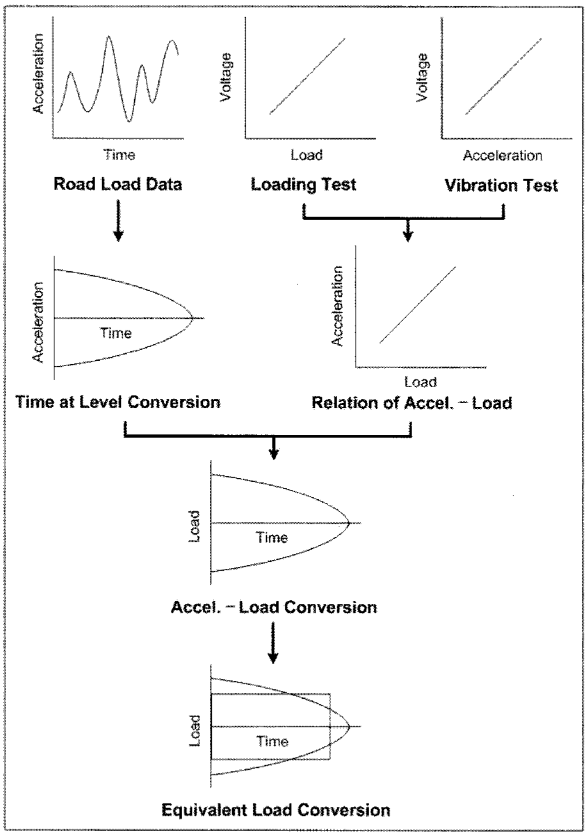


Figure 9. The life test procedure of cooling fan motor.

using the acceleration data obtained from actual vehicle test, the relationship between the load and output voltage obtained from motor load test, and the relationship between the acceleration and output voltage obtained from vibration excitation test. From these results, acceleration data obtained from actual vehicle test can be converted into the load data, which is plotted in histogram form in Figure 10.

We performed a series of processes as shown in Figure 9, in order to plot a histogram of acceleration and time

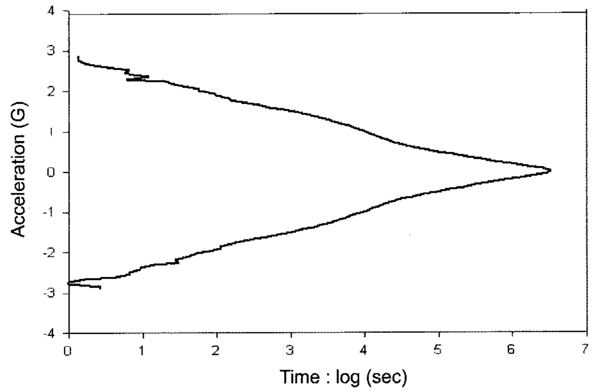


Figure 10. The histograms of the acceleration-time obtained by vehicle driving load test.

from the measured data in Figure 2. This histogram is based on the operating profile for vehicle given in Table 1 which is suggested by Korea Automotive Technology Institute (KATECH), and represents the severity of driving 160,000 kilometers on Korean roads.

Meanwhile, based on the above results and processes, the measured acceleration from actual vehicle test is converted into the load acting on the motor bearing, and the resulting histogram is shown in Figure 11. Here, we calculated the equivalent load from the integrated value of the curve on the graph in Figure 12, and found the relationship which can be used for accelerated life test without changing the severity by using different loading factors.

We could have derived equation (1) by accelerated life time for the conversion to equivalent load. This equation is summarized in accordance with test procedure developed. This is the equation for the relationship between motor bearing load and life time, which then used to calculated the equivalent load.

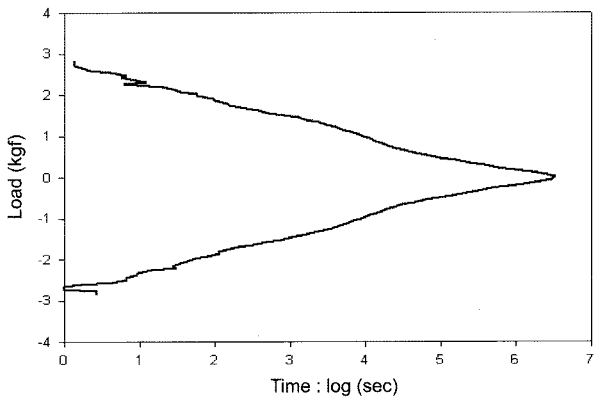


Figure 11. The histograms of bearing force transferred from the acceleration data.

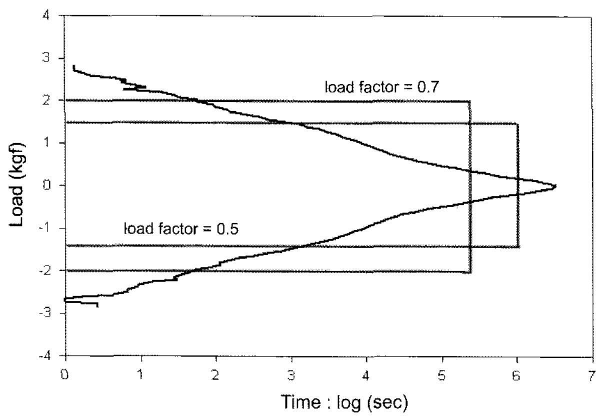


Figure 12. The equivalent load from the integrated value of the curve.

$$T_{acc.}=\frac{|t_1P_1| + |t_2P_2| + \cdots + |t_nP_n|}{2 \times P_{max} \times l_f} \quad (1)$$

$T_{acc.}$: Accelerated life time,
$t_1, t_2, ..., t_n$: Operating time of motor,
$P_1, P_2, ..., P_n$: load(N),
P_{max}: Maximum load,
l_f: load factor

3. CONCLUSIONS

In an effort to develop a life test method for automotive cooling fan motor, a different approach from the previous method has been taken to present the new life test method which forces the motor bearing to wear and eventually fail by the damage.

Firstly, we conducted a load test to measure the bending load, by mounting a strain gage on the motor shaft, and conducted vibrational excitation test to find the relationship between acceleration and load.

Secondly, we attached an accelerometer on the motor and drove the vehicle along the roadway, to measure the load under actual mounting condition, and presented the results in the form of function of acceleration against time.

Thirdly, using the relationship between the measured acceleration and load of motor, and the relationship between the acceleration and time from road test, we found the relationship between motor bearing load and life time, which then used to calculate the equivalent load. With this load values, we found the relationship which can be used for accelerated life test without changing the severity by using different loading factors.

Therefore, the evaluation of life is performed by applying the equivalent load obtained through the above three steps, to the bearing of cooling fan motor. In conclusion, the significance of this thesis lies in its presentation of the accelerated life evaluation method for cooling fan motor, which is one of the electric components in vehicles, with the consideration of field condition.

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