RESEARCH CONCERNING THE INFLUENCE OF THE LUBRICANT TEMPERATURE ON THE FUNCTIONING OF HYDROSTATIC GUIDANCE SYSTEMS

PASCU MARIUS*

„Vasile Alecsandri" University of Bacău, Romania

***Abstract*:** This paper presents a study about the influence of the lubricant temperature on the functioning of hydrostatic guidance systems of machine tools. The quality of the working fluid is especially important in the functioning of the hydrostatic guidance systems; during the functioning, it is subjected to the long-term action of high temperatures, speeds and pressures which have a very wide range of variation. By means of the Simhydraulics program in the Matlab Simulink programming environment, was made a functional simulation pattern of a hydrostatic charging system which analyzes the behavior of the lubricant under high temperature when it passes through a restrictor.

Keywords: hydrostatic guidance system, Simhydraulics, lubricant, restrictor

1. INTRODUCTION

Hydrostatic guide ways are well known for their high motion accuracy, low friction and virtually no wear, so they are widely applied in ultra-precision machine tools and coordinate measuring machines [1]. In recent years, researchers have investigated some methods to predict the influence of lubricant temperature on the functioning of hydrostatic guidance systems of machine tools, for the purpose of giving some guidelines to the accuracy design. Xiaoqiu Xu, built finite element model of lubricating oil film of hydrostatic bearing with multiple oil pads, carry on analysis calculation for temperature field of hydrostatic bearing with multiple oil pads adopting finite volume method [2]. Fillon and Bouyer, have analyzed the relationship between temperature and film thickness in the case of hydrodynamic bearings. They found that for high speed work, maximum temperature becomes a critical parameter [3].

Yanqin, built viscosity-temperature equation of lubricating oil film and mathematics model of oil film temperature of hydrostatic bearing, simulate the temperature field of hydrostatic bearing. The result show that temperature distribution of hydrostatic bearing is much the same under various oil film thicknesses, but the influence of oil film thickness of temperature rise for hydrostatic bearing is greater [4]. Hunter and Zienkiewicz, analyzed the effect of temperature variations within the thickness of the oil film, and the ensuing viscosity variations which are thought to be responsible for the lift in parallel surface bearings, are studied with reference to the classical case of an infinitely wide inclined pad. They obtain a numerical solution for a typical bearing for different thermal boundary conditions and they made a comparison with results of the classical analysis [5].

Among the organs of machine tools, the guiding systems are the mobile joints the most subjected to the destructive friction force. It is well known that the reduction of this unwanted phenomenon which is always present on the level of the contact elements during relative movement is achieved by means of lubricants. The

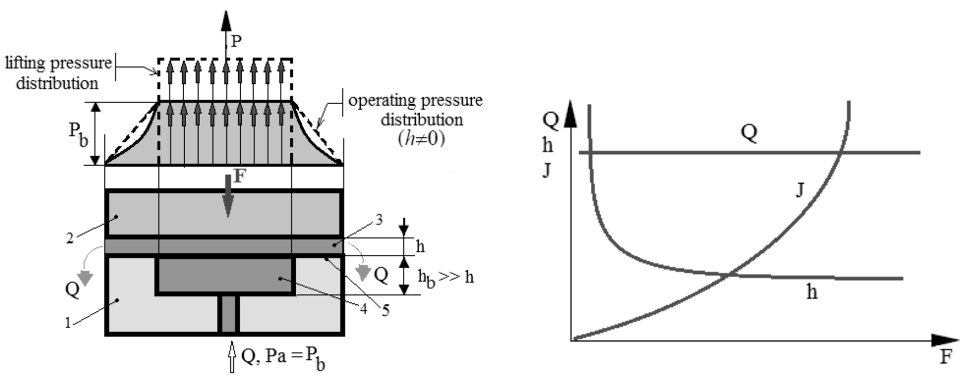
* Corresponding author, e-mail: pascu_marius83@yahoo.com

use of the hydrostatic guiding systems in building machine tools ensures their high performance, with direct effects on the quality of the marks achieved through the metal cutting operations [6].

This paper analyses the behavior of hydrostatic guideways considering the influence of temperature lubricant in the case of input through capilary tube restrictor**.** In this study, the model of hydrostatic guideway was simulated by applying Simhydraulics program environment.

2. ANALYSIS AND DETERMINATION OF THE LUBRICANT TEMPERATURE

A typical example of hydrostatic guidance system from a construction and functional point of view is presented in Figure 1.a; it is made up of two parallel flat surfaces, allowing the relative movement of the carriage without guiding. On one of the surfaces there are some pockets (alveoli) through which the lubricant is supplied under pressure.



a) b)

Fig. 1. The functioning principle of a hydrostatic guidance system:
a)1-guidance, 2-carriage, 3-lubricant film, 4-hydrostatic pocket, 5-collar, h-thickness of the lubricant film on the collars, h_b- thickness of the lubricant film in the hydrostatic pocket, Q-the lubricant discharge, P_a-input pressure, P_b-pocket pressure, F-input load;
b) the discharge characteristics Q, thickness of the lubricant film h and static stiffness J.

The operating principle presented here is relatively simple: the pressure field P which is formed within the hydrostatic pocket 4 (generated by the input from the outside under pressure) is opposed to the force F which supplies the guidance system, maintaining the two opposing surfaces 1 and 2 separated by a continuous lubricant film 3. In the example resented we can also notice the fact that, in case of great loads, the thickness of the lubricant film varies very little, the discharge being always constant, Figure 1.b. This hydrostatic principle can be found in all types of classical hydrostatic guidance systems.

The lubricants used in the energetic circuits and the command circuits of hydrostatic guidance systems are the mineral oils derived from crude oil by extracting certain fractions containing heavy hydrocarbons. In exceptional cases, animal or vegetal oils are used, but only in combination with different substances as mixtures, in order to upgrade the characteristics of mineral oils.

The use of such an upgraded lubricant is indicated in case the main guidance systems of the heavy machine-tools must work in fluid friction mode and when, due to the low speed and the great loads, this mode cannot be achieved using usual oil (mineral), as it is pushed out from between the guiding surfaces. It is also used in the hydrostatic guiding systems of the feeding mechanisms, when we must achieve the fluid friction and a uniform movement without skipping at low and medium speed.

The fluids used undertake serious cyclical modifications in temperature, pressure and speed and they come into contact with different parts of the system. The difficult operating conditions impose the following requirements on the functional fluids: thermal stability, adequate viscosity in any working conditions, compatibility with the installation materials, etc.

At present, there is a large range of functional fluids divided into several classes from the chemical point of view, but none of them has all the qualities necessary for a given transmission. Consequently, choosing a lubricant is in general a compromise which ensures the essential requirements but imposes restrictions on the system structure and the operation conditions.

During the functioning of a hydrostatic guidance system, a lubricant comes into contact with different sources of heat. The physical pattern presented in Figure 2 is probative in that respect, the lubricant enters the circuit with a controlled (known) temperature T_R and consequently it alters until it enters the interspaces of the hydrostatic guidance system as follows [6]:

$$T_b = T_R + \frac{1-\eta}{\eta} \cdot \frac{P_{ref}}{\rho \cdot c_s} + \frac{P_{ref} - P_{buz}}{\rho \cdot c_s} + \frac{C_t}{Q \cdot \rho \cdot c_s}, \tag{1}$$

where: η is the pump efficiency, P_{ref} is the pump return pressure, P_{buz} are the pocket pressure, ρ is lubricant density, c_s – specific heat of the lubricant, C_t – heat transferred to the lubricant from the input system, Q is the lubricant discharge, T_b are pocket temperature.

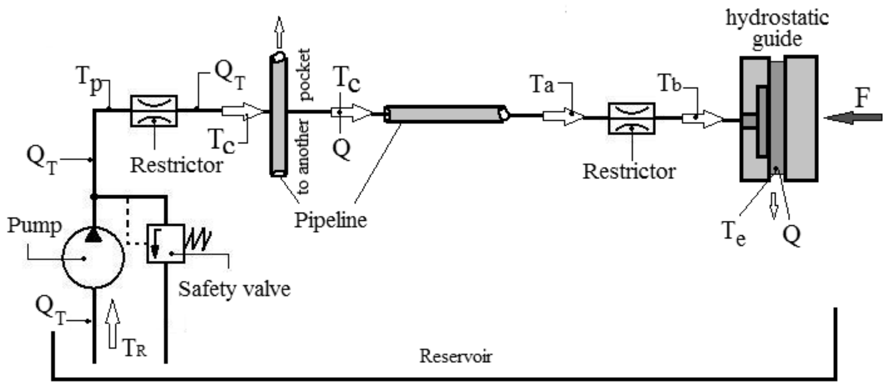


Fig. 2. The supply system of hydrostatic guide with existing heat sources.

As C_t has small values, usually negative ones, it can be neglected. The input system (the pipes for example) usually receives heat from the oil, it does not release heat to it. After the alterations, the relationship (1) becomes:

$$T_b = T_R + \frac{P_{ref}/\eta - P_{buz}}{\rho \cdot c_s} \tag{2}$$

When the lubricant passes through the capillary restrictor, its temperature also modifies, reaching the value of:

$$T_c = T_R + \frac{1}{\rho \cdot c_s}\left[\frac{P_{ref}}{\mu} - \frac{1}{2}\left(P_w - P_{buz}\right)\right] \tag{3}$$

where: μ is dynamic viscosity of the lubricant in the carrying area, P_w are oil pumping power.

An important increase in temperature is produced through the fluid friction when the lubricant passes through the interspace, through the fluid friction caused by the relative movement of the surfaces insulated by the lubricant as well as by the infusion of heat received by the oil from the active surfaces of the guidance system. Globally, these phenomena lead to the temperature at the bearing exit:

$$T_e = \frac{P_w^1 + P_{fluid} + P_l}{Q \cdot \rho \cdot c_s} + T_b \tag{4}$$

In the relationship above, P_w^l is the oil pumping power through the interspace (P_w^l=P_{buz}Q), P_{fluid} are the power through the fluid friction at relative speed v, and P_l is the power received by the oil from the surface of the pivot and especially of the collars.

A suggestive image of the complexity of this matter is presented in Figure 3.

$$P_l = P_{l1} + P_{l2} \tag{5}$$

where:

$$P_{l1} = P_{prag1} + P_{buz1} \tag{6}$$

$$P_{l2} = P_{prag2} + P_{buz2} \tag{7}$$

The temperature at the inner side of the pocket T_i, is:

$$T_i = T_b + \frac{P_{buz1} + P_{buz2}}{Q \cdot \rho \cdot c_s} \tag{8}$$

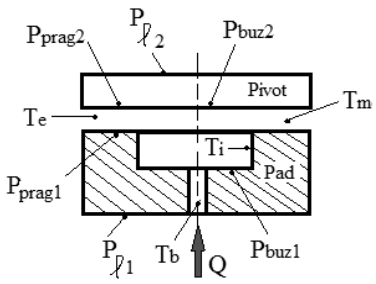


Fig. 3. Model for calculation of the energetic balance of a hydrostatic support.

The average temperature on collar T_m is:

$$T_m = \frac{T_i + T_e}{2} \tag{9}$$

It is especially difficult to find out the working temperature T_m, for which the viscosity μ of the lubricant in the carrying area is determined, if we take into consideration all the dissipators and all the heat sources existing on the input circuit.

3. SIMULATION OF THE LUBRICANT TEMPERATURE IN THE CASE OF INPUT THROUGH CAPILARY TUBE RESTRICTOR

For the simulation of a lubricant temperature when passing through a capillary tube restrictor, I used the Simhydraulics program in the Matlab Simulink programming environment. The advantages of the Simhydraulics program make this kit become a necessary soft for performing the simulation tests of the complex hydrostatic systems [7].

The block diagram has a special role in this simulation program (Figure 4); it is a graphical pattern that solves the equation system which describes the mathematical model associated to the process. The block diagram includes a series of preset symbols named blocks, linked through interconnecting lines. The diagram of the input system with capillary tube restrictor proposed for testing is presented in Figure 5.

For the simulation of the pattern chosen we considered the following parameters: the load on the guide, F = 10,000 N; the shape of the plate is rectangular (Figure 6), with the dimensions X=100 mm and Y= 60 mm; the shape of the pocket is rectangular, with the dimensions x =60mm, y=20mm respectively; the thickness of the lubricant film is h=20μm; the movement speed of the mobile element is v=5m/s.

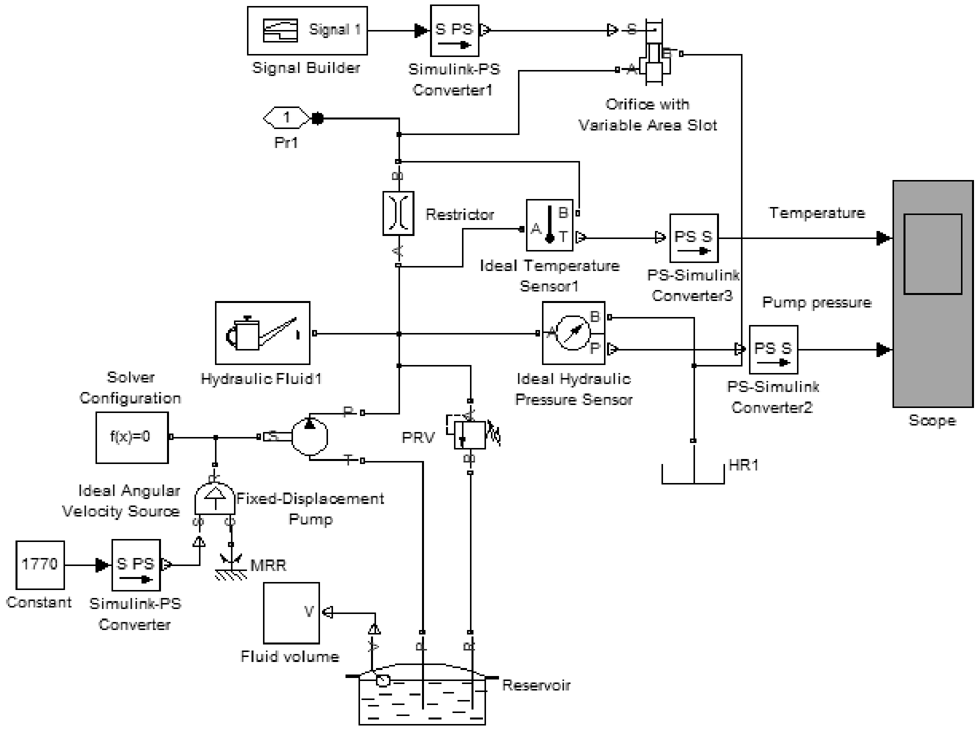


Fig. 4. Testing circuit built using the Simhydraulics program.

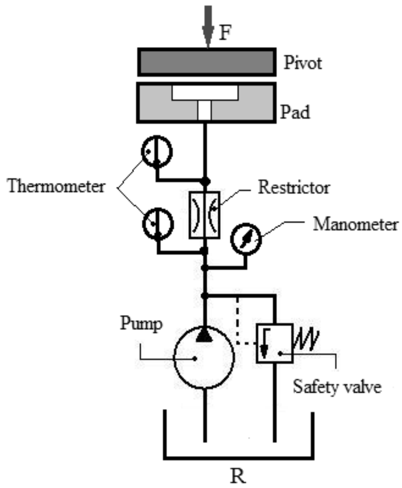


Fig. 5. Simulated hydrostatic input system.

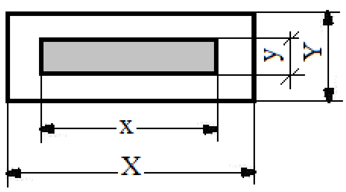
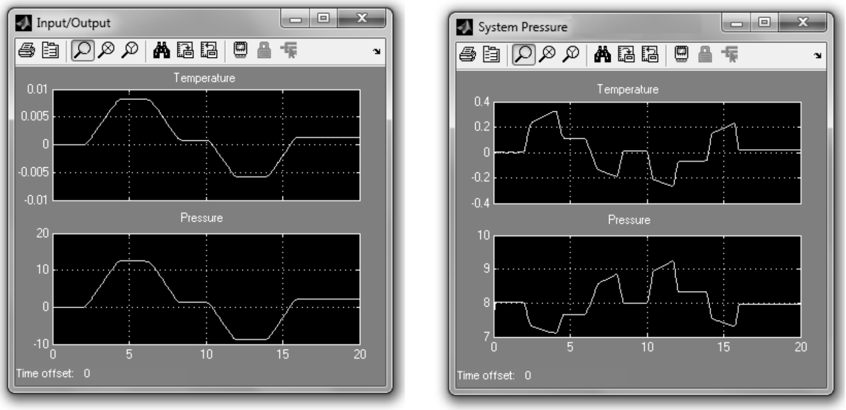


Fig. 6. The shape and size of hydrostatic pocket.

I choose a Skydrol LD-4 mineral oil, with the dynamic viscosity $\eta = 20 \cdot 10^3$ Ns/m^2 , the density $\rho = 900$ kg/m^3 and the specific heat $c_s = 1822$ J/kg·K. Figure 7 presents the functional diagram for testing the model chosen using the preset symbols and blocks of the Simhydraulics program. The simulation results are shown in Figure 7.



a) b)

Fig. 7. Simulation results:
a) for the initial parameters; b) after altering the parameters.

By analyzing the obtained results it can be observed the direct dependence between the increase of temperature and the pumping pressure. The value of temperature has a small increase with viscosity, in conclusions the temperature and viscosity must be correlated. If the decreases of the P_{fluid} power is imposed, it is better to decrease the lands areas instead the increase of the film thickness; if the lands areas is reduced with 25%, the flow rate is increases 4 times (P_{fluid} decreases at 4 times); if the film thickness increases 2 times, the flow rate increases 8 times and P_{fluid} decreases 16 times. In the both cases, the temperature is reduced with the same value. In order to decreases the lubricant temperature, the used type of restrictor must be considered. The volume of the capillary is very low, thus the effect of the compressibility of the fluid inside the capillary is low.

4. CONCLUSION

The absolute qualities of the hydrostatic guidance systems make them prevail over the other bearing couplings (sliding bearings, roller bearings, classical or roll guiding systems, ball screws, etc.); in many applications, their use becomes requisite. In this paper is analyzed the behavior of a lubricant subjected to temperature variations and the influence of these variations on the functioning of the hydrostatic guiding systems of machine tools.

By means of the Simhydraulics program in the Matlab Simulink programming environment, was performed the modeling and the simulation of an input system of a hydrostatic guide which analyzes the behavior of the lubricant under the influence of temperature when it passes through a capillary tube restrictor. This method allows us to select the type of adjustment for the system parameters and emphasized the following characteristics:

- according to the diagrams in Figure 7 we can notice the direct connection between the increase in temperature and the pump return pressure;
- in order to achieve a minimum and stable temperature we need to lower the fluid friction force by reducing the area of the collars.

An important factor that contributes to decreasing the system temperature is the reduction of the viscosity by diminishing the viscous frictions and by the reduction of the absolute variation as a result of the increase in temperature.

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