Numerical simulation analysis and design of membrane-type restrictor
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ABSTRACT - The flow-control restrictor influences the performance of hydrostatic bearing. Membrane-type restrictor can actively vary the flow resistance of the restrictor in response to the loading of the bearing. Through proper design, theoretically, a bearing system with infinite static stiffness may be achieved. This study adopted a numerical simulation method to more accurately calculate the deformation of membrane. From the simulation, the optimal design of restrictor would be determined and the restrictor manufactured. In addition, the effects of parameters in a membrane-type restrictor on the performance of hydrostatic bearing were also studied.

1. INTRODUCTION

Ever-narrowing tolerance and increasing geometric shape accuracy requires machine tools with much higher precision and accuracy. The use of hydrostatic bearing in machine tools might offer a way to achieve this required precision [1]. Bearing is a machine element whose function is to support the motion of machine parts and reduce the cost due to friction, so low friction is basic requirement for bearing.

There are two types of bearings, contact and non-contact. Contact bearings have mechanical contact between elements, and they include sliding, rolling, and flexural bearings. Non-contact bearings include externally pressurized and hydrodynamic fluid-film and magnetic bearings. In general, non-contact bearing has the characteristic of low friction due to no contact [2].

Each type of bearing has its own operating principle and advantages. In hydrostatic lubricated bearings, one of non-contact bearing, there is fluid film between the bearing surfaces maintained by a pressure source outside the bearing [3]. Due to the film between bearing surfaces, the bearing could have the characteristics of low friction and almost no wear. In addition, because the pressurized fluid film has high damping characteristics, the crash resistant is better than contact bearing. In addition, the lubricant film produces an "averaging" of the roughness and other defects.

The principal requirements of the design of hydrostatic bearings are low friction, adequate load carrying capacity and high stiffness. There are several methods to improving the stiffness of hydrostatic bearings. The simplest method is to reduce the nominal bearing gap, but this might cause the contact between bearing surfaces, especially at high load. Another method to increase in stiffness might be achieved by using double film bearing. However, double film bearings require extreme manufacturing accuracy [4].

In hydrostatic bearing system, a supply system provides the pressure and flow. A compensating device, namely, restrictor is needed in supply systems to regulate the pressure in response to different load. With different types of restrictors, the hydrostatic bearings show different performances. Adopting proper restrictor can improve the stiffness of bearing and load carrying capacity.

There are mainly two types of restrictor: passive restrictor and active restrictor. The passive restrictor like capillary restrictor and orifice restrictor is commonly used in industry because of the low manufacturing costs and the easy processing. However, the flow resistance of passive restrictor does not actively respond to different load, so the stiffness of the system with passive restrictor is relatively low. In general, active restrictor has better compensating ability than that of passive restrictor. Common active restrictor are spool valve restrictor and membrane-type restrictor. Spool valve restrictor adjust resistance by moving the valve inside. The resistance of membrane-type restrictor is controlled by only deflection of the membrane. The reaction time of spool valve is longer than that of membrane-type restrictor. Therefore, the use of membrane-type restrictor can achieve not only good compensating ability but also high efficiency.

Although, the development of membrane-type restrictor has been more than fifty years, the analysis theory and technology has not been developed fully. There is no systematic procedure to design a membrane-type restrictor.

Chang [5] proposed a process for designing membrane type restrictors. She analyzed membrane deformation and flow fields by finite difference method. The effects of parameters in membrane-type restrictor on the performance of hydrostatic bearing with a single circular pad was studied in her study. The two main parameters she studied were: thickness of membrane, and assembly clearance.

The procedure proposed by Chang [5] to design membrane-type restrictor is still quite complicated. In this study, it is of interest to find out a way to simplify the design process. Based on the known results of simulations and experiments, a simplified design process was proposed in this research.

2. METHODOLOGY

In this study, it is of interest to establish a procedure that can simplify the design process of membrane type restrictor. The procedures and contents of this study are summarized in Figure 1. In order to optimize the operation of the restrictor, the relationship between
membrane clearance and recess pressure should be revealed first. A simplified model is adopted to analyze the optimal relationship between membrane deflection and recess pressure such that an infinite static stiffness for bearing can be achieved. This analysis may provide a guide for the optimal design of restrictor. A simulation study is then conducted for the detail design of restrictor. In the end, experiments were conducted to verify simulation results.

By first deriving the stiffness of an ideal membrane, it was concluded that it was hard to find a membrane with similar deflection curves. Therefore, it was assumed that the deflection of the membrane changes linearly with a change in load. The variable, $K_r^*$, was deemed the non-dimensional constant membrane stiffness. By running simulations on the effects of film thickness and recess pressure on different $K_r^*$ values, it was determined that a $K_r^*$ value of 1.33 would be ideal for this study as shown in Figure 2.

4. CONCLUSION
Based on the optimal design, the ideal performance can be reached in an approximate pressure ratio range from 0.2 to 0.5. The membrane-type restrictor could be design for the single pad bearing according to this research. From the stress analysis, the center of membrane may suffer from stress concentration. Therefore, a material with higher yield strength should be chosen for the membrane. Also, the thickness of membrane should not be too thin. The thickness of membrane and the assembly clearance are the key parameters, but the error of process could not be avoided. This situation could be solved by regulating the supply pressure because the optimal non-dimensional membrane stiffness is related to supply pressure. The measured resistance values were not the same as those of simulation. The machining error of clearance and membrane might have caused the differences. In addition, temperature would influence the viscosity of oil and this would affect the resistance.

REFERENCES