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Development of a Lab-Scale High-Pressure Gas-Bearing Circulator for Using a VHTR Simulated Loop

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1. Introduction

A small scale gas loop that can simulate a VHTR (Very High Temperature Gas Cooled Reactor) is now under development in KAERI [1]. Control of gaseous impurities in the circulating gas in the primary loop is a significant operating requirement that dictates the choice of a circulator that is lubricated by circulating gas. The oil vapor induced by a circulator will contaminate and damage the sophisticated high temperature components of the primary loop. Therefore, a VHTR simulated high-temperature gas loop needs an elimination of the oil systems required by traditional bearing designs. A gas-bearing circulator which has an oil-less bearing system is now widely used in the industry for low-pressure turbo-machinery. In this study, we discussed the design and test results of a lab-scale high-pressure gas bearing circulator to be operated at a small scale gas loop.

2. Principle of the Foil bearing

Foil bearings are a type of gas bearing. A shaft is supported by a compliant, spring loaded foil journal lining. Once the shaft is spinning fast enough, the working fluid pushes the foil away from the shaft so that there is then no contact (Figure 1). The shaft and foil are separated by the gas's high pressure which is generated by the rotation which pulls gas into the bearing via viscosity effects. A high speed of the shaft with respect to the foil is required to initiate the gas gap, and once this has been achieved, no wear occurs. The foil bearings easily wear by contacting with the shaft during a startup or shutdown of the circulator. Figure 1 shows a 10% bearing wear after 100 starts and stops. To prevent an excessive wear on the gas bearings during a startup, the circulator motor accelerates the rotor to 3,000 rpm in less than one second. Unlike aero or hydrostatic bearings, foil bearings require no external pressurization system for the working fluid. The advantage of foil bearings is an elimination of the oil systems, increased reliability, higher speed capability, higher and lower temperature capability (40K to 2500K), high vibration and shock load capacity, and a quieter operation [2].

3. Design of a lab-scale gas bearing circulator

The design condition of the VHTR simulated gas loop is as follows;

- Working fluid Nitrogen

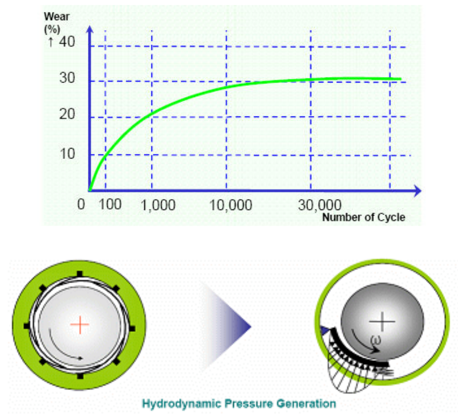

Figure 1. Principle of a lifting shaft and bearing wear with number of on/off cycles

- Design Temperature 1000 °C
- Design pressure 6.0 MPa
- Design Flow 0.034 kg/sec

This design condition of the VHTR simulated gas loop is the reference operating condition of a gas-bearing circulator except for the design temperature. The design temperature of a circulator depends on the cooler outlet temperature because the position of the circulator is normally located between a cooler outlet and a heater inlet. The value of the loop total pressure loss is used to determine the compression ratio of a circulator. The total pressure loss of the primary loop is estimated as 60KPa where the loop pressure is 4.0MPa and the flow is 0.034 kg/sec [3]. In consideration of the calculation uncertainty and the circulator operating flexibility, the design pressure loss of the circulator should be over 100KPa. The collected requirements for designing a lab-scale circulator are listed in Table 1.

4. Results and discussions

As we can see from Figure 2, the body of the circulator is mounted on two pairs of ANSI Class1500 flanges with enough strength to withstand a loop pressure of 6.0MPa. Because of a motor and coils are installed in the circulator body, it is easy to upgrade the operating pressure without a gas leakage. The diameter of the impeller is 50mm and the rotor is designed to adapt to a single stage and foil bearing system. As a result of an

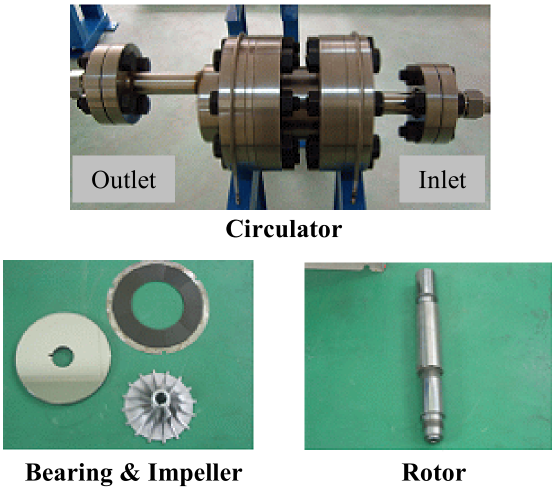

Figure 2. Pictures of the circulator and the major parts

atmospheric performance test [4], the lab-scale circulator runs smoothly and reached 36,000 RPM within 1.0 sec. The circulator efficiency (h) is degraded as the revolution speed is increased (Figure 3). The niobium magnet in the circulator is abruptly degraded in its capacity at a high temperature (>150℃). Therefore, we restricted the circulator inlet temperature to less than 50℃, by considering the circulator internal rising temperature (Figure 4). Because we adopted a leaf type bearing that has a higher compression ratio, we obtained a satisfactory pressure head performance (Table 2).

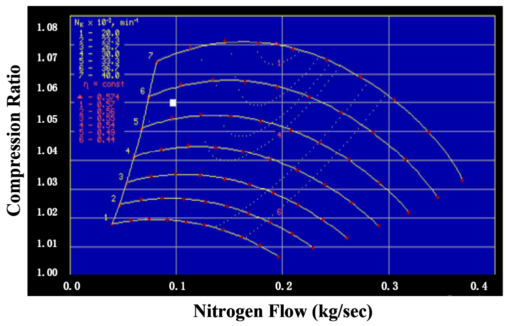

Figure 3. Circulator characteristic curves

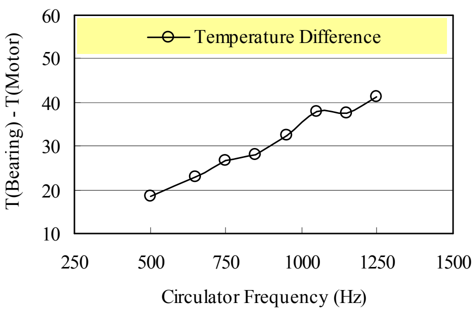

Figure 4. Circulator internal rising temperature

Table 1. Design Requirements of a Lab-Scale Circulator

Item	Design Requirement
Working Fluid	Nitrogen
Normal Flow	0.1 kg/sec
Compression Ratio	> 1.06 at 4.0 MPa
Inlet Temperature	50 ℃
Design Pressure	6.0 MPa
Speed Control	RPM Controlled by Invertor

Table 2. Performance of a Lab-Scale Circulator

Parameter	Measured Data
Power	0.75 kW
Efficiency	0.57 ~ 0.44
Speed	36000 RPM
Compression Ratio	1.01 ~ 1.08
Starting / Stopping Time	0.08 / 0.09 sec
Impeller / Stage	Air Bearing / Single
Min. / Max. Operating Freq.	550 / 1200 Hz
Operating Temperature	Max. 50 ℃ at Inlet

5. Conclusions

We designed and tested a lab-scale gas circulator for a VHTR simulated gas loop. We obtained the following results for the circulator;

1. The pressure of the foil bearing circulator is successfully achieved at 6.0 MPa
2. The circulator efficiency is degraded as the revolution speed is increased
3. The maximum limit (50 ℃) of the circulator inlet temperature is a primary concern for the cooler capacity
4. The oil-less foil bearing circulator has many potential advantages for a small-scale high-temperature and high-pressure gas loop

ACKNOWLEDGEMENTS

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