Basic Study of Degradation Test for Magnetic Contactors and Reliability Centered Maintenance

Haeng-Soo Ryu†, Gyu-Hwan Han* and Nam-Sik Yoon**

Abstract – The mechanical endurance is the critical characteristic of Magnetic contactors (MCs), which are widely used in such industrial equipments as elevators, cranes, and factory control rooms in order to close and open the control circuit. Testing time, however, is so long in most cases that some method of reducing the testing period is required. Therefore, the degradation test by the detected vibration of MCs is developed to reduce the testing time in this work. The degradation test data are analyzed and the prediction model is provided. Also, the possibility of this technology for Reliability Centered Maintenance (RCM) will be shown. This will reduce the period of the product development and raise the reliability of the equipment in power distribution.

Keywords : Degradation test, LabVIEW, Magnetic contactor, Reliability Centered Maintenance (RCM)

1. Introduction

Magnetic contactors (MCs) are mainly located in the end of the power distribution system, meaning the nearest position of the electrical load. MCs are composed of a magnetic component, a contact point, and some frames to hold them as shown in Fig. 1. The magnetic contactor switches the load 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 the design of a magnetic contactor is defined as the number of no-load operating cycles that would be attained or exceeded by 90% of all the apparatus of the design before it is necessary to repair or replace any mechanical parts. 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 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]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].

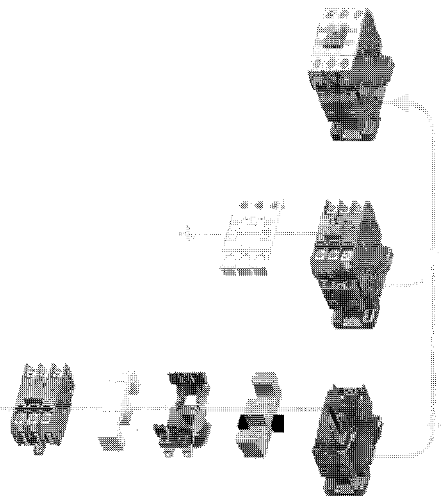


Fig. 1. A schematic diagram of magnetic contactors

In this paper, the design of a degradation test for a magnetic contactor is presented and statistical analyses of the degradation test results are provided. The degradation indices of MCs are vibration and sound. The magnetic contactor used for the degradation 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

† Corresponding Author: LS Industrial Systems, Co., Ltd., Korea (hsryu@lsis.biz)
* LS Industrial Systems, Co., Ltd., Korea
** Dept. of Electrical and Electronic Engineering, Chungbuk National University, Korea
Received 30 January 2007 ; Accepted 8 May 2007

(PLC) is used. Also, it is generally used to control the equipment through using the ladder diagram that is programmed by a test engineer with considering the field condition. In order to measure the vibration and sound of MCs, the NI-4472 (National Instrument) is used with sensors. The types of sensors used are Sensors 352C22 and 130D20 (manufactured by PCB PIEZOTRONICS).

Failure analysis was done to examine the failure mode and is the same between the use condition and the degradation test. The failure mode is the deformation of core. To learn more about that, refer to the related paper. [7]

2. Degradation test of Magnetic contactor

2.1 Degradation test and RCM

The degradation test provides a means to predict the reliability of life of the interest in a cost- and time-effective way. Generally, some performance quantity or a damage index would change over the time of operation; i.e., degradation. When it reaches a certain level (threshold), a failure occurs. Having tracked the degradation path for a while, the reliability can then be predicted by extrapolating the degradation trend to its threshold. It can even be done without observing any failures. However, degradation rates at use condition are usually so low that appreciable degradation might not be observable during tests in a short period of time. To see the degradation trend clearly, the applied load/stress in a test usually needs to be raised to accelerate the degradation process. A statistical physical model is then employed to summarize the test results and predict the reliability at normal use condition.

This degradation test idea has been adopted here to predict the life of MCs within a short period of test duration. However, in the MCs case, degradation index is not well defined. Research has been extensively carried out world-wide in identifying the major MCs mechanical failures. The degradation test approach has been developed and implemented in the Power Testing and Technology Institute to characterize the reliability of MCs cost effectively and time effectively. [3]

From an engineering viewpoint, there are two elements to the management of any physical asset. It must be maintained and from time to time it may also need to be modified. The major dictionaries define maintain *as cause to continue (Oxford) or keep in an existing state (Webster).* This suggests that *maintenance means preserving something.* On the other hand, they agree that to modify something means to change it in some way. Therefore, maintenance is ensuring that physical assets continue to do what their users want them to do and reliability-centered maintenance is a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context. [6]

2.2 Failure Analysis

Effective data analysis depends highly upon an accurate failure analysis. The main failure mechanism for 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 measuring the vibration. During the mechanical durability test, the occurrences of the failures were identified by sound level meter or by the naked ear and the failure modes were validated by inspecting the disassembled samples. In this study, a new approach is applied in order to detect the occurrence of the failure through the measurement of vibration. The failure mode is deformation of core as shown in Fig. 2.

Fig. 2. Deformation of core

2.3 Experiment Set Up

The degradation test was conducted with NI LabVIEW. LabVIEW is a graphical programming language that uses icons instead of lines of text to create application. In contrast to text-based programming languages, where

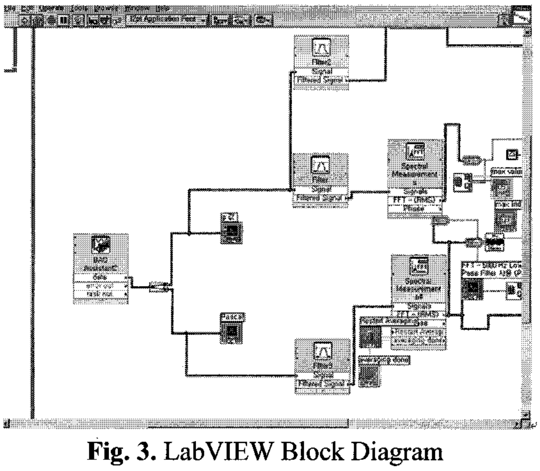


Fig. 3. LabVIEW Block Diagram

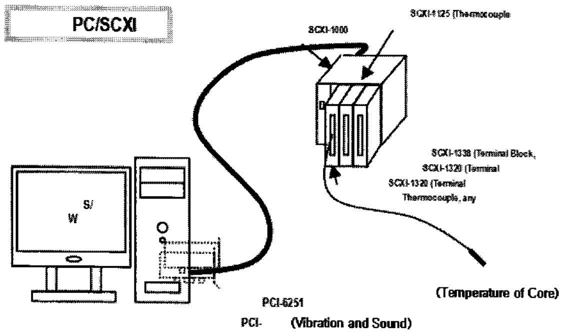


Fig. 4. Construction of the test apparatus

instructions determine program execution, LabVIEW uses dataflow programming, where the flow of data determines execution. The LabVIEW Block Diagram of this study is captured as shown in Fig. 3.

The configuration of the test apparatus is given in the below diagram. It is composed to measure vibration data and to operate the magnetic contactor as shown in Fig. 4. The temperature of the core is measured to consider the effect of an impact.

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 5. 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.

In Fig. 5, A (120℃/30 degrees) is the area where the value of the coil resistance is increasing so that the

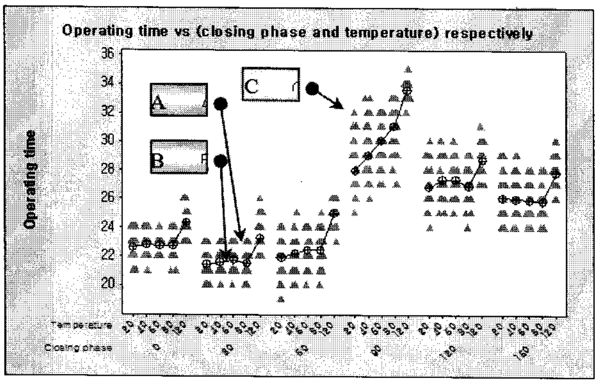


Fig. 5. The result of pre-test

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

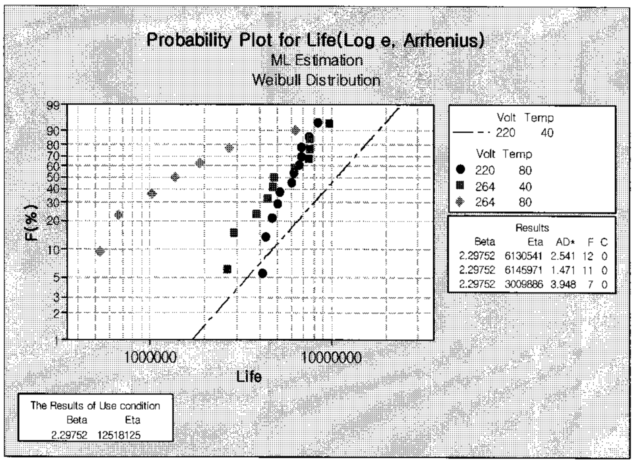


Fig. 6. Statistical analysis of test results

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 Fig. 6.

The accelerated factors are derived from the test results. Shape parameter is 2.298, B is 1973.842, and n is 3.90179. 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.

The combined acceleration factor is derived by the equation

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

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.

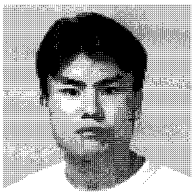
As Further studies, extra ALT related with same temperature will be conducted in order to acquire more life data so that the testing standard could be established. And then, the failure model will be organized with considering spring, core, and magnetic force.

Acknowledgements

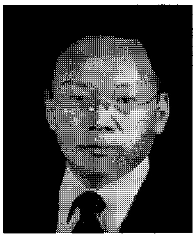
The authors would like to acknowledge the Power Testing & Technology Institute (PT&T, LS Industrial Systems), Cheongju, Korea, for conducting the tests and for failure investigations.

References

[1] Wayne Nelson, "Accelerated Testing-Statistical Models, Test Plans, and Data Analyses, Ed. New York: John Wiley & Sons, 1990, pp. 63–64.
[2] Anderson, Sweeney, Williams, "Modern Business Statistics", Ed, Ohio: South-Western, 2003.
[3] IEC International Standard for Contactors and Motor-starters-Electromechanical Contactors and Motor-starters (Standards style), IEC International Standard 60947-4-1, 2005.
[4] H. S. Ryu, S. Y. Park, G. H. Han, Y. I. Kwon, N. S. Yoon, "To Ensure A Product Reliability The Study on Accelerated Stress Tests for Magnetic Switch Used In Power Distribution System, in Proc. 36 th Summer Annu. Conf. KIEE, Korea, 2005, pp. 377-380.
[5] LabVIEW Manual, National Instrument Corporation, 2006.
[6] John Moubray: Reliability Centered Maintenance, 200 Madison Avenue, NY: INDUSTRIAL PRESS INC, 1997.
[7] H. S. Ryu, S. Y. Park, G. H. Han, Y. I. Kwon, N. S. Yoon, "Design and Analysis of an Accelerated Life Test for Magnetic Contactors", Journal of Electrical Engineering & Technology, vol.2, no.2, pp.188-193, Jun. 2007.



Haeng-Soo Ryu
He received his B.S and M.S degrees in Electrical Engineering with a focus on power system stability and renewable energy sources from the University of Dongguk, Seoul, Korea in 1999 and 2001, respectively. Currently, he is working toward his Ph.D. degree in Electrical Engineering with a focus on the physics of failure and reliability testing at the National University of Chungbuk, Korea.



Gyu-Hwan Han
He received his B.S. degree in Electrical Engineering from Chungbuk National University and his M.S. degree in Industrial Engineering with a focus on reliability prediction and accelerated life testing from the Cheongju University of Korea in 1985 and 2006, respectively. His interests are in the physics of failure and reliability testing.

Nam-Sik Yoon
He received his B.S. degree from Sogang University and his M.S. and Ph.D. degrees in Physics from the Korea Advanced Institute of Science and Technology in 1989, 1992, and 1996, respectively. Since 1999, he has been with the Chungbuk National University of Korea as a Professor in the School of Electrical and Electronic Engineering. His research interests are in modeling and development of new plasma devices, and also, the physics of failure and reliability testing of electrical devices.