# HIGH-TEMPERATURE BLOWER FOR MOLTEN CARBONATE FUEL CELL SUPPORTED BY MAGNETIC BEARINGS

**Masaru Ohsawa,[1] Kazutaka Yoshida,[2] Hiroshi Ninomiya,[3] Tai Furuya,[1] Eishi Marui[1]**

## ABSTRACT

The high-efficiency Molten Carbonate Fuel Cell is a next-generation, clean power source. One critical requirement of this power source is that it needs a high-temperature blower capable of recycling 700℃ cathode gas. The blower should be oil-free and have an extended life cycle. We have developed a high-temperature blower, supported by magnetic bearings, which fulfills this requirement. The rotor mass of the blower is 80 kg and the designated speed of the rotor is 12000 $min^{-1}$. We carried out a 1500-hour continuous rotation test of a 500 kW MCFC test apparatus. The system was operational even when the temperature of the magnetic bearing reached to about 400℃.

## INTRODUCTION

Magnetic bearings are non-contact thus allowing a rotor to have higher rotation speed and minimized energy loss. Rotation machinery supported by magnetic bearings can not only be made smaller and have longer service life, but also feature better preventive maintenance and no friction-related mechanical damage. Magnetic bearings realize rotation machinery that need no lube-oil. The setback is that the magnetic bearings have poor magnetic properties under very high temperatures (near the Curie-point of the materials or over the oxidized temperature of wire materials). Therefore, magnetic bearings should be used under reasonable temperatures (up to about 400℃).

Meanwhile, the high-efficiency Molten Carbonate Fuel Cell (MCFC) is looked forward to as a clean power source for the next-generation. The R&D of MCFC has currently been carried

[1]Ebara Research Co., Ltd., 4-2-1 Honfujisawa, Fujisawa 251, Japan, phone: 81-466-83-7644, fax: 81-466-82-9371, e-mail: ohsawa 04539@erc.ebara.co.jp.
[2]Ebara Corporation, 11-1 Asahi-cyou, Haneda, Ootaku 144, Japan.
[3]Ebara Densan Co., Ltd., 4-2-1 Honfujisawa, Fujisawa 251, Japan.

out as part of Japan MITI's (Ministry of International Trade and Industry ) New Sunshine Project.The New Energy and Industrial Technology Development Organization (NEDO) has been carrying out the MCFC project in order to develop a 1000 kW class pilot plant by 1999.

The molten carbonate fuel cell (MCFC) is a direct current generating system, the electricity being generated during water production by a chemical reaction between hydrogen and oxygen. The MCFC power generation system is constructed of four subsystems : 1) Fuel processing subsystem , 2) Stack peripheral subsystem , 3) Heat recovery subsystem, and 4) System control subsystem.

In the stack peripheral subsystem, a high-temperature blower recycles 700℃ cathode gas, from the cathode outlet to the cathode inlet, to keep the working temperature of the fuel cell at optimum levels. The basic conceptual objectives in the development of this blower are: 1) High efficiency, 2) Compactness, and 3) Improved maintenance capabilities.

The high-temperature blower we developed is supported by magnetic bearings. The structural concept is based on an overhanging type, single-stage centrifugal blower whereby the impeller is attached directly on the shaft-end of a high-speed motor supported by magnetic bearings. The R&D for a blower with the above structural requirements was carried out under the following four objectives : 1) Selecting the material for the blower, 2) Selecting the electrical material, 3) Developing a magnetic bearing, and 4) Developing an exclusive cooling technique.

We conducted tests, including simulation tests, on the above using element testing equipment. After verifying element techniques, we constructed a high-temperature blower for a 500 kW MCFC experimental apparatus and carried out a 1500-hour continuous rotation test of the blower using high-temperature gas.

After the continuous rotation test, we constructed high-temperature blowers for an actual 1000 kW MCFC plant, scheduled to be operated in 1999.

This paper presents the test results of the element test of magnetic bearings and the test of the magnetic-bearing-supported, high-temperature blower the 500 kW MCFC test apparatus.

## HIGH-TEMPERATURE BLOWER OUTLINE

### BLOWER SPECIFICATIONS

| | | |
|---|---|---|
| Type of blower: | An overhung single-stage, horizontal centrifugal blower | |
| Gas composition: | cathode outlet gas (vol. %) | |
| | $O_2$ : | 7.7 |
| | $N_2$ : | 73.8 |

$CO_2$ : 6.2
$H_2O$ : 12.3
Suction pressure / Discharge pressure : 1.90 / 2.10 kg/cm$^2$G
Total adiabatic efficiency : ≧75 %
Flow rate : 3893 kg/h
Rotating speed : 12000 min$^{-1}$
Rated motor power : 37 kW
Gas temperature of impeller inlet : 700℃
Diameter of impeller : 315 mm
Allowable maximum temperature in motor and magnetic bearings : $<$400℃

## STRUCTURAL FEATURES

Figure 1 illustrates the cross-sectional structure of the high-temperature blower for the 500 kW MCFC experimental apparatus. A five-axis control-type magnetic bearing system is used and includes radial magnetic bearings at the left and right sides of the motor rotor, and a thrust bearing at the end of the shaft. The impeller is attached directly on the shaft-end, opposite the thrust bearing side. Touchdown bearings are arranged adjacent to the magnetic bearings for protection. A labyrinth seal is employed between the impeller and impeller-side radial magnetic bearing. This seal and compressed air prevented leakage of cathode gas from the impeller casing into the magnetic bearing and motor sections, thus preventing corrosion by cathode gas. The compressed air also cooled the motor and the magnetic bearings. The casing was made from non-magnetic materials. The expansion coefficient of non-magnetic material was larger than that of magnetic materials. Springs were set between the casing and the magnet bearing stator body, to adapt to longitudinal by temperature differences (normal & high).

## NATURAL FREQUENCIES

We measured the natural frequencies (free-free) of the rotor. The first bending natural frequency was 335 Hz, the second frequency was 720 Hz, and the third and the fourth were 1135 Hz and 1490 Hz. The modes of the first and second bending natural frequencies are shown in Figure 2. The shaft-ends tend to vibrate in modes first and second. Simulation test results of natural frequencies of the rotating rotor are shown in Figure 3. The rated rotating speed was designed as 12000 min$^{-1}$; therefore, the blower was rotated as rigid rotor.

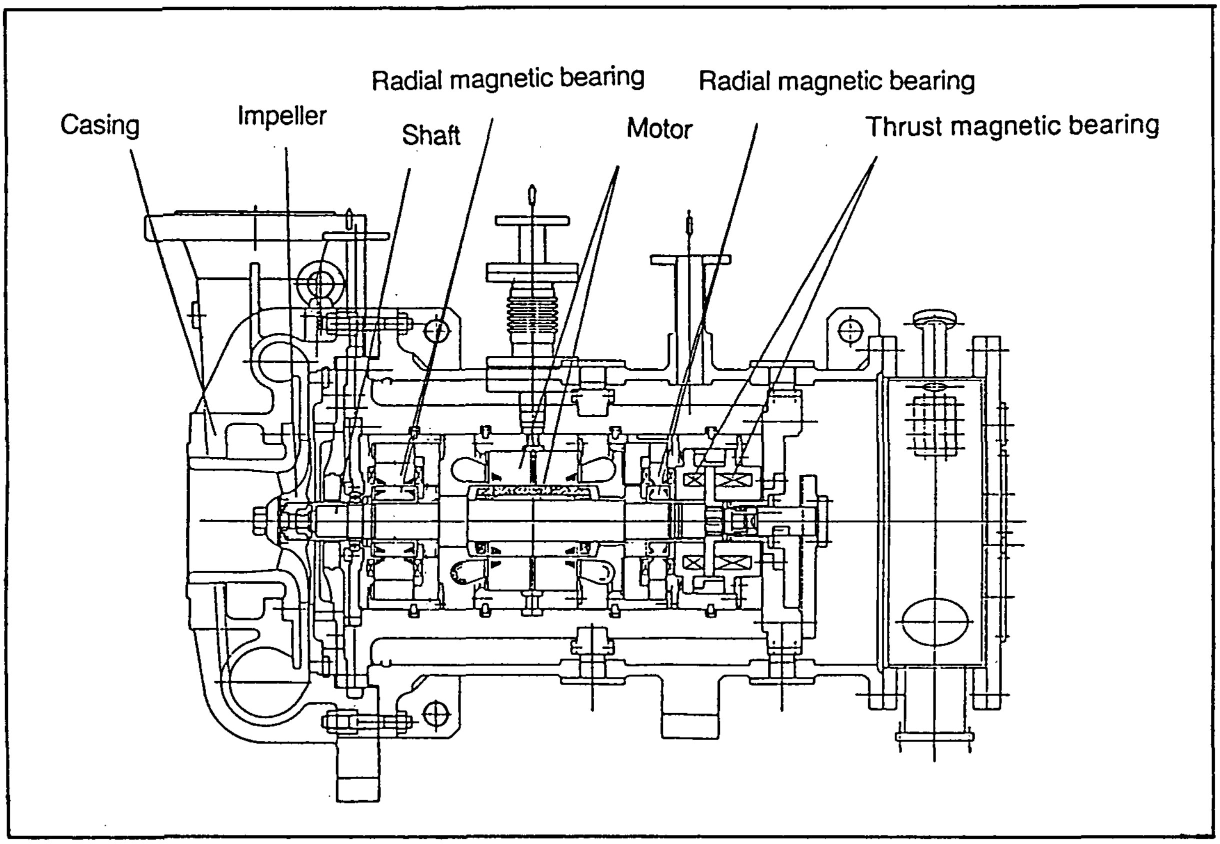


Figure 1 High temperature blower assembly

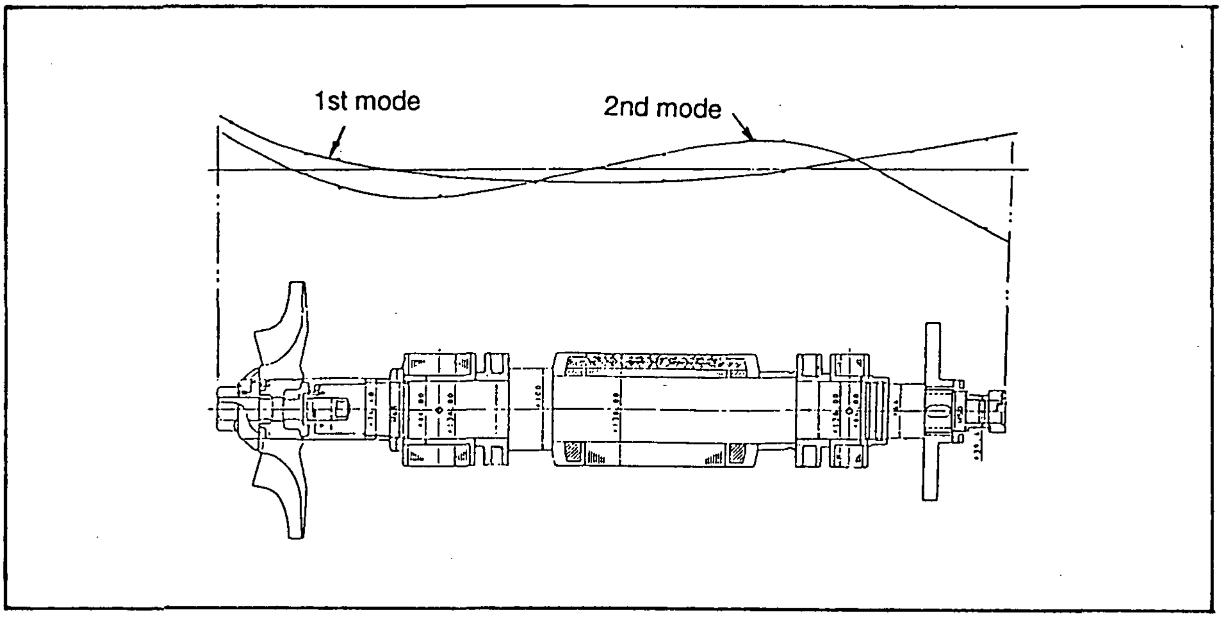


Figure 2 Natural mode of the rotor

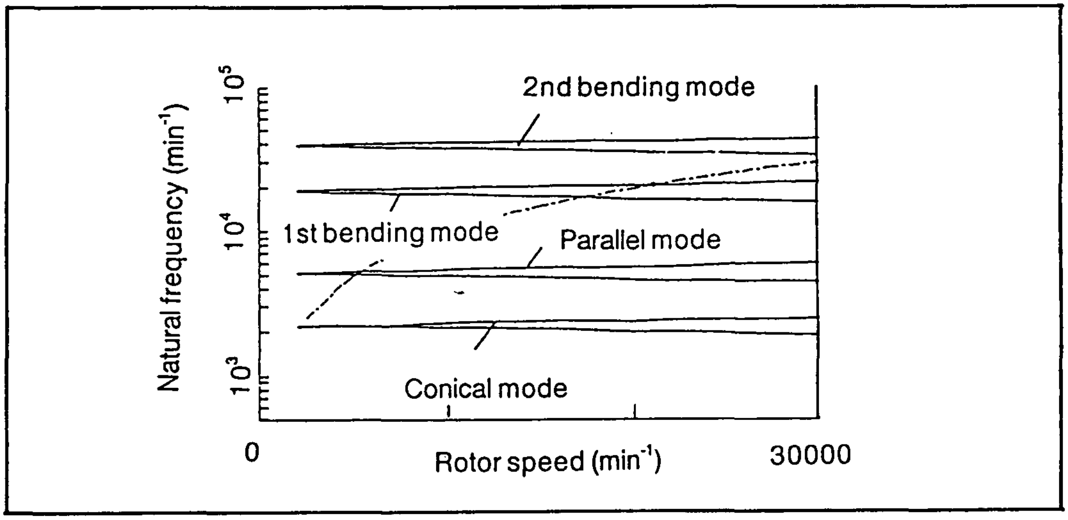


Figure 3 Natural frequency of rotating rotor

## MATERIAL CHARACTERISTICS

We assessed the magnetization characteristics of several magnetic materials, as well as insulation resistance characteristics of some wire materials, for radial and thrust magnetic bearings and sensors. The A-C magnetization curves of typical electric steel for radial and thrust magnetic bearings at 400℃ temperature are nearly equal to those at room temperature. As the Curie-point temperatures of the materials for radial and thrust magnetic bearings are higher than 600℃, no thermal-caused problems are expected if the designed maximum temperature in motor and magnetic bearings is 400℃. However, as the Curie-point temperature of the applied thrust sensor target material was about 350℃, we had to the thrust sensor target material to keep its temperature lower than that of the radial bearing.

Copper wire material for magnetic bearings and sensors becomes easily oxidized in temperature ranges above 300℃. We used A-type nickel-plated, inorganic coated copper wire (see Figure 4) as nickel plating protects copper from becoming oxidized, up to a temperature of about 400℃. Inorganic coating, unlike organic coating, provides sufficient insulation resistance characteristics in high temperature ranges (see Figure 4). Another feature of the A-type wire is that it is harden by heating. Although stainless-steel-plated, inorganic coated copper wire could also be used for magnetic bearings in temperature ranges above 400℃, forming coil from stainless-steel-plated wire is not easy and this type of wire is very costly.

The touchdown bearing is constructed from ceramic balls and stainless-steel-race. It requires $MoS_2$ for lubrication. However, as $MoS_2$ becomes oxidized at temperatures of about 400℃, we set the allowable maximum temperature of the high-temperature blower for the 500 kW MCFC experimental apparatus as about 400℃.We also designed each temperature range to be kept at adequate levels by air cooling. Results of simulation tests on temperature distribution and element test were put to use here.

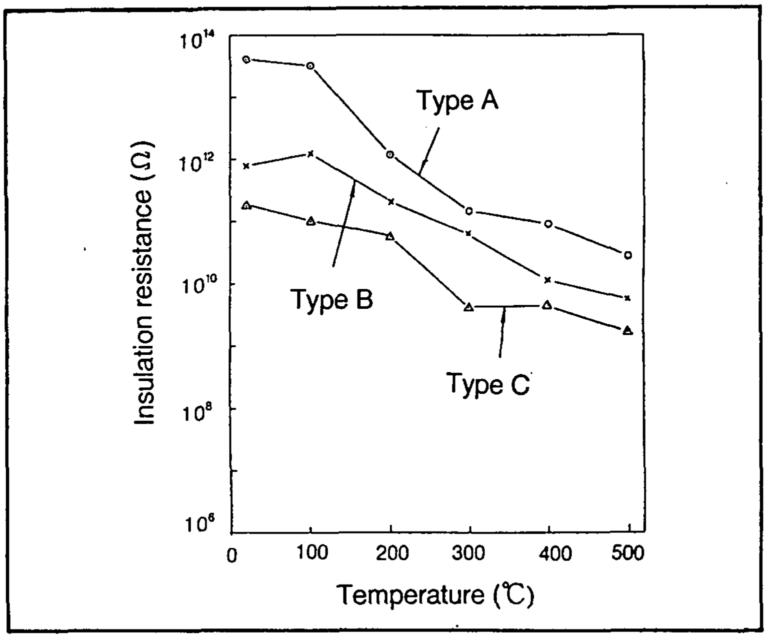


Figure 4 Insulation resistance characteristics of wire material

## MAGNETIC BEARINGS

The magnetic bearing system (five-axis control-type) used in this blower could detect relative displacement between the rotor and stator, control the five degrees of freedom by use of electromagnets, and support the rotor in a non-contact state. The specifications and components of the magnetic bearings for the blower used in the MCFC operating test are as the following.

Each magnetic bearing consists of the following components:

1) A body for the magnetic bearing and relative displacement sensor,

2) A sensor amplifier, 3) A phase-compensating circuit unit, and 4) A servo amplifier.

The sensor was an inductive type. The sensor amplifier was placed adjacent the blower. A system was used in which V/A and A/V conversion of the sensor output signal could be performed serially by the sensor amplifier and compensatory circuit respectively. The servo amplifier was a PWM type with a voltage of 150V.

The mass of the rotor was 80 kg, while the estimated static hydraulic thrust force was approximately 1300N. The radial clearance of the radial bearing was 0.6 mm and the thrust clearance of the thrust bearing was 0.7 mm under room temperature.

## TEST RESULTS

### TOUCH DOWN TESTS

A touchdown test was performed, prior to the construction of the high-temperature blower for the 500 kW MCFC experimental apparatus, to check the reliability of the touch down bearings. A test apparatus was used which had almost the same shape and dimensions as the high-temperature blower for the 500 kW MCFC experimental apparatus. A dummy disk was used instead of the impeller and the magnetic bearings were heated up to about 400℃ by heaters.

Figure 5 shows the loci of the rotor whirl when the rotor was touched down on the touch down bearings (rated speed of 12000 $min^{-1}$ and temperature of 350℃). Vibration became relative greater at about 3000$min^{-1}$. The reliability of the touch down bearings were verified through several touch down tests.

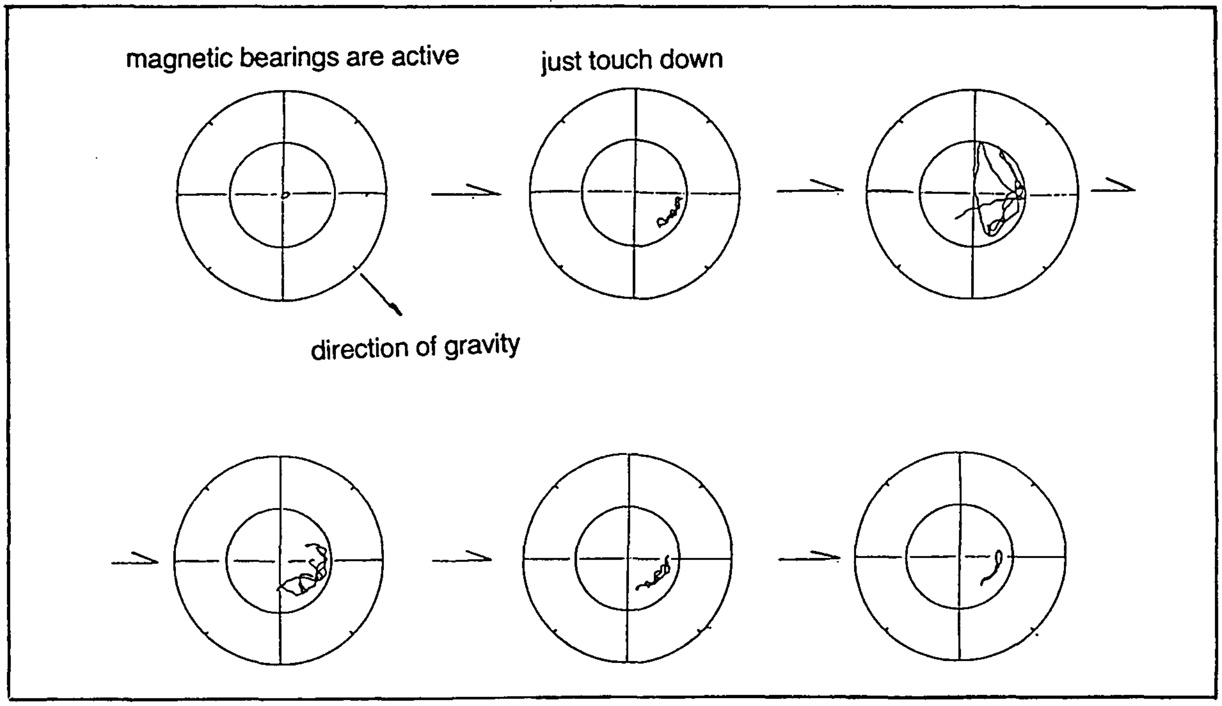


Figure 5 Loci of the rotor whirl during touch down test

### BLOWER PERFORMANCE FACTORY-TEST

Blower performance factory tests were carried out for the 500 kW MCFC experimental apparatus to check the stability of the magnetic bearing system and blower performance in normal and high temperature. The test blower was a gas circulating, closed loop type with a heating section. A heater was used to heat up the gas at the blower inlet to 700℃. Excess heat from the motor heat was used as well. The temperature of the impeller-side, radial magnetic bearing was about 400℃, while that of the thrust-side, main thrust bearing stator body was about 300℃.

The natural frequency of the bending mode in high temperature ranges was estimated to be lower than that under normal temperature. Figure 6 shows the transfer functions of the compensation circuit. We used three narrow-wide-frequency-band-phase-lead compensations, each tuned to each bending mode natural frequency for damping effects.

Figure 7 shows the open loop characteristics of the impeller-side radial magnetic bearing. These were measured in a levitated state. In order to stabilize the magnetic bearings, they were provided with ample gain and phase margins for the open loop transfer function. Measurement

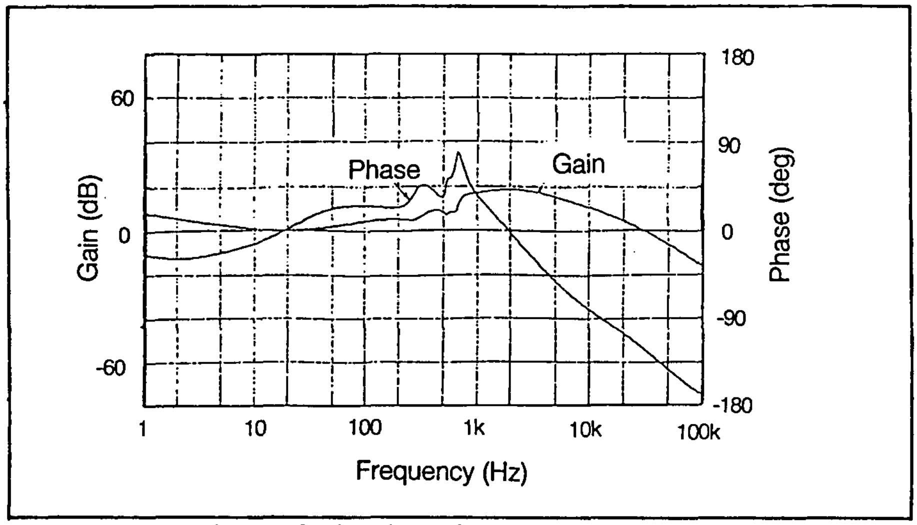


Figure 6 Transfer functions of the compensation circut

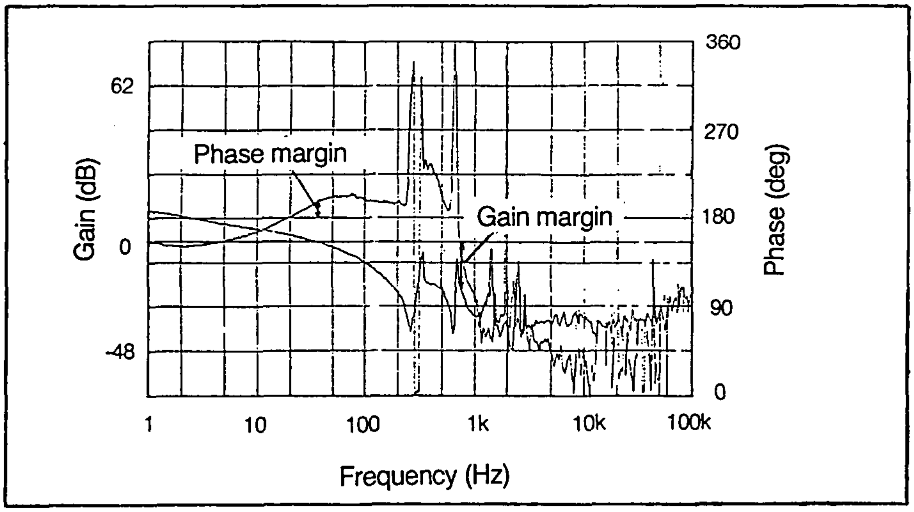


Figure 7 Open loop characteristics

results indicated that this system was stable. The same indications were obtained for the other bearings.

Figure 8 shows vibration frequency spectra of the impeller-side radial sensor, measured when the speed of rotation increased to 12000 $min^{-1}$. The maximum whirl of the rotor was 30 $\mu$ mp-p, smaller than the clearance of the touch down bearing.

We measured the blower performance for high temperature operated gas. The total adiabatic efficiency was 80%, higher than the designed efficiency. The blower performance was determined as satisfactory .

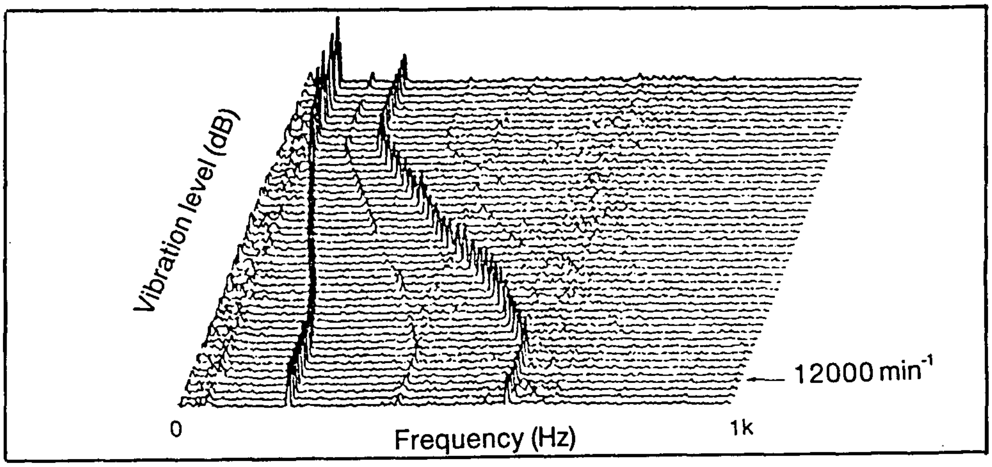


Figure 8 Vibration of the impeller side radial sensor

## CONTINUOUS ROTATION TEST USING THE MCFC EXPERIMENTAL APPARATUS

Following the factory test, we carried out a 1500-hour continuous rotation test using the 500 kW MCFC experimental apparatus. There were no problems encountered during this continuous rotation test. Figures 9 and 10 show the vibration of the rotor, at the rated flow point and in the surging flow rate, respectively. The magnetic bearing system was stable even when the blower was operated under a surging flow. No touch-down due to unstable of magnetic bearings occurred during the continuous rotation test.

## CONCLUSION

Tests were conducted using a high temperature blower, featuring a five-axis control type magnetic bearing system, in which actual high temperature gas was handled. The tested magnetic bearings and their displacement sensor were found to operate satisfactorily without problems, even at temperatures of up to about 400℃. Furthermore, the operation of the tested magnetic bearings was found to be stable, despite the static hydraulic thrust force and the low

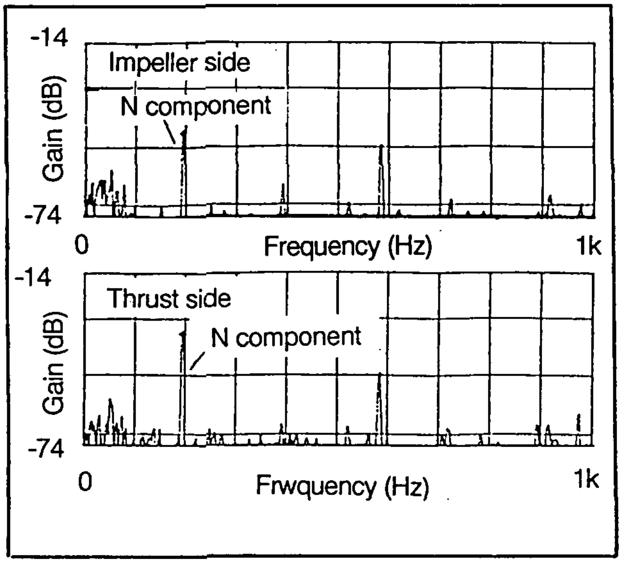


Figure 9 Vibration of the rotor (rated flow point)

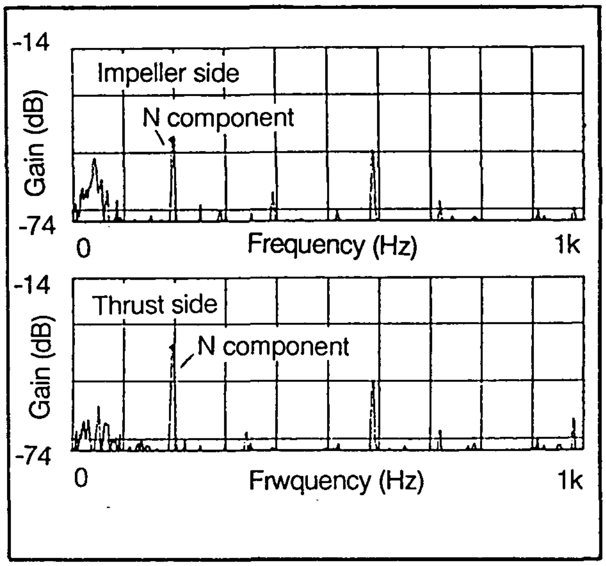


Figure 10 Vibration of the rotor (in surging flow)

frequency hydraulic force in the surging flow. A 1500-hour continuous rotation test, using the high temperature blower unit in a 500 kW MCFC experimental apparatus, was also carried out and the results were satisfactory as well. A high-temperature blower model, supported by magnetic bearings and capable of withstanding temperatures of up to about 400℃ was prototyped for this test. This success increased the range of applications in the market for devices operable at extremely high temperatures. A high-temperature blower, rated motor power of 75 kW, is now being developed for use in an actual 1000 kW MCFC plant.

## ACKNOWLEDGMENT

This study has been carried out as a part of the New Sunshine Program of the Ministry of International Trade and Industry (MITI) under a contract with the New Energy and Industrial Technology Organization (NEDO), and in a shared work in the Technology Research Association for Molten Carbonate Fuel Cell Power Generation System. The authors would like to express their cordial thanks to the people concerned.

## REFERENCES

Junichi Sakai, et al.1991. "Development of High-Temperature Blower for Molten Carbonate Fuel Cell," EBARA ENGINEERING REVIEW, 153:8-17