# A Study on the Reliability Improvement of oil cooler for precision Machine Tools

Seung Woo Lee* · Hwa Ki Lee**
*Intelligent Machine Systems Research Center, KIMM
**Department of Industrial Engineering, INHA University

# 정밀공작기계용 오일쿨러의 신뢰성 개선 연구

이 승 우* · 이 화 기**
*한국기계연구원 지능기계연구센터 · **인하대학교 산업공학과

## Abstract

신뢰성이란 단기간에 측정되는 성능과는 다른 지표로서 흔히 장기간에 걸쳐 평가되는 품질의 척도이다. Oil Cooler는 공작기계(machine tools)의 주축 및 구동부 등에서 발생하는 열 변형을 제어하는 장치로서 공작기계의 신뢰성 향상을 위해서는 oil cooler의 신뢰성 개선이 이루어져야 한다.

본 연구에서는 oil cooler의 신뢰성 개선을 위해 고장률 데이터베이스를 이용한 신뢰성 예측과 이를 통한 취약부품 분석을 실시하고 신뢰성 시험기를 통한 oil cooler의 신뢰성을 평가하였다. 이를 통해 oil cooler의 정량적 신뢰도를 계산하였으며 신뢰성 향상을 위한 공정기법을 개발하여 적용하였다. Oil cooler의 신뢰성 개선을 통해 공작기계 및 반도체 제조 장비 등과 같은 제조 시스템의 신뢰성 향상을 기대할 수 있으며, 제안된 기법을 이용하여 다른 기계류 부품의 신뢰성 평가 및 개선에 적용할 수 있다.

Keywords : Reliability Prediction, Quantitative Reliability Evaluation, Reliability Improvement, Oil Cooler

## 1. Introduction

Recently, in almost all industries, the implementation of production technologies which incorporate a reliability concept - rather than product design and production on the basis of the conventional, simple concept of safety factors or a margin of error - is required(Saleh and Marais, 2006). In particular, mechanical systems and structure, such as machine tools, function with all the parts linked together. Therefore, the reliability of each part determines the reliability of the entire system(Lee, Song and Lee, 2003 and Kim, Lee, Song and Lee, 2005).

Oil coolers are used to control thermal deformation in machine tools, of which about 70% of the process error is analyzed to be dependent upon thermal deformation(Lee, Song, Park, and et al, 2001). In an oil cooler, the oil absorbs the heat generated in the machine structure, the refrigerant takes the heat from the oil, and the heat is finally cooled by cooling system of the oil cooler. Such a structure makes it difficult to discover internal failures and change the faculty pasts.

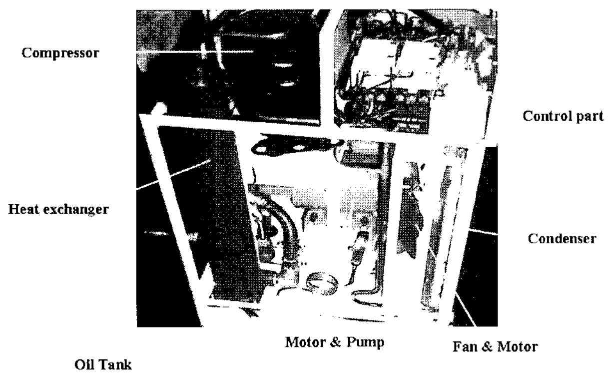
In this study, reliability prediction, reliability testing, and process improvement were implemented of oil coolers, and the results were analyzed.

2007년 5월 접수; 2007년 6월 수정본 접수; 2007년 6월 게재확정

## 2. Reliability Prediction

The objectives of the reliability prediction, in terms of ensuring the reliability of a designed system, are to confirm the reliability of the designed system in its development phase, and to improve its reliability and prevent any damage that may be caused by unexpected accidents. A number of methods, including FMEA, FTA, Worst Case Analysis, failure rate database, test data, etc., are available for reliability prediction. The Failure rate database method was used in this study.

The failure rate database method was used in this study for mechanical parts since their failure rates are subject to a wide obtaining reliability information(RAC, 1977). For the failure rate database of mechanical parts, NPRD95(Non-electric Part Reliability Data 95) which provides failure information on mechanical and non-electric/electronic parts were used, while the EPRD(Electric Part Reliability Data) was used for electric/electronic parts(RAC, 1995 and DOD, 1995). It was presumed that these reference databases follow an exponential range of distribution. In case of proper parts are not found, the method of relative part comparing is used. After calculating the each part's failure rate, RDB(Reliability Block Diagram) with cooling oil and refrigerant flow as its center is composed(MOA Soft Inc., 2002 and Lee and Lee, 2005).




<Figure 1> Structure of Oil Cooler System

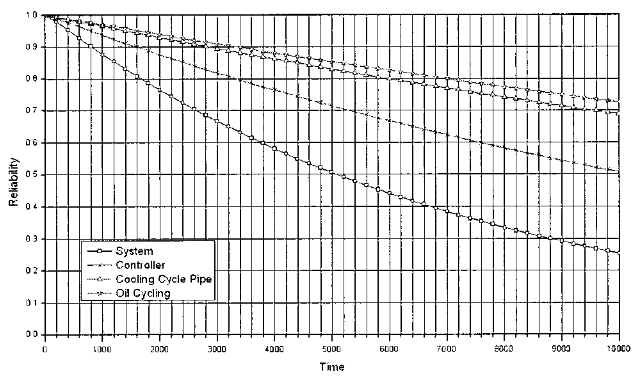
The oil cooler used in this study was a relay on/off-type system with a cooling capacity of 1,000 ㎉/hour. The oil cooler comprised a controller which controls the relay on/off according to the set-up and measured temperature, an oil recycling part which circulates cooling oil through the cooler and heat generating parts of the machine system, cooling recycle pipe which cools down hot oil with a phased transition of the refrigerant. <Figure 1> shows the structure of oil cooler system.

According to the results of the reliability prediction of the oil cooler system, the MTBF(Mean Time Between Failure) was 7,247 hours, the failure rate was 137.477 failures/million hours, and reliability was analyzed to be 0.989822. The prediction condition was duty cycle 100%, operation temperature 30℃, and the operation condition was Ground Begin Controlled. <Table 1> shows the results of the reliability prediction of the oil cooler system and its subsystem. On all the parts of the entire system, the controller is the most liable to failure, accounting for about 50% of all failures.

<Table 1> Reliability prediction results of the oil cooler system and its subsystem

| Classification | Failure rate (failures/million hours) | MTBF (hours) |
|---|---|---|
| Controller | 67.889328 | 14,730 |
| Oil Cycling | 32.182621 | 31,073 |
| Cooling Cycle Pipe | 37.405279 | 26,734 |
| Oil Cooler System | 137.477228 | 7,274 |

<Figure 2> shows the reliability change of the oil cooler over time, showing that the reliability of the controller degrades faster than other parts.




<Figure 2> Reliability change of the oil cooler system over time

# 3. Reliability Test

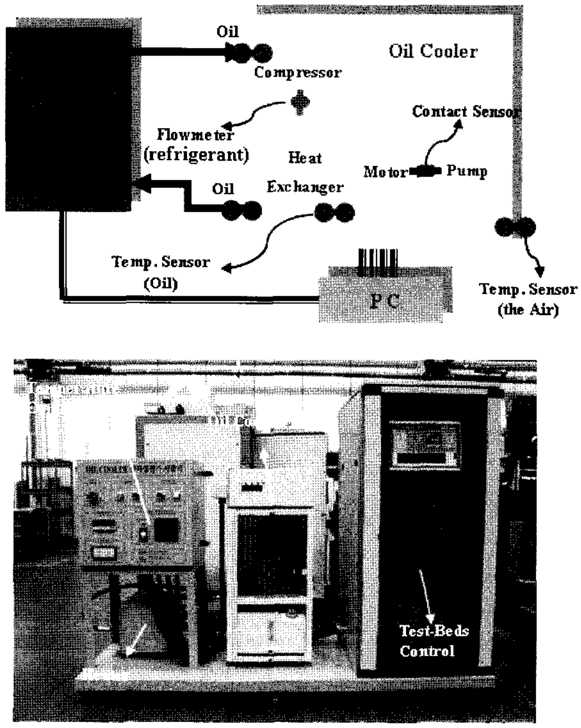
## 3.1 Reliability Tester

Six evaluation items were derived and measured for the quantitative reliability evaluation of the oil cooler system, namely the precision flow temperature measurement, the compressor on/off signal from the controller, the overload in the electric motor and condenser, the refrigerant leakage through a crack in the copper tube, and the flow rate of refrigerant and cooling oil. <Table 2> lists the evaluation item and measurement method for the reliability test of the oil cooler.

<Table 2> Evaluation items and Measurement method used in reliability test for oil cooler

| Evaluated item |
|---|
| - Precision flow temperature<br>- On/Off motion of controller<br>- Detect Motor/Pump connection<br>- Motor & Condenser overload<br>- Refrigerant leakage<br>- Flow rate |
| Method of measurement |
| - Precision temperature sensor<br>- Detects compressor on signal<br>- Contact type(accelerator sensor)<br>- Alarm signal<br>- Pressure gauge(Compressor outlet)<br>- Cumulative cooling oil meter<br>(to calculate cooling capacity) |

<Figure 3> shows the concept and schematic of oil cooler reliability tester. The tester consisted of a heater, temperature controller, and tester controller. Instead of increasing the cooling oil temperature by revolution of the spindle, heater is used to increase oil's temperature. Two types of test method are used; manual and automatic mode. In manual mode, test is performed under certain temperature and heating condition, while in automatic mode various test conditions such as temperature and heating time are set. The tester controller can simulate temperature changes in real machine tools by programming. For safety purpose, the heater power is turned off at 60℃ and is available for remote control.




<Figure 3> Structure of reliability Tester for oil cooler's reliability test

## 3.2 Reliability Test and Results

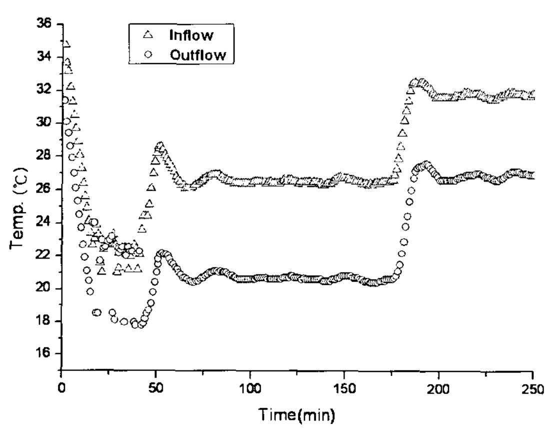
The survey results showed that most oil coolers installed in machine tools are turned on and off at 8 minute intervals. That is, 'on' for 5 minutes(cooling) and 'off' for 3 minutes. The reliability test conditions were set up on the basis of these time intervals and the operation of the machine tools was classified into the 3 phase shown in the <Table 3> in order to carry out the test.

In the first phase, the machine tools is warmed up, at which point the temperature control characteristics of the oil cooler can be mentioned and the heater is then turned off. In the second phase, the spindle is turning but is not actually cutting a workpiece. The heater generates heat 1,000 ㎉/hour, which is same as the rated cooling capacity of the oil cooler. In the final phase, the spindle is rapidly accelerated for actual cutting and the temperature of the oil in the oil cooler rises sharply as a consequence. The entire test cycle takes four hours.

<Table 3> Reliability Test Conditions

<table>
<tr><th colspan="3">Test condition</th></tr>
<tr><th>Phase</th><th>Heat<br>(kcal/hour)</th><th>Time<br>(min)</th></tr>
<tr><td>1</td><td>0</td><td>30</td></tr>
<tr><td colspan="3">· Machine tools is warming up<br>· Operating with heater off<br>· Check cooler's temperature control characteristics<br>· The on/off intervals of the compressor are shortest when tested at room temperature</td></tr>
<tr><td>2</td><td>1000</td><td>120</td></tr>
<tr><td colspan="3">· Continuous heating<br>· Continuous spindle turning<br>· Cutting force is not applied yet</td></tr>
<tr><td>3</td><td>1500<br>~1800</td><td>90</td></tr>
<tr><td colspan="3">· Rapid temperature rise<br>· Rapid spindle accelerate<br>· Cutting force applied</td></tr>
</table>

<Figure 4> shows the temperature change occurring in the inlet and outlet during the reliability test.




<Figure 4> Temperature change of cooling oil over time(Test condition phase)

In the first phase, the cooling oil temperature decreases because the oil cooler is operating while the heater is off. In the second phase, as the oil temperature rises in accordance with the increasing speed of machine spindle that heater is on, it can be seen that the oil, which cooled down to the set-up temperature of the oil cooler, flows out. In the third phase, the cooling oil temperature rises and the set-up temperature cannot be maintained even when the oil cooler is operating at its maximum capacity.

The evaluated cooling capacity reached a maximum of 1,200 ㎉/hour, which satisfies the rated cooling capacity of 1,000 ㎉/hour.

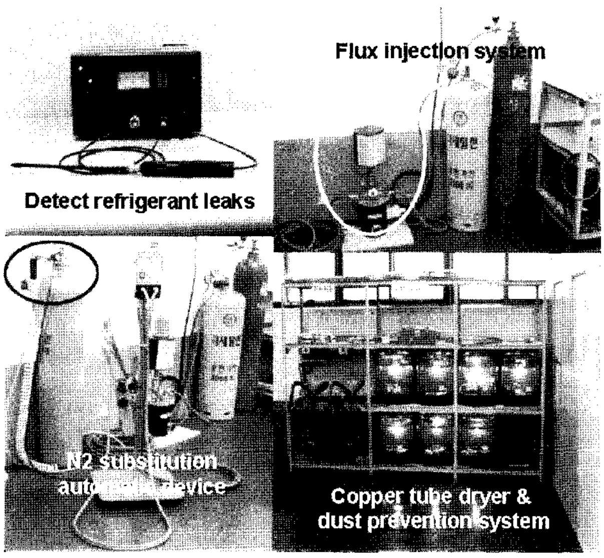
The reliability test was conducted using the developed tester, as shown in <Table 3>. from which two failure modes were obtained. The failure modes occur at the stoppage of oil cooler operation and when the temperature exceeds ±2.0℃ of the control range. The former failure mode occurred during the 6,405th hour at the relay in the controller, while the latter failure mode occurred during 6,650th hours, when a refrigerant leak resulted in inaccurate temperature control.

Data stoppage occurred in 5,200th hour due to the failure of the tester. For the quantitative reliability evaluation, using the collected failure data, the failure distribution function and parameters were derived and suitability of the failure distribution function was judged and selected by $\chi 2$ inspection and Kolmogorov-Smirnov inspection. The failure rate, MTBF, and failure distribution function are the reliability indicators which could be obtained(KSA, 1992). Regarding the calculated quantitative reliability measure, failure distribution was the Weibull, the parameters were analyzed to be eta=6587.228, m=63.918 and MTBF to be 6,528 hours. Since the shape parameter was larger than 1, the failure was judged to have been cause by wear.

## 4. Reliability Improvement

On the basis of the reliability prediction and the analyses of the problem identified in the reliability test, the manufacturing process of the oil cooler could be improved to effect a reliability improvement. Quantitative data including the temperature of each part of the oil cooler and the operational conditions of the parts could be controlled; performance indexes were provided in accordance with the standard specifications such as ISO an in-company for management. In addition, the data obtained through an analysis of the customer service was fed-back in order to use the basic data for performance and reliability improvement.

In order to prevent a refrigerant leak, which is one of the major causes of reliability degradation a copper tube dryer and dust prevention system were installed and operated as shown in <Figure 5>.




<Figure 5> Improving Process for Reliability Improvement

A detection system was operated to detect detection system was operated to detect refrigerant leaks at the refrigerant injection area. Furthermore, in order to prevent copper tupe welding defects, flux was injected during the welding process to clean up the copper tube surface, and an automatic N2 substitution device was constructed for copper tube welding to prevent the generation of weld scale. refrigerant leaks at the refrigerant injection area.

Furthermore, in order to prevent copper tupe welding defects, flux was injected during the welding process to clean up the copper tube surface, and an automatic N2 substitution device was constructed for copper tube welding to prevent the generation of weld scale.

While four on/off relays were used in conventional controller, the design could be improved so that one relay could perform the on/off motion. And the fuse was replaced with a more reliable one for use in a deteriorating environments.

## 5. Conclusion

This paper presents a methodology for the quantitative prediction and evaluation of an oil cooler used in thermal deformation control for precision machine tools, through a reliability prediction and test. With the obtained results, the weak points of the oil coolers in question were identified, and the process could be improved for reliability enhancement. The results are summarized below.

(1) A reliability prediction was conducted on the basis of the reliability data of the oil cooler components and the results were confirmed to be similar to the investigated customer service data.

(2) Failure rate database, such as NPRD95 and EPRD, were used for reliability prediction. The MTBF of the oil cooler was calculated to be 7,247 hours. Through the analysis, it was found that about 50% of the failures occurring in the oil cooler system occurred in the controller. The weak part, that is higher failure rate, in the subsystem were also analyzed.

(3) Using the reliability tester developed to test the reliability of oli coolers, two sets of failure data and one of stoppage data were obtained. The failures were caused by the relay in the controller and the inaccurate control of the temperature arising from a refrigerant leak. Using these data, the failure distribution of the oil cooler was analyzed to be in accordance with the Weibull distribution. The MTBF using reliability test was calculated to be 6,528 hours.

(4) Through this reliability evaluation, methods of reliability improvement were proposed, including the redesign of the controller, the improvement of the welding method used for the refrigerant copper tubing, and the replacement of weak parts and so forth.

## 6. References

[1] Saleh, J.H. and Marais, K., "Reliability: How much is it worth? Beyond its estimation or prediction, the (net) present value of reliability.",

Reliability Engineering and System Safety, 91(2006):665-673.

[2] Lee, S.W., Song, J.Y. and Lee, H.K., "A Study on Reliability Evaluation for core units for Machine Tools.", Journal of Applied Reliability, 3(2003):41-58.

[3] Lee, S.W., Song. J.Y., Park, H.Y. and et al, "Quality Function Deployment of core units for a Reliability Evaluation of Machine Tools.", Proceedings of KSPE(spring), 1(2001):59-62.

[4] Kim, B.S., Lee, S.H., Song, J.Y. and Lee, S.W., "A Study on Failure Mode analysis of Machining Center.", Journal of Korean Society Machine Tools Engineering, 14(2005):15-23.

[5] Lee, S.W. and Lee, H.K., "Reliability Prediction for VDI Turret.", Journal of the Society of Korea Industrial and Systems Engineering, 28(2005):49-54.

[6] MOA Soft Inc., A guide book of reliability prediction, Kyowoosa, 2002.

[7] Reliability Analysis Center, Failure Mode/Mechanical Distribution Document, RAC, 1997.

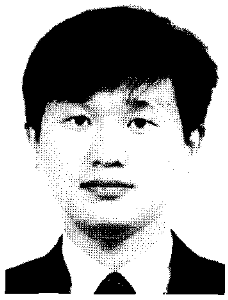
[8] Reliability Analysis Center, Non-electric Part Reliability Data Document, RAC, 1995.

[9] Department of Defense, MIL-HDBK-217F N2 document, DOD, 1995.

[10] Korean Standard Association, Distribution and Statistics of Reliability, KSA, 1992.

## 저 자 소 개

이 승 우



현재 한국기계연구원 지능기계연구센터 선임연구원으로 재직 중. 인하대학교 산업공학과 박사. 관심분야는 생산시스템 모델링 및 분석, 기계류 부품 신뢰성 평가, 전문가시스템, 지능공작기계 임.

주소: 대전시 유성구 장동 171 한국기계연구원 지능기계연구센터

이 화 기

현재 인하대학교 산업공학과 교수로 재직 중. 서울대학교 원자핵공학과 학사, 미 Texas A&M 대학교 산업공학과 석사 및 박사. 관심분야는 생산 분야 및 물류분야의 일정계획, 시뮬레이션 등.

주소: 인천시 남구 용현동 253 인하대학교 기계공학부 산업공학전공