Design of Machines and Structures, Vol. 10, No. 2 (2020), pp. 155–159.
https://doi.org/10.32972/dms.2020.027

INTRODUCTION OF ACTIVE AND PASSIVE CONTROL OPTIONS FOR HYDROSTATIC PRESSURE CHAMBERS

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Abstract: One of the critical points in the design of hydrostatic bearings is the proper selection of the pressure control of the bearing recess, yet the design methods do not pay much attention to this. In addition to conventional solutions, the control of the pressure recesses can be accomplished by the use of volumetric and pressure-sensitive valves in the hydraulics to achieve greater bearing stiffness. A new way of regulating can also be the regulation of the recess with proportional valves.

Keywords: *hydrostatic bearings, recess pressure control, bearing stiffness*

1. INTRODUCTION

Hydrostatic bearings are a special type of fluid-lubricated bearings, where the fluid film layer separating the shaft and inner journal bearing surface and the supporting force is built in the pressure chambers supplied with an external power supply instead of a hydrodynamic force due to the wedge effect between the surfaces. Hydrostatic bearings therefore have much better starting conditions and static stiffness than hydrodynamic bearings, but their design is more complicated, because the pressure of the oil film in the pressure chambers has to be regulated.

The control of the pressure chambers is necessary because the centralized shaft deviates with a given eccentricity in the direction of the pressure chambers due to the load. Due to the bypass shaft pin, the gap size in the direction of eccentricity decreases, which causes a decrease in the volume flow of the pressure chambers, as a result of which the pressure in the pressure chambers increases. Due to the deflected axis, the gap size in the direction of eccentricity decreases, which causes a decrease in the volume flow of the pressure chambers, as a result of the pressure in the hydrostatic chambers increases. In contrast, in the pressure chambers from which the shaft moves, there is an increase in volume flow and a pressure drop. The resulting pressure difference is necessary to return the shaft to its centralized position close to the unloaded position [1], [2]. To ensure shaft aligning, the pressure ratio (β) between the supply pressure and the chamber pressure must be maintained independently of by means of a pressure control element. The control can be done with the help of conventional passive elements (capillary and permanent throttle element) or with active valves (2-way flow control valves, pressure-sensitive valves, and proportional flow volume/directional valves) [3].

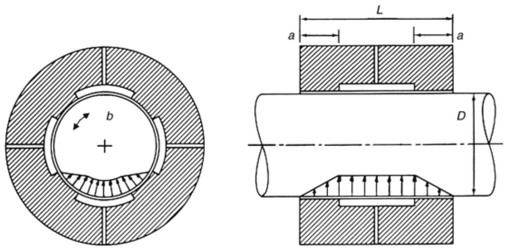

Figure 1
Unloaded pressure field distribution of the hydrostatic journal bearing [1]

2. CONVENTIONAL PRESSURE CHAMBER CONTROL METHODS

The simplest chamber control can be achieved with passive throttles, in which the fluid flow can be laminar or turbulent. Laminar control elements are mostly capillary tubes with a high L/D (tube length / inner diameter) ratio. The advantage of using a capillary tube is that the pressure drop is uniform, so that no heat loss due to a sudden pressure change occurs (however heat is generated from friction). Main drawback is that the control is dependent of the viscosity of the fluid.
Volume flow of oil in the capillary line [2]:

$$Q = \frac{(p_s - p_r)\pi {d_k}^4}{128 \upsilon l_k} \tag{1}$$

where:

p_s – supply pressure;
p_r – pressure chamber pressure;
d_k – inner diameter of the capillary tube;
l_k – length of the capillary tube;
υ – kinematic viscosity of the film fluid.

It can be seen from *Equation (1)* that the inner diameter of the capillary tube can only be increased slightly because it can greatly increase the volume flow (in other words, the fluid demand), which causes an undesirable friction loss. A further disadvantage is that it can only be used at low speeds due to the size limitations of the installation, as the oil film flow must remain laminar, which is lower (Re ~ 1000) for fluids flowing between eccentric cylinders than for fluids flowing in a circular cross-section pipeline.

Turbulent, passive pressure chamber control is possible by incorporating a constant throttle. With a low L/D ratio, greater stiffness can be achieved than with capillary tubes, furthermore the flow is independent on the viscosity of the oil. The main drawback is the higher risk of clogging due to the narrow throttle cross section.

With the traditional control technique, the static bearing stiffness of hydrostatic bearings can be optimized for the size of the bearing gap and the pressure ratio. The highest bearing stiffness can be achieved in capillary control ($\beta = 0.5$), in throttle elements ($\beta = 0.67$) by setting the pressure ratio [3].

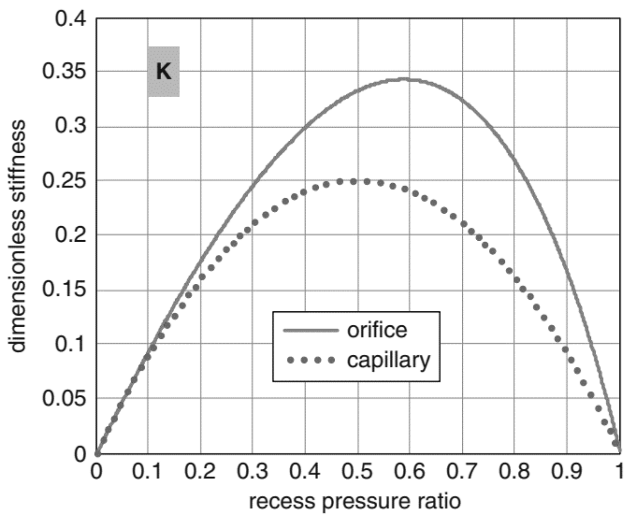

Figure 2
The dimensionless static stiffness of a hydrostatic bearing on a given pressure ratio at different passive flow control units [5]

3. PRESSURE CHAMBER CONTROL OPTIONS WITH ACTIVE VALVES

It can also be used to control pressure chambers with volume flow units, which are also often used in hydraulics, which can be realized by means of a valve or by means of constant flow pumps connected to pressure chambers separately, serving several circuits at the same time. By stabilizing the volume flow, the bearing stiffness and load capacity can be further improved compared to the passive control elements. In this case, the bearing stiffness and the maximum load can be set directly by controlling the supply pressure. For control, a pressure relief valve must be installed for each branch. In practical application, there is always a minimum pressure difference between the bearing pad pressure and the supply pressure due to flow losses, which is at least 2 bar [4].

To control the volume flow, the development of pressure-sensitive valves was also started. With these valves the gap size can be stabilized in a certain load force range and the "infinite bearing stiffness" can be achieved with them. Currently, two main control modes are known: slide-valve and diaphragm valve control. The design of a slide valve is almost identical to a pre-controlled two-way flow control valve, in which the chamber pressure is halved compared to the supply pressure due to the surface ratio of the valve plates. Infinite bearing stiffness is achieved with the valve, but it responds slowly to load changes.

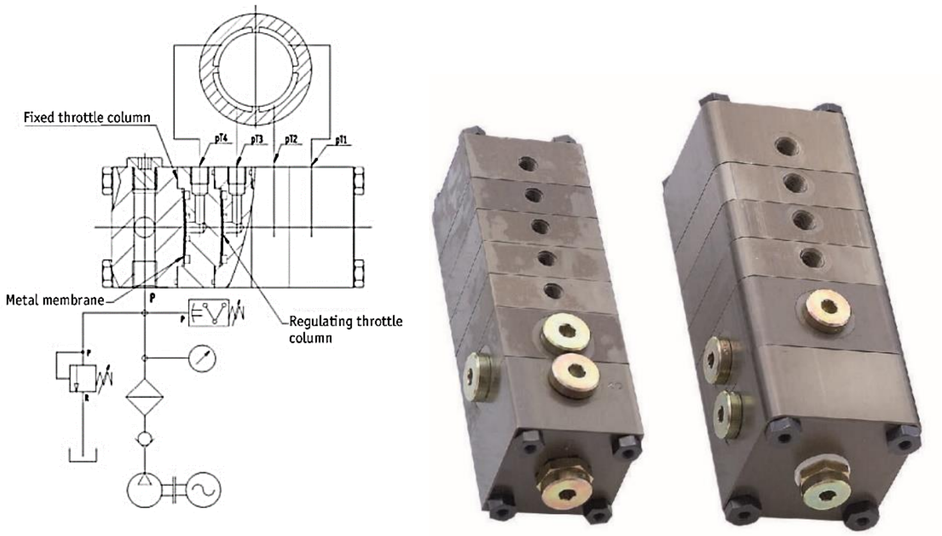

Figure 3
Progressive diaphragm (PM) flow control valve block
for hydrostatic pressure chamber control (Hyprostatik) [5]

Currently, one of the best controls can be achieved by installing diaphragm valves. It controls the volume flow in the diaphragm valve under the influence of the load force. The progressive diaphragm (PM) valve manufactured by Hyprostatik has a fixed and adjustable control part [5]. The first regulator is turbulent throttle, allowing viscosity and temperature-independent control. The fluid flow is then controlled by the elastic deformation of the membrane plate, so the PM flow regulator operates without wear or hysteresis. Due to the low weight of the steel diaphragm disc and the high control forces, the PM flow controller quickly follows the pressure change. Thanks to the automation of today's machines, it is increasingly possible to have a more direct connection between electrical and hydraulic systems. Previously, only discrete-operated directional valves were available, which in turn only provided a switching function, so they are not suitable for steeples volume flow variation. Hydraulic proportional devices generate an output signal, pressure or volume flow proportional to the input signal, which depends on the operation. The regulation of hydrostatic bearings by proportional valves was addressed by Yang X. [6].

With the help of displacement sensors, the size of the bearing gap – i.e. the thickness of the oil film layer – can be measured in real time. By processing the signal in a PID controller, the electric current acts on the torque motor coil of the servo valve and moves the spindle so that the proportional valve opening can be controlled. By controlling proportional valves, a constant bearing gap size can be set, similar to a diaphragm valve.

4. Summary

Hydrostatic bearings can be controlled by capillary tubes, throttles, flow control valves or pressure-sensitive valves. Capillary control can only be used at low speeds, because of the limited allowed Reynolds number the turbulent flow may appear earlier in the bearing than in the capillary tube.

With pressure-sensitive valves, a constant bearing clearance can be ensured, which provides greater and more stable stiffness compared to capillary control. Permanent bearing clearance can also be achieved by controlling proportional directional valves.

Acknowledgement

The described article was carried out as part of the EFOP-3.6.1-16-00011 *Younger and Renewing University – Innovative Knowledge City – institutional development of the University of Miskolc aiming at intelligent specialisation* project implemented in the framework of the Szechenyi 2020 program.

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