Purdue University
Purdue e-Pubs

International Compressor Engineering Conference

School of Mechanical Engineering

2002

Development Of The Compressor For Miniature Pulse Tube Cryocooler

K. Toyama
Fuji Electric Corp. Ltd.

Y. Yasukawa
Fuji Electric Corp. Ltd.

K. Ohshima
Fuji Electric Corp. Ltd.

T. Kamoshita
Fuji Electric Corp. Ltd.

T. Takeuchi
Fuji Electric Corp. Ltd.

DEVELOPMENT OF THE COMPRESSOR FOR MINIATURE PULSE TUBE CRYOCOOLER

*Kentaro Toyama, E-Mail: toyama-kentaro@fujielectric.co.jp
Yukio Yasukawa, E-Mail: yasukawa-yukio@fujielectric.co.jp
Keishi Ohshima, E-Mail: ohshima-keishi@fujielectric.co.jp
Fuji Electric Corporate Research and Development, Ltd., 1 Fuji-machi Hino-city Tokyo Japan;
Tel.: 81-42-585-6061; Fax: 81-42-585-6205
*Author for Correspondence

Tomoyoshi Kamoshita, E-Mail: kamoshita-tomoyoshi@ fujielectric.co.jp
Takayuki Takeuchi, E-Mail: takeuchi-takayuki@ fujielectric.co.jp
Fuji Electric Co., Ltd., 1 Fuji-machi Hino-city Tokyo Japan
Phone:+81-42-585-6061,Fax:+81-42-585-6205

ABSTRACT

A compressor for a cryocooler demands less vibration, high reliability, miniaturization, and low cost. The piston and the cylinder are arranged to be non-contacts in order to improve reliability in the developed compressor. The moving element including the piston is supported with flexure bearings on one side of this piston, and miniaturization and low cost have been realized. A clearance seal constituted with the piston and the cylinder is maintained by optimizing rigidity of flexure bearings and the distance between flexure bearings. The flexure bearings were designed by using nonlinear structural analysis. The life-time of the compressor was estimated to be more than 50000 hours by this result. Specifications of the compressor are compression capacity of 65W, dia._92mm, 190mm length, 6.5kg weight, efficiency of 65%.

INTRODUCTION

This compressor was developed for use with a small Stirling type pulse tube cryocooler. Because there are no moving parts except for the compressor, a pulse tube cryocooler can obtain less vibration and high reliability. For these reason, pulse tube cryocoolers are expected to be used for commercial and satellite applications. In recent years, the needs of super-conducting devices used in base stations for mobile radio communication have risen. We have developed Stirling cryocoolers for artificial satellites, having a cooling capacity of 1.4W @ 70K and a life-time of more than 50,000 hours. This high reliability expertise has been applied to the pulse tube cryocooler developed at this time. This pulse tube cryocooler has cooling capacity of 2.5W @ 70K, and in-line configuration, and consumption power of 120W. Main specifications are shown in table 1.In addition, a photograph of the pulse tube cryocooler is shown in figure 1, and the cooling capacity of this cryocooler is shown in figure 2. This pulse tube cryocooler was developed for mass production. Accordingly, the compressor for a cryocooler demands less vibration, high reliability, miniaturization, and low cost.

COMPONENTS

A compressor for a cryocooler demands less vibration, high reliability, miniaturization, and low cost. Some devices were added to the compressor structure in order to satisfy these requirements. Structural features of a developed compressor are described below. The structure of this compressor is shown in figure 3.

Piston Arrangement

This compressor has two facing pistons in order to eliminate inertial force and reduce generated vibrations.

Support of Moving Element

The moving element including a spiral part for a current-feeder, a piston and a coil is supported on one side of a piston by two units of flexure bearings. Support of moving element at both sides of a linear motor part has been adopted in conventional compressors. However, assembly of a moving element is easy in the mode that we adopted this time (in which a moving element is supported on one side of a piston) and the dimension in the axial direction of a compressor can be reduced. The moving element produced experimentally is shown in figure 4.

Flexure Bearings

Oxford type geometry is used for the flexure bearings. Each flexure bearings unit is composed of a couple of spiral flexure parts. Two flexure bearings are used per piston, and these flexure bearings are mounted on the piston, on the side opposite the piston face. A titanium-copper alloy, for which blanking is easy to perform, is used for the flexure bearings. In addition, the same titanium-copper alloy is used in the spiral part for a current-feeder. The flexure bearings were designed on the basis of fatigue characteristics of titanium-copper alloy shown in figure 5.

Clearance Seal

The piston is inserted in a cylinder with a gap of 30-50 micrometers, and it is maintained by flexure bearings. A piston and cylinder have a structure that does not come in contact due to the rigidity of flexure bearings in the radial direction. In addition, this compressor is miniaturized, by using the yoke of a linear motor as a cylinder.

Pressure Vessel

To reduce the size and weight of a compressor, a yoke of a linear motor is used as a pressure vessel. The yoke and pressure vessels (a flat head) are welded at both sides, and this welding completely penetrates the joint for improved reliability.

Other Components

To achieve low cost, components of this compressor are produced with processes such as blanking or injection molding. In addition, materials having low levels of out gas were used in the components, so that the helium gas refrigerant would not be contaminated.

RELIABILITY

In a compressor of a pulse tube cryocooler, the factors affecting the life and reliability are fatigue of flexure bearings, contamination of helium gas and external leaks. Therefore, we performed reliability assessment with regard to these factors.

Reliability of Flexure Bearings

Reliability in this compressor is influenced by the flexure bearings and the spiral part for a current-feeder. Non-linear structural analysis (that considered large deformation and stress stiffness) by the finite element method (FEM) was used for this fatigue design. We also carried out a comparison of analysis results with measurements of the manufactured flexure bearings model. A stress analysis example of flexure bearings by FEM is shown in figure 6. In addition, measured value was compared with analytic value of spring property. The result is shown in figure 8. Agreement between the measured values and analysis results was within a deviation error 8%. Accordingly, we understood that the design of flexure bearings was possible by using nonlinear structural analysis. Titanium-copper alloy having a high fatigue limit was used for the flexure bearings and spiral part for a current-feeder. Safety factor for the fatigue limit of titanium-copper alloy (cf. figure 5) is the same as that of a cryocooler developed for satellite applications. As for the spiral part for a current-feeder, since a larger factor of safety is adopted than for flexure bearings, reliability must be improved further. The moving element, including a spiral part for a current-feeder, a piston and, a coil, is supported on one side of a piston by two units of flexure bearings. If rigidity of the flexure bearings is weak, deflection of the piston becomes large, and the piston will touch the cylinder. The deflection of a piston was designed using nonlinear structural analysis so that reliability deteriorated due to this contact. An example is shown in figure 8. Furthermore, resonance will cause a piston to touch a cylinder when the natural frequency of a moving element is close to the operating frequency. Therefore, modal analysis of a moving element was also performed. The results are compared to measured values in table 2. In addition, the result of measured deflection of a piston is shown in figure 9. The x-axis is the number of cycles, and the y-axis is the percentage of a measured value for a specific piston deflection. The piston deflection of an engineering model developed this time satisfied the design specifications, and a piston and a cylinder were able to be sealed with a non-contact arrangement and with a minute differential gap. Performance tests were repeat 10^9 times, and the deflection of a piston did not change after this test. This test is currently ongoing.

Reliability of Refrigerant

Cooling capacity decreases when the helium gas refrigerant of this cryocooler becomes contaminated. There are 12 kinds of parts that contribute to contamination of the helium gas in a compressor. Thus, we examined the relationship between pollution level and cooling capacity. The combination of materials, cleaning approach, and outgassing condition were changed, contaminated gas was made, and an acceleration test that applied a theorem of Arrhenius was performed. Base on those results, the relationship between environment temperature and generation of contaminated gas was understood. In addition, test using this contaminated gas, clarified the relation between gas pollution level and cooling capacity. The relationship between gas pollution level and cooling capacity is shown in figure 10. The y-axis is the ratio of the cooling capacity when having used a contaminated refrigerant. If the contamination level of helium gas becomes large, the cooling capacity deteriorates. Therefore, we chose the component materials, cleaning approach, and outgassing condition such that the drop in cooling capacity did not exceed10%.

Reliability of Outside Leak

In a seal preventing outside leakage of the helium gas refrigerant of a cryocooler, there is a flange bonded part (separable parts for simplicity and easiness of assembling and adjusting) and a permanently bonded part. The metal seal that used soft metal with the results with a conventional cryocooler was used in the flange bonded part, and an electron beam welding method was utilized at the permanent bonded part, thereby improving reliability.

LOW COST

It is important that the cryocooler be low cost for mass production. Because the compressor is the most expensive part of the cryocooler, improvement of a compressor became necessary. Therefore several measures were applied to the developed compressor. The main measures are listed below. As the result, a low cost compressor was successfully developed.

1) Application of blanking to flexure bearings, and spiral part for a current-feeder.
2) Injection molding of bobbin with a resin
3) Unidirectional assembly of a moving element
4) Dual-use of cylinder with yoke.
5) Dual-use of pressure vessel with yoke

CONCLUSIONS

A compressor having small size, low cost and high reliability was successfully developed for a pulse tube cryocooler. The specifications of the compressor are compression capacity of 65W, 92mm outer diameter, 190mm length, 6.5kg weight, efficiency of 65%, and a life-time not less than 50,000 hours. Main specifications of the compressor are shown in table 3. By improving motor efficiency, and reducing eddy current loss, we will miniaturize the compressor in the future.

ACKNOWLEDGEMENTS

The authors wish to sincerely thank all members who participated in development of this cryocooler.

REFERENCES

Futoshi Fujinami, "Development Trend of Micro Cryocooler", cryogenic engineering, Vol.30 1995

Yukio Yasukawa, "Development of Miniature Pulse Tube Cryocooler", cryogenic engineering, 2001

(Figures and Tables)

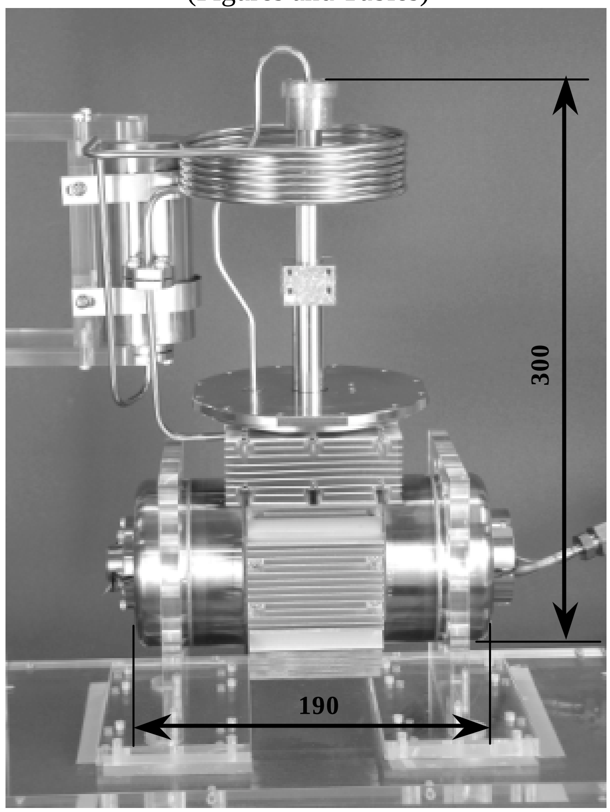

Figure 1: Prototype of the Miniature Pulse Tube Cryocooler.

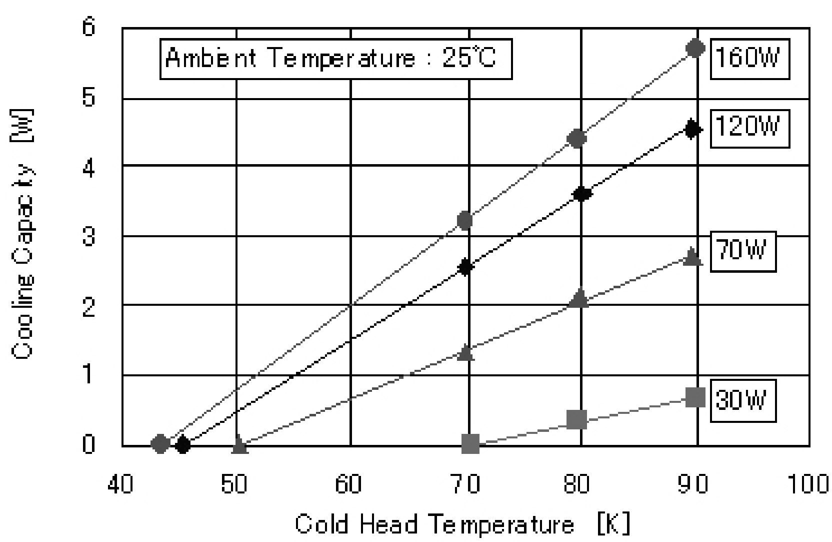

Figure 2: Load Lines for the Miniature Pulse Tube Cryocooler.

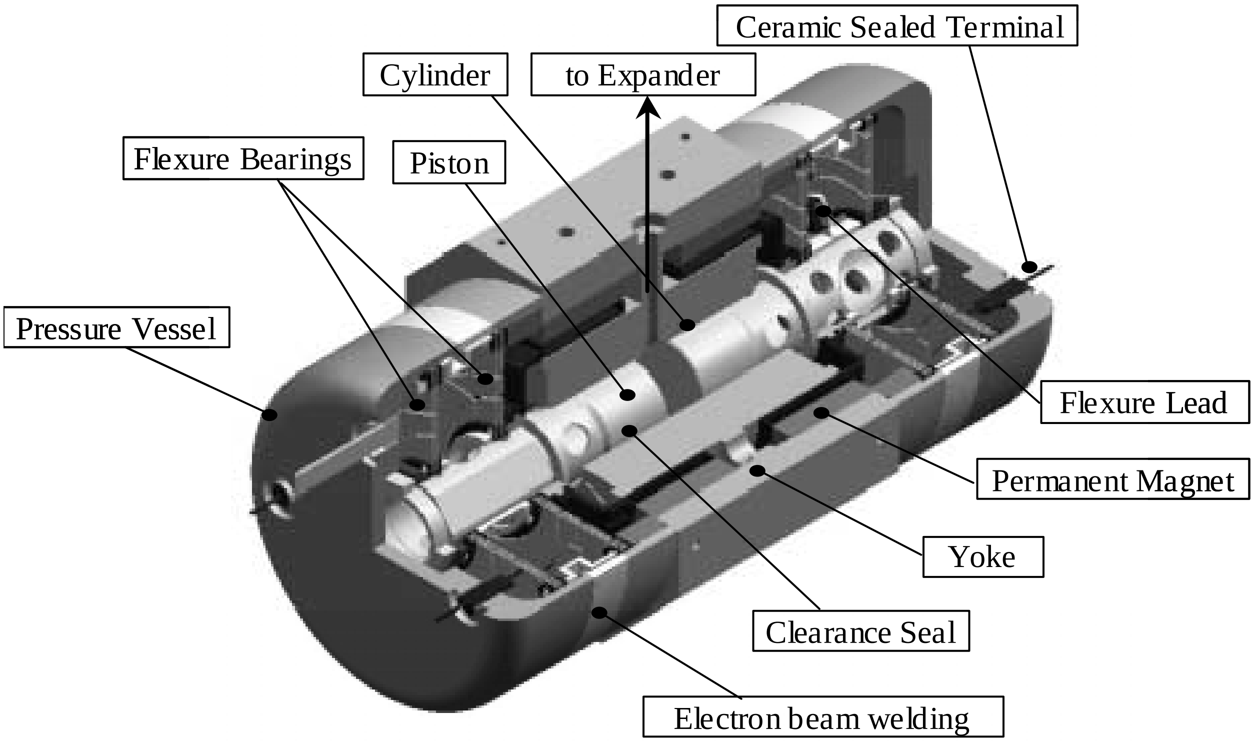

Figure 3: Structure of Compressor.

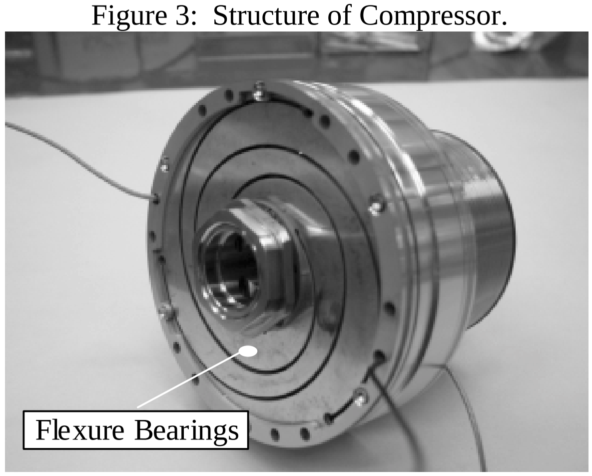

Figure 4: Flexure Bearings.

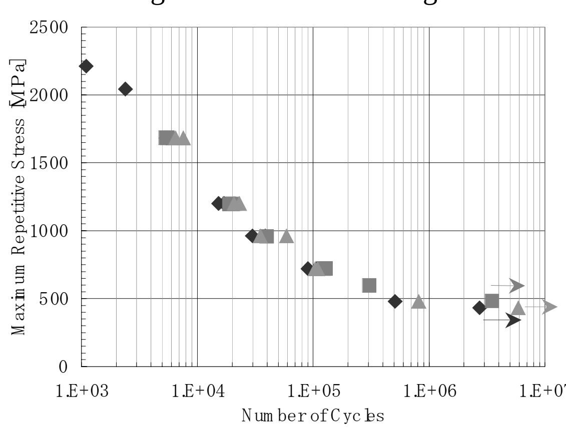

Figure 5: Life Curve of Titanium-Copper Alloy.

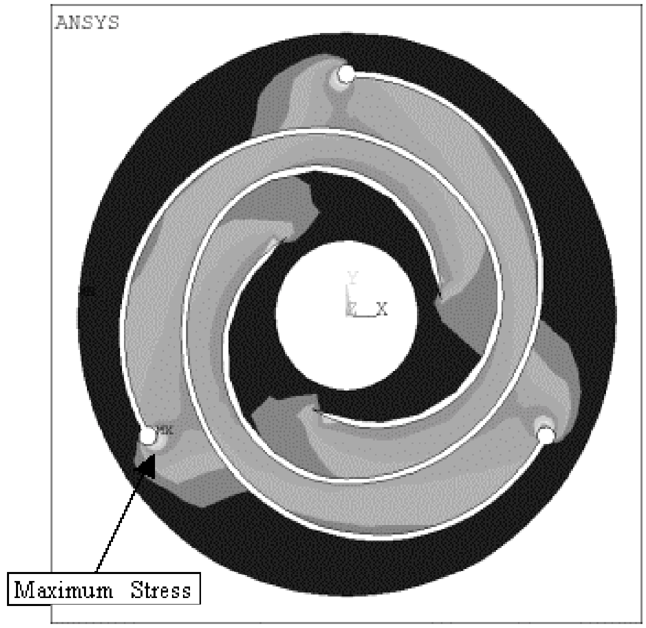

Figure 6: Stress Analysis of Flexure Bearing.

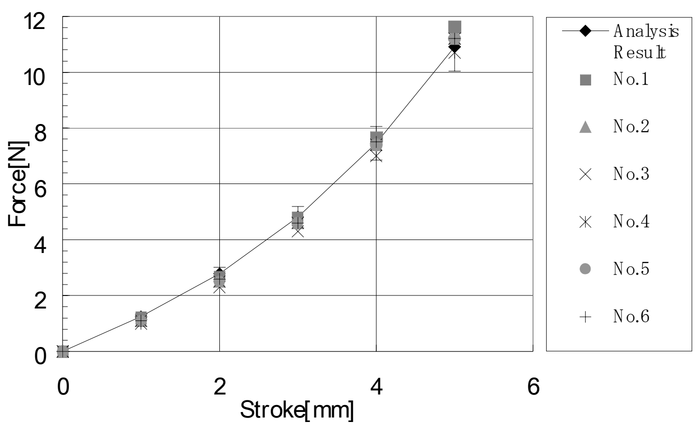

Figure 7: Spring Curve of Flexure Bearing.

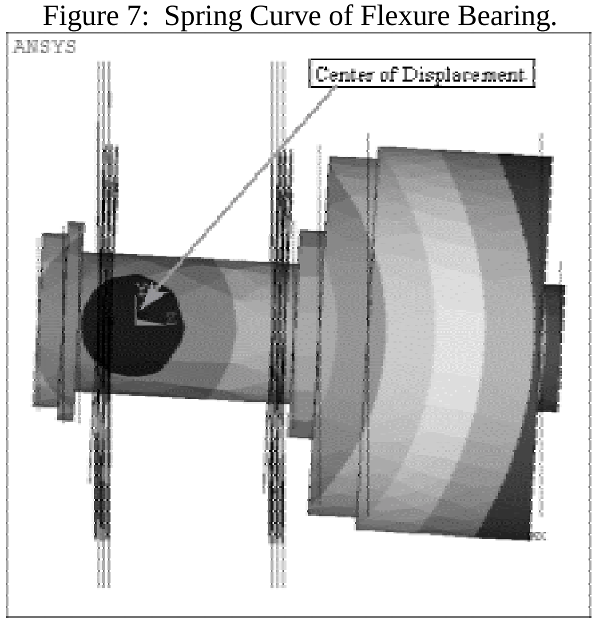

Figure 8: Displacement Analysis of Moving Elements.

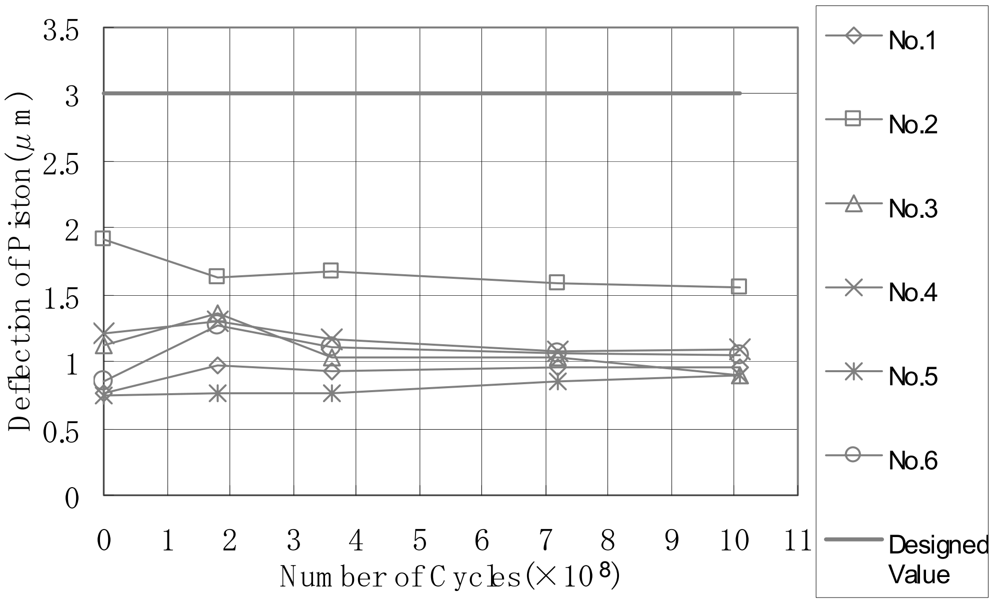

Figure 9: Measure of Piston Deflection.

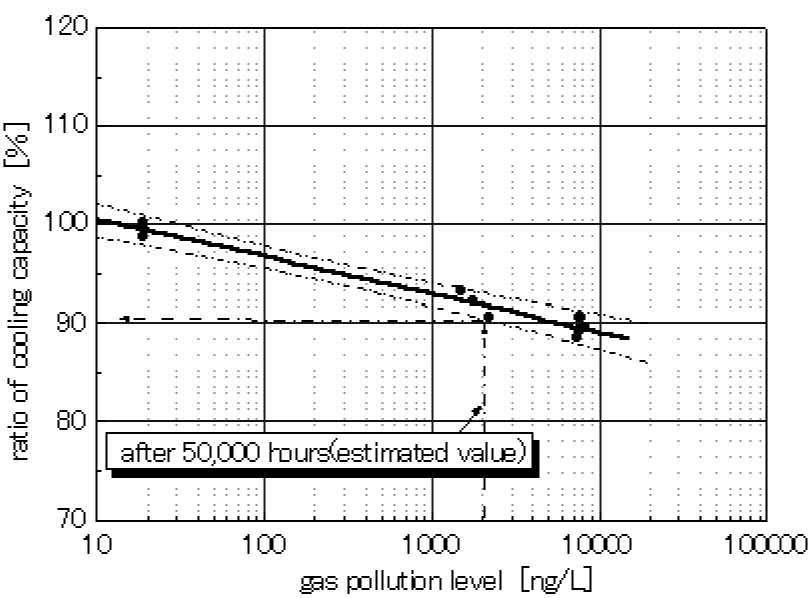

Figure 10: Gas Pollution Level and the Cooling Capacity

Table 1: Specifications of Miniature Pulse Tube Cryocooler.

Cooling Capacity	2.5W at 70K
Electrical Input Power	120W
Operating Frequency	50Hz
Ambient Temperature	25℃
Weight	8.5kg

Table 2: Result of Modal Analysis.

Mode	Analysis Value	Measurements
1	19.4Hz	16.5Hz
2	138.3Hz	104.8Hz
3	140.4Hz	123Hz

Table 3: Specifications of the Compressor.

Compression work	65W
Electrical Input Power	120W
Operating Frequency	50Hz
Life Time	50,000h
Dimensions	Dia.92*L190mm
Weight	6.5kg
Motor Efficiency	65%