# Design and Analysis of an Accelerated Life Test for Magnetic Contactors

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**Abstract** – Magnetic contactors (MCs) are widely used in industrial equipment such as elevators, cranes and factory control rooms in order to close and open the control circuits. The reliability of MCs mainly depend on mechanical durability and international standards such as IEC 60947-4-1, which stipulates the testing method for MCs. Testing time, however, is so long in usual cases that a method of reducing testing time is required. Therefore, a temperature and voltage-accelerated life testing (ALT) method has been developed to reduce the testing time in this work. The accelerated life test data are analyzed and acceleration factors (AFs) are provided.

**Keywords:** Magnetic contactor, Accelerated life test, MINITAB, Weibull distribution, Acceleration factor.

## 1. Introduction

Magnetic contactors are composed of a magnet, a contact point part, and frames to hold them as shown in Figure 1. MCs switch loads by opening and closing the contact point by exciting and degaussing the magnetic coil. The voltage and current capacity of the magnetic switches for alternating current range from 220V-11A to 690V-5A and also from 220V-800A to 690V-630A respectively. In the field operation, the magnetic switches are generally used below 690 V-800 A.

The mechanical durability of an MC design is defined as the number of no-load operating cycles that would be attained or exceeded by 90 % of entire the apparatus of the design before it is necessary to repair or replace any mechanical part. The magnetic contactor shall be installed as for normal service; in particular, the conductors shall be connected in the same manner as for normal use. During the test, there shall be no voltage or current in the main circuit. The coils of the control electromagnets shall be supplied at their rated voltage and, if applicable, at their rated frequency. If resistance or impedance is provided in series with the coils, whether short-circuited during the operation or not, the tests shall be carried out with these elements connected as in normal operation.

After the mechanical durability test, the magnetic contactor shall still be capable of complying with the operating conditions specified in the limits of the operation of the contactors and in the operating limits at room temperature. There shall be no loosening of the parts used for connecting the conductors. Any timing relays or other devices for the automatic control shall still be operating [3].

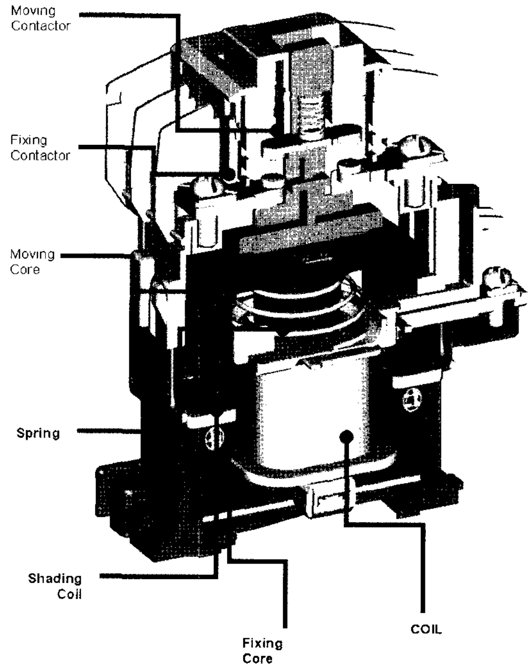


**Fig. 1.** A schematic diagram of magnetic contactor

The Weibull distribution is commonly used as product life distribution, because it models either increasing or decreasing failure rates easily. It is also used as the distribution for product properties such as strength (electrical or mechanical), elongation, resistance, etc. It is also used to describe the life of the roller bearing, electronic components, ceramics, capacitors, and dielectrics in life testing. According to the extreme value theory, it may describe a "weak link" product that consists

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Received 3 October, 2006 ; Accepted 12 January, 2007

of many parts from the same life distribution and fails with the first part failure. The probability density function (p.d.f.) and the cumulative distribution function (c.d.f.) of Weibull distribution are given as follows, respectively.[1]

$$f(t)=\left(\frac{\beta}{\eta^{\beta}}\right)t^{\beta-1}\exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right],\quad t>0 \tag{1}$$

$$F(t)=1-\exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right],\quad t>0 \tag{2}$$

Here, shape parameter $\beta$ and scale parameter $\eta$ have positive values. The parameter $\eta$ is also called the characteristic life and it represents the 63.2th percentile of the distribution. In Weibull distribution, $\beta$ determines the shape of the distribution and $\eta$ determines the spread of the distribution. Figure 2 represents p.d.f.s of Weibull distributions for some values of $\beta$.

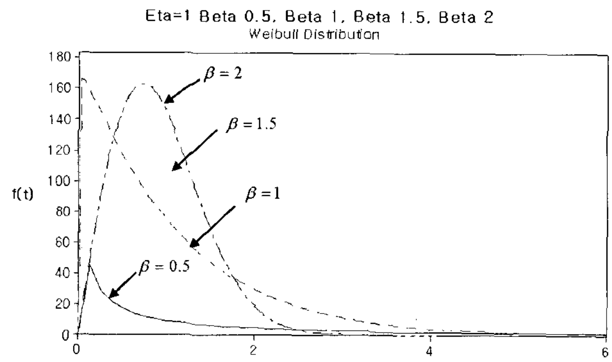


**Fig. 2.** Weibull probability density functions

Figure 3 shows the probability plot of the life test data obtained in the accelerated tests conducted for assessing the reliability of the magnetic contactors and it indicates that Weibull distribution is appropriate for describing the lifetime of the magnetic contactors.

In this paper, a design of an accelerated life test for a magnetic contactor is presented and statistical analyses of the accelerated test results are provided. Temperature and voltage are used as accelerating stresses. The magnetic contactor used for the accelerated life test is the rating of 440 V-9 A and the coil rating is 220 V. In order to operate the magnetic contactor, the programmable logic controller (PLC) is used. Also, it is generally used to control the equipment by using the ladder diagram that is programmed by a test engineer in field condition.

Failure analysis was done to find out the reason for the different failure modes and the photographs of the typical failure modes are given in Sec. III.

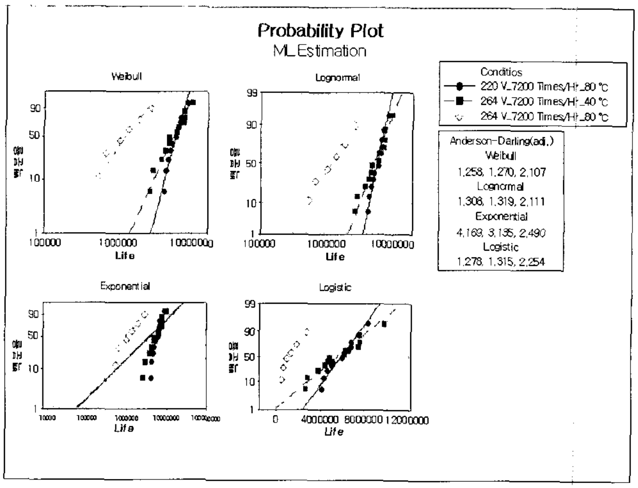


**Fig. 3.** Probability plots of the test data

## 2. ALT of Magnetic contactor

### 2.1 Selection of Stresses and Life-Stress Models

The effectiveness of an accelerated life test is primarily determined by the suitable choice of accelerating stresses. To be effective, the test must provide rapid and predictable acceleration of field-condition failure-mechanisms without inducing any non-typical field condition failure modes or degrading the reliability of good devices. MC failures due to mechanical stresses can be rapidly accelerated with the application of both voltage and thermal stresses. Considering the withstanding of voltage applied to coil, 1.2 times (120%) rated voltage of the accelerated level is selected. For the thermal stress, the temperature of 80 ℃ is selected as the accelerated level. The voltage and current in the use condition are 220 V and 40 ℃ respectively.

The Arrhenius accelerated model, which is widely used to model product life as a function of thermal stress, is considered for temperature stress [1]. The Arrhenius life-stress relationship is given by

$$L(V)=Ce^{\frac{B}{T}} \tag{3}$$

where $L$ is the quantifiable life measure, such as mean life, characteristic life, etc. $T$ represents the stress level (formulated for temperature and temperature values in absolute units, i.e., degree Kelvin). $C$ is one of the model parameter to be determined. $B$ represents the ratio of Boltzman's constant to activation energy and it is another model parameter to be determined.

The Inverse Power Law (IPL) Model commonly used for non-thermal accelerated stresses is considered for voltage stress. IPL relationship is given by

$$L(V) = \frac{1}{KV^n} \quad (4)$$

where $L$ represents a quantifiable life measure and $V$ represents the stress level. $K$ and $n$ are model parameters to be determined.

Most practitioners use an acceleration factor, which is the ratio of the life between the use level and an accelerated stress level, i.e

$$AF = \frac{L_{Use}}{L_{Accelerated}}, \quad (5)$$

where $L_{use}$ and $L_{accelerated}$ mean the life measures at use condition and accelerated condition, respectively.

For the Arrehenius and IPL models, acceleration factors are given by (6) and (7) respectively.

$$AF_{Arrh} = \frac{L_{Use}}{L_{Accelerated}} = e^{(\frac{B}{T_{Use}} - \frac{B}{T_{Acc}})} \quad (6)$$

$$AF_{IPL} = \frac{L_{Use}}{L_{Accelerated}} = \left(\frac{V_{Acc}}{V_{Use}}\right)^n \quad (7)$$

Applying both the voltage and temperature acceleration, the combined acceleration factor is given by

$$AF_{Arrh} = \frac{L_{Use}}{L_{Accelerated}} = e^{(\frac{B}{T_{Use}} - \frac{B}{T_{Acc}})} * \left(\frac{V_{Acc}}{V_{Use}}\right)^n. \quad (8)$$

To obtain the acceleration factors from the accelerated life test data, we need estimators of parameters $B$ and $n$.

## 2.2 Failure Analysis

Effective data analysis depends highly upon an accurate failure analysis. The main failure mechanism for current MCs is a loss of functionality caused by fracture or deformation of parts such as core and coil. The functionality loss for the devices could be easily detected by increased sound level. During the life test, the occurrences of the failures were identified by sound level meter or ears and the failure modes were validated by inspecting the disassembled samples. Usually, the sound level is below 30 dB in normal close state but it increases to above 30 dB in failure state.

Three representative failure modes of MCs are fracture of core, deformation of core, and fracture of shading coil and the proportions of each failure modes are given in Figure 4.

**Table 1.** The sound level of MC

| Sample No. \ Model | A | B | C |
|---|---|---|---|
| 1 | 21.5 dB | 23.3 dB | 25.0 dB |
| 2 | 20.6 dB | 19.1 dB | 27.5 dB |
| 3 | 23.5 dB | 21.1 dB | 27.7 dB |
| Average | 21.9 dB | 21.2 dB | 26.7 dB |

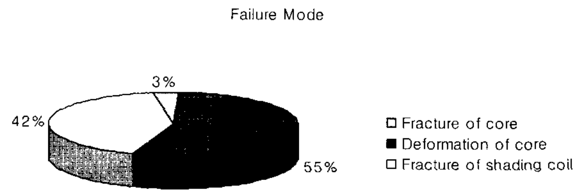


**Fig. 4.** The proportions of failure modes

Figures 5, 6, and 7 show the three representative failure modes of MCs.

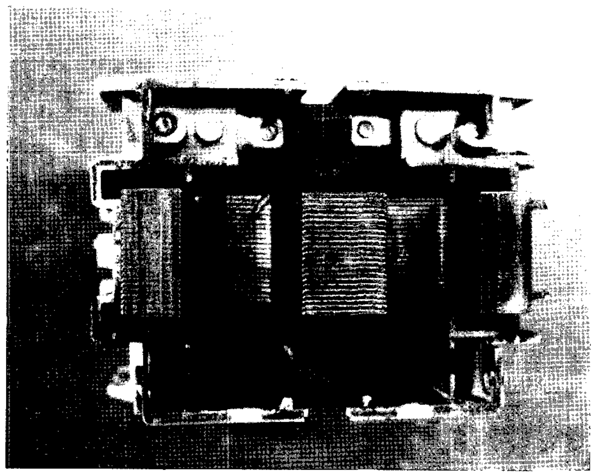

**Fig. 5.** Fracture of core (Failure mode of Type A)

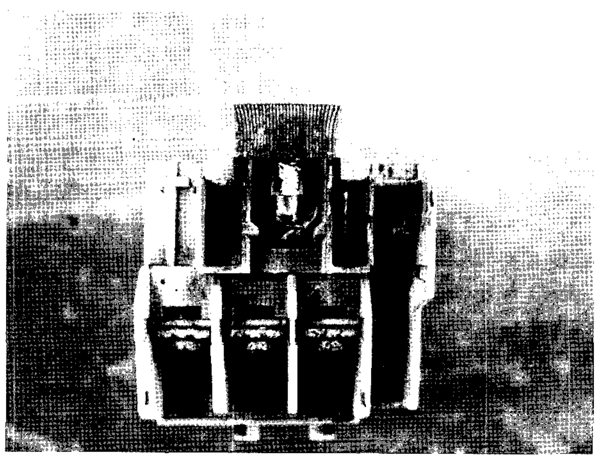

**Fig. 6.** Deformation of core (Failure mode of Type B)

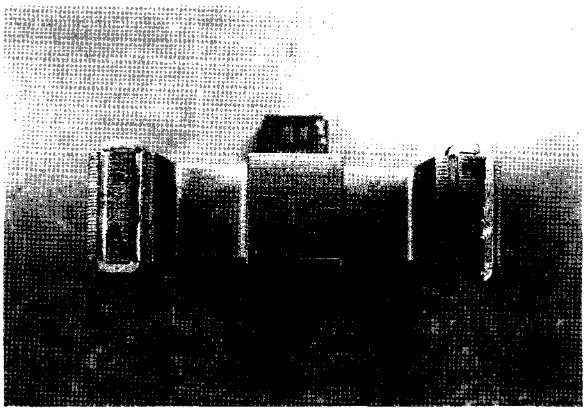

**Fig. 7.** Fracture of shading coil (Failure mode of Type C)

## 2.3 Experiment Set Up

The accelerated life test was conducted in the temperature and humidity chamber and the test plan is given in Table 2 with the number of test samples. The total number of test samples is 30 ea. The life at use condition will be estimated by using the accelerated life-stress models.

**Table 2.** Test plan

| | 40 ℃ | 80 ℃ |
|---|---|---|
| 220 V | - | 12 ea |
| 264 V | 12 ea | 6 ea |

The configuration of the test apparatus is given in the below diagram. It is composed to measure characteristic data and to operate the magnetic contactor as shown in Figure 8.

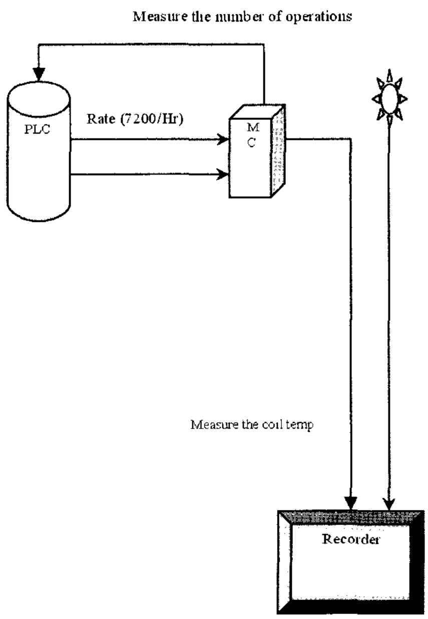


**Fig. 8.** Configuration of test apparatus

For accelerated life testing, the samples are attached to the jig and located in the humidity and temperature chamber as shown in Figure 9.

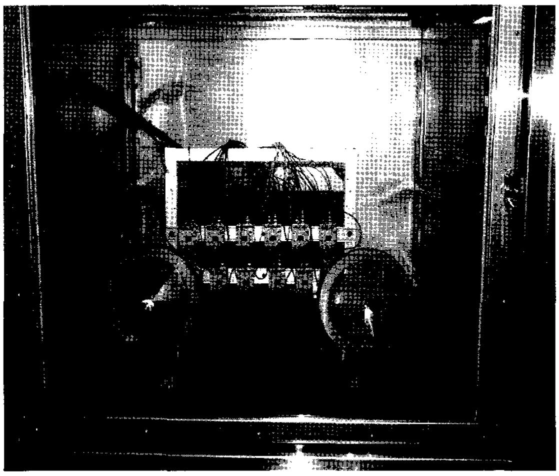

**Fig. 9.** Experimental setup

## 2.4 Testing and Results

The testing levels of temperature are determined according to the pre-test results for operating time with changing the temperature and closing phase. The pre-test results are given in Figure 10. The temperature is possible to control in the test but the closing phase is somehow difficult so that only the temperature is selected as an acceleration stress and the testing voltage and rate are fixed. The rate is an accelerated factor of time and the voltage is an accelerated factor of shock. In this work, acceleration factors for the temperature and the voltage levels are obtained.

The results of pre-tests in the range of 40 ℃ and 80 ℃ indicate that the operating time is approximately the same along with closing phase.

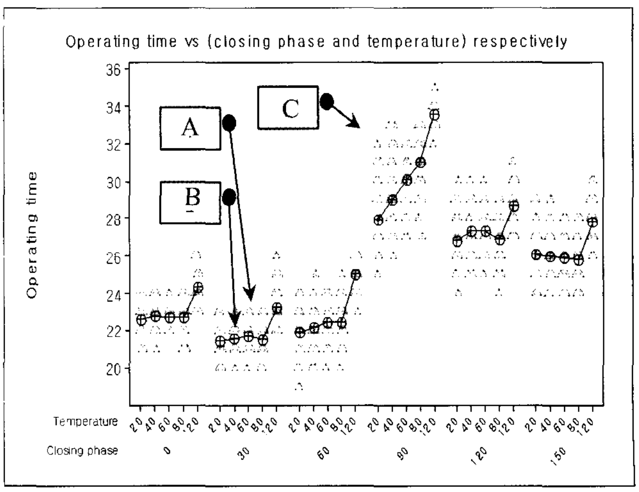


**Fig. 10.** The result of pre-test

In Figure 10, A (120℃/30 degrees) is the area where the value of the coil resistance is increasing so that the operating time is longer than B. B (80℃/30 degrees) is the area where the value of the spring elasticity is decreasing so that the operating time is shorter than A. Finally, C (20~120℃/90 degree) is the area of the smallest starting current so that the operating time becomes shortest. As the result of this experiment, two testing conditions were determined, i.e., use condition of 40 ℃ and an accelerated condition of 80 ℃. The closing phase was not controlled in the field so that it is not considered as an accelerated stress. The accelerated testing levels of voltage are determined according to a previous study [4]. The probability plots of the accelerated life test data are given in Figure 11.

The accelerated factors are derived from the test results. Shape parameter is 2.298, B is 1973.842, and n is 3.902. The results indicate that temperature and voltage are good stresses to reduce the testing period. The acceleration factor is 2.042 for temperature and 2.037 for voltage. The combined acceleration factor is 4.159. Table 3 shows acceleration factors at the various test conditions.

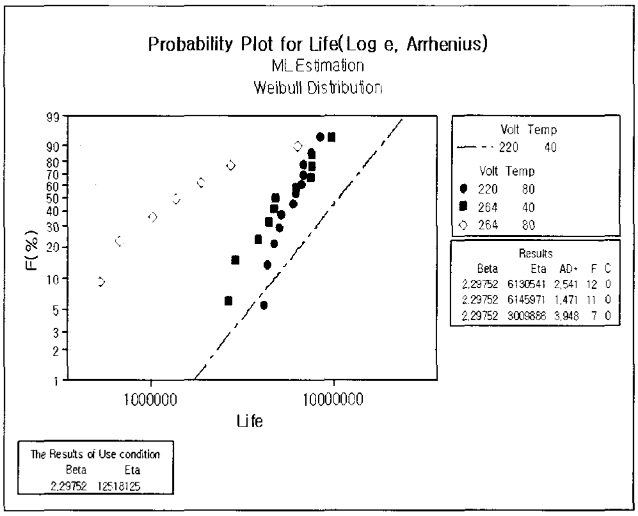


**Fig. 11.** Statistical analysis of test results

**Table 3.** Acceleration factor

| Test condition | Acceleration factor |
|---|---|
| 40 ℃ 220 V | 1.000 |
| 40 ℃ 264 V | 2.037 |
| 80 ℃ 220 V | 2.042 |
| 80 ℃ 264 V | 4.159 |

The combined acceleration factor is derived by the equation

$$AF = e^{\left(\frac{1973.842}{313.76} - \frac{1973.842}{353.76}\right)} * \left(\frac{264}{220}\right)^{3.90179} = 4.159. \quad (9)$$

## 3. Conclusion

The test results in this work show that Weibull distribution is appropriate for representing the life of MCs. An accelerated life test model with IPL and Arrhenius relationships is used to assess the reliability of MCs and acceleration factors are derived using the model. Usually, the life test for MCs takes almost 87 days in the use condition but it will be reduced to approximately 21 days in the accelerated condition.

The three representative failure modes of the MCs observed during the test were fracture of core (see Figure 8), deformation of core (see Figure 9), and fracture of shading coil (see Figure 10). All of the failure modes are associated with the action of repetition through operating.

As Further studies, extra ALT related with same temperature will be conducted in order to acquire more life data so that the testing standard could be established. And then, the failure model will be organized with considering spring, core, and magnetic force.

## Acknowledgements

The authors would like to acknowledge the Power Testing & Technology Institute (PT&T, LS Industrial Systems), Cheongju, Korea, for conducting the tests and for failure investigations.

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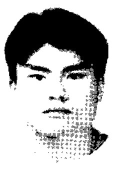

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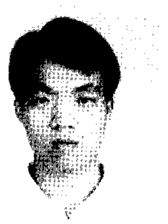

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