Internal Flow and Stability of Balance Piston for a Rocket Pump

Norio Kimura, Department of Applied Mechanics and Aerospace Engineering, WASEDA University, Tokyo, Japan
Yuki Yoshii, Department of Applied Mechanics, Graduate School of WASEDA University, Tokyo, Japan
Kengo Uchiyama, Department of Applied Mechanics, Graduate School of WASEDA University, Tokyo, Japan
Akiha Shibata, Mitsubishi Heavy Industry, Aichi, Japan
Kazuyoshi Miyagawa, Department of Applied Mechanics and Aerospace Engineering, WASEDA University, Tokyo, Japan

ISROMAC
SYMPOSIA ON ROTATING MACHINERY
Since 1985

Long Abstract

Introduction

Rocket pump, which delivers the liquid propellants to the engine combustion chamber, are required to higher delivery pressure and higher rotational speed than an industrial pump, and usually operated in very sever condition. Therefore, large axial thrust is often generated on the rotor. To balance the rotor axial force automatically, balance piston which is one of the axial thrust balancing system is often applied. A balance piston is equipped in the back shroud of the main impeller, and consist of No.1 orifice located at the impeller outlet, No.2 orifice located at the small-radius position of the back shroud and balance piston chamber located between both orifices. If a rotor assembly moves in the axial direction, the opening rate of the orifice clearances change, thus the pressure field in the balance piston chamber is changed and the fluid force on the rotor back shroud also changes, so the rotor assembly moves back axially to balance the system. In this way, the balance piston is stable in the static condition, but self-exited oscillation in the axial direction sometimes occurred in the rocket turbopumps. Therefore, it is necessary to examine the dynamic characteristics and the stability of balance piston by experiments and computations.

1. Test Facility and Method

The experimental investigation was performed with the balance piston test facility as shown in Fig.1. Fig.2 shows the balance piston cross section of the test facility. The working fluid is air at normal temperature. The rotor assembly can move in the axial direction in order to adjust the No.1 and No.2 orifice clearance. The rotor assembly is able to be oscillated axially by rotating motor and crankshaft, and axial oscillating frequency Ω can change up to 70 Hz. The total clearance of No.1 and No.2 orifice is 0.7 mm, and rotor oscillating amplitude is 0.1 mm. Also, rotational speed N can change up to 2500 rpm. High pressure air is supplied to the balance piston by air compressor, and the supply pressure P can be adjusted by the valve. The influence of the rotational speed and supply pressure to the balance piston can be investigated by the above mentioned test facility. The static pressure at the inlet, outlet points of No.1, No.2 orifice and at two points on balance piston chamber surface in different radial position is measured, so total static pressure measurement point is 6 points. The measurement of flowrate is performed at the upstream of the balance piston by hot wire anemometer. By these experimental devices, the measurement of pressure field and flowrate fluctuation of the balance piston were examined.

To compare with the experimental investigation, one-dimensional theoretical calculation and one-dimensional simulation using a multi-domain simulation tool, AMESim were carried out. Furthermore, the internal flow of the balance piston were examined by LES. Finally, by using the acquired information in various ways, the investigation of the balance piston characteristics in the actual liquid hydrogen turbopump condition was examined by using CFD simulation.

Fig.1 Test Facility

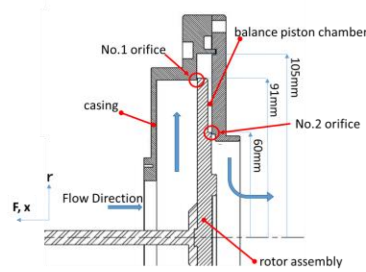


Fig.2 Balance piston of the test facility

2. Result and Discussion

Fig.3 shows the phase difference θ of static pressure in the balance piston chamber from displacement of the rotor assembly under the condition of N=2000 rpm, P=1000 PaG. The phase difference θ increases as the axial oscillating frequency Ω increases, and achieve about -120 degrees at 60 Hz in both experiment and LES.

Fig.4 shows the vorticity contour around the balance piston under the condition of N=2000 rpm, P=1000 PaG and minimum No.1 orifice clearance (0.25 mm) by LES, and the relationship between the vorticity counter and the balance piston stability was examined. Under the condition of Ω=70 Hz (Fig.4 (b)), the vorticity in the balance piston chamber is higher than that under the condition of Ω=10 Hz (Fig.4 (a)). Thus, changes of the oscillating frequency Ω causes the difference of the vorticity field in the balance piston chamber. In this condition, the fluid damping coefficient is positive, thus the balance piston system is stable.

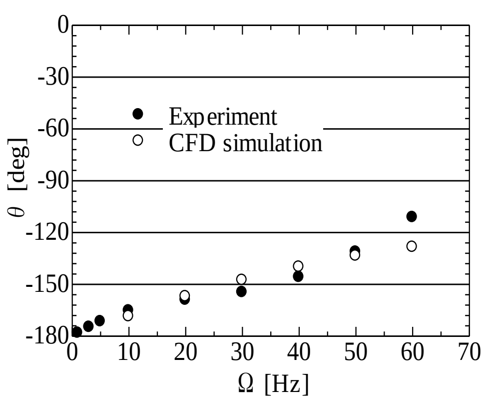
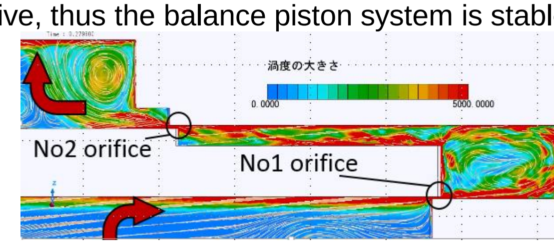
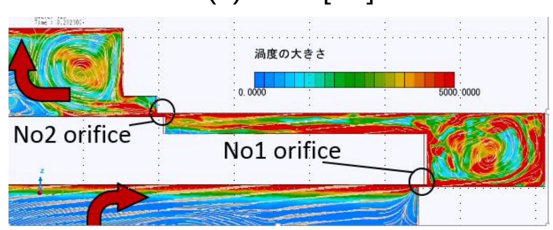


Fig.3 Phase difference of chamber pressure



(a)Ω=10 [Hz]



(b)Ω=70 [Hz]

Fig.4 Vorticity counter

Reference

[1]. Kawasaki, S.,Kimura, T.,Uchiumi, M.,Shimura, T.,Hayashi, M. and Matsui, J.,2012,''Numerical Investigation of Axial Force Dynamics on Balance Piston of a Rocket Pump'', *Isromac-14*

[2]. Shimura, T., Kawasaki, S., Uchiumi, M., Kimura, T., Hayashi, M. and Matsui J.,2012,''Dynamic Response of an Axial Thrust Balancing System for Rocket Pumps'', *Isromac-14*

[3]. Shimura, T., Kawasaki, S., Uchiumi, M., Kimura, T., Hayashi, M. and Matsui, J., 2012, "Internal Flow and Axial Thrust Balancing of a Rocket Pump," ASME J. Fluids Eng., 134(4), p. 041103