STUDY AND RESEARCHES CONCERNING THE USE OF POROUS RESTRICTOR IN THE CASE OF HYDROSTATIC GUIDEWAYS

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Abstract: The increase of manufacturing accuracy on the machine tools depends mainly on the motion accuracy of the mobile elements as: rams, tables, pads, etc., accuracy that can be achieved, firstly, by minimization of the friction in the guide ways. This problem is solved by replacing the sliding friction with the rolling friction but especially by using the hydrostatic guide ways, where the contact surfaces are separated by a continuous film of fluid under pressure. The present paper describes mathematical modeling of hydrostatic guide ways having a porous restrictor in order to analyze the influence of functional parameters on the film lubricant thickness.

Keywords: porous restrictor, hydrostatic guide way, pressure, viscosity, portent force

1. INTRODUCTION

The increase and diversification of production on the machine tools equipped with bearings, hydrostatic guide ways and screws requires a careful study of these systems. On the other hand, the development of some non-conventional technologies for cold forming and the design of some automatic manufacture systems, leads to the necessity of the knowledge of design principles and norms of hydrostatic systems that are included in the above mentioned machine tools.

The use of hydrostatic guide ways in machine tools manufacture gives it superior performance, with direct effects on the quality of parts obtained by cutting [1]. The machine tools equipped with hydrostatic guide ways are more reliable, have very high productivity, and, not least, become more competitive on the international market. In the machine tools, the guide ways are the elements that are the most subjected on the destructive action of friction [2].

It is known that in order to minimize the unwanted effect of this phenomenon, but always present the elements in contact and relative motion, it is necessary to use liquid or gaseous fluids. The problem that occurs in the case of hydrostatic guide ways is to maintain the thickness of fluid at a constant value when the external loadings present the important variation [3]. This involves the use of a single constant flow pumps to feed multiple hydrostatic pockets, with the condition that on each circuit is mounted a hydraulic resistance as restrictor or throttle.

The fixed supply device named throttle, restrictor or compensatory element, represent an important component in the supply system with lubricant in the case of a hydrostatic guide way. The use of compensatory elements leads to maintain the pressure at a constant value, being necessary when is supplied more pockets from a single pump. Xiaofeng, Lin and Taiyong have numerically analyzed the aerostatic guide ways equipped with porous

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restrictors by using finite element method. They have developed a new procedure for analysis and improvement of porous compensating elements. P. Tan et. al. have studied the porous restrictors from Al and Ti alloy particles. The results shows that the maximum pore size is increased with the increase of Al powder particle size, porosity and permeability is increased only when the particle size of Al is larger -400 / 600 of the mesh network. Durazo-Cardenas examines the porous restrictors made by ceramic materials used in the construction of hydrostatic guide ways.

The researches shows that use of these types of restrictors represents an improved alternative of the hydrostatic guide ways due to its high stiffness, low price and due to the fact that, in service, its generate low temperatures.. By taking into account those above mentioned it can be conclude that the porous restrictors are used in the hydrostatic and aerostatic guide ways.

The applications of the porous restrictors are rarely showed in the literature and the problem of their use is not enough studied. This paper presents a simple guide way system using the porous restrictor as a technical solution that can be applied successfully in the field of machine tools, especially for hydrostatic guide ways.

2. THE FIXED SUPPLY DEVICES

The introduction of the compensatory elements in the pressure supply scheme is equivalent to the use of an supplementary hydraulic resistance in the fluid circuit. In Figure 1, the working principle of the compensatory elements is presented. It divides the total pressure drop between the power source with constant pressure p_a and the external environment as follows [4]:

$$\Delta p = p_a - p_0 = (p_a - p_b) + (p_b - p_0) \tag{1}$$

where: Δp – the pressure drop; p_a –supply pressure, p_b – pressure in pocket; p_o – pressure in guide way. If the external loading is increased, the fluid film thickness is decreased, that leads to the decrease of the terms p_a-p_b, in other words, the increase of the pressure p_b in pocket. For this reason it can be conclude that the used compensatory element must be a hydraulic resistance for which Δp is a function of the flow rate developed in the mentioned element.

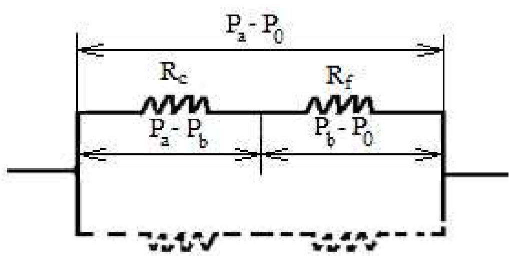

Fig. 1. Functioning principle of supply with the constant pressure [4].

The main constructive and functional solutions of restrictors are as follows: linear restrictors – in this case the flow rate equation have the general form as follows [5]:

$$Q_r = \frac{k_r}{\mu}(p_a - p_b) \tag{2}$$

where: k_r – the constant of restrictor, μ – the dynamic viscosity of oil, p_a– supply pressure and p_b – pressure in pocket. For the nonlinear restrictors- the flow rate is expressed by equation:

$$Q_c = (p_a - p_b)^{\alpha} \tag{3}$$

where: p_a – supply pressure, p_b – pressure in pocket and α – flow rate coefficient in it simplest form, an example of restrictor is represented by the capillary tube having the dimensions d_c and l_c. The flow regime in the capillary is laminar. By applying the Hagen-Poiseuille relation the flow rate can be obtained:

$$Q_c = \frac{\pi d_c^4}{128\mu l_c} \tag{4}$$

where: d_c– diameter of capillary, μ – dynamic viscosity, l_c – length of capillary. The restrictors of the capillary tube type are characterized by simple design and less sensitive to temperature variation. As main disadvantage are mentioned: risk of obstructing, require the ultra-filtration of the lubricant high dimensions and slow performances for high loadings. By comparing with the linear restrictors of capillary tube types it can be concluded that the nonlinear restrictors have some advantages as: superior performances especially at high loadings, small dimensions and very compact.

3. THE POROUS RESTRICTOR

As it is shown in Figure 2, [6], a wide range of porous restrictors can be manufactured. The porous restrictor is made by using a table of porous material that is mounted between the pressures supply source and hydrostatic pocket as it is show in Figure 3.

Fig. 2. Constructive solutions of porous restrictors [6].

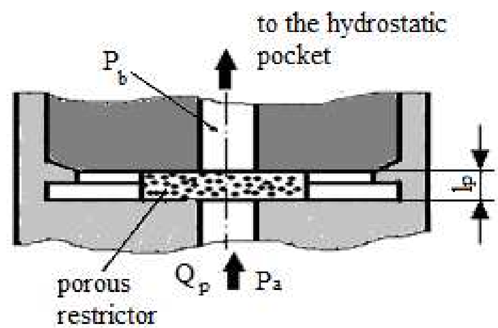

Fig. 3. Principle scheme of the porous restrictor [7].

It is known that permeability represents a complex geometric parameter, essential for characterizing of a porous environment. If the porous environment is modeled by the tangent spherical grains, the permeability can be calculated after Moscow, as follows [7]:

$$k_p = \frac{s_3^2 d_e^2}{96(1-A)} \tag{5}$$

where: $S_3=S_p/S_t$, represents the ratio between total frontal surface of pore and the wetted surface by lubricant; $A=V_p/V_t$, represents the ratio between the pore volume and total volume of tablet made by porous material. In the case of a maximum compactness the following relation is recommended:

$$k_p = 1{,}215 \cdot 10^{-4} d_e^2 \tag{6}$$

where: d_e – the diameters of the spherical grains that are equals between. Due to the fact that this situation is hardly to obtain, it can be used the recommended value for the sintered metallic materials having the porosity between 20% and 45 %, namely k_p=0.5(10^{-4} -10^{-12}). It can be observed that the range of k_p is very large and, in this case, the experimental method remains the most reliable method in the determination of $k_{p.}$ From the D'Arcy law, the flow rate can be calculated as follows:

$$Q_P = \frac{\pi d_p^2}{4} \cdot \frac{k_p}{\mu} \cdot \frac{p_a - p_b}{l_p} \tag{7}$$

where: d_p – diameter of particle, k_p – permeability coefficient, μ – oil viscosity, p_a –supply pressure, p_b – pressure from hydrostatic pocket, l_p – restrictor width. The change in porosity due to partial clogging of the restrictor will influence the constant k_p and will change the geometric constant of the restrictor.

4. THE MATHEMATICAL MODELLING OF THE HYDROSTATIC GUIDEWAY SYSTEM WITH THE POROUS RESTRICTOR

In Figure 4, the working principle of the hydrostatic guide way system equipped with the porous restrictor is schematically presented. The fluid having supply pressure p_a will pass through the porous material having the resistance ρ_1, reaching at a pressure p_j, for entry in the gap. In order to cross the entire gap, the fluid under pressure is supposed to a new pressure drop from p_j to p_{atm} (the air pressure). At the end of gap the fluid crosses the resistance ρ_2.

As a consequence if p_a, have a constant value, p_j is influenced by two resistances: the porous material resistance $\rho_1$and the plane gap resistance ρ_2. When the fluid under pressure are crossing in the porous material, between the contact surfaces a thin film having the thickness h is created. At the same time a portent force proportional to entire surface of the porous restrictor will occurs.

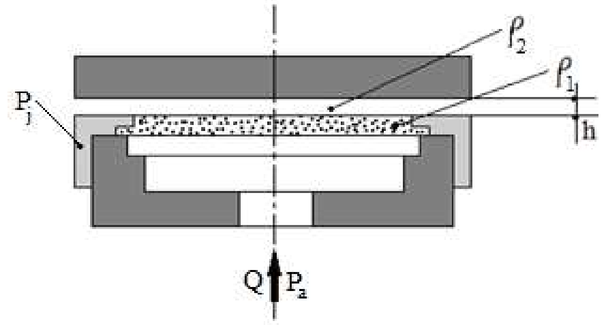

Fig. 4. Hydrostatic guide way system equipped with porous restrictor.

The portent force assures the sustentation of the mobile element of machine tool. Also, the portent force acts on the guide ways. Due to the fact that they gap in the porous restrictor are very small, it can be suppose that the fluid flow is laminar. As a consequence the D'Arcy law may be written as follows:

$$V_y = \frac{dQ}{dS} = \frac{k_p}{\mu} \cdot \frac{\partial p}{\partial y} \tag{8}$$

where: V_y – is the fluid velocity on y direction; μ – dynamic viscosity, p – pressure, k_p – permeability coefficient, dQ – the flow rate in the element of surface dS, normal to direction y. in the case when the porosity of material are in range 20-60%, the permeability coefficient k_p has the values in range $0.5\ldots10^{-4}$. The loss of pressure on the distance d_y can be determined from the above mentioned hypothesis, by using the Poiseuille relation as follows:

$$d_p = \frac{32\mu V_y}{d_m^2} d_y \tag{9}$$

where: d_m – is the maximum diameters of pores. The flow rate for a single pore is expressed as follows:

$$Q_1 = \frac{\pi}{4} \cdot d_m^2 \cdot V_y \tag{10}$$

From equations (9) and (10) another relation for the flow rate can be determined:

$$Q_1 = \frac{\pi d_m^4}{128\mu} \cdot \frac{d_p}{d_y} \tag{11}$$

If N_i, represents the number of orifices on the unitary surface, from the relation (11), values of flow rate which cross in the unitary surface of porous material can be determined as follows:

$$dQ = N_i \cdot Q \cdot ds = \frac{N_i \cdot \pi \cdot d_m^4}{128\mu} \cdot \frac{d_p}{d_y} \cdot ds \tag{12}$$

In the case when the flow in the directions that are not normal to the element of surface is neglected, from (10) and (14) the following equation can be written:

$$N_i = \frac{128 k_p}{\pi d_i^4} \tag{13}$$

A porous restrictor having N_i orifices on the element of surface is considered. It is known that the flow on the other direction than the normal direction to normal to surface is neglected if the thickness of the porous surface insufficiently small. In the gap having the thickness *h*, the flow velocity of the fluid can be determined by using the Reynolds relation:

$$U = \frac{1}{2\mu} \cdot \frac{\partial P}{\partial x}\left(z^2 - hz\right) \tag{14}$$

where: U- velocity of fluid, z – the current value of height, h – the thickness of the lubricant film, μ – dynamic viscosity. The volume flow rate is expressed by the following relation:

$$Q = 2D\int_0^n udz = \frac{D}{\eta} \cdot \frac{\partial p}{\partial x}\int_0^n (z - hz)dz \tag{15}$$

The pressure variation in the gap for lubrication is given by the relation:

$$d_p = \frac{12Q}{Dh^3}\eta dx \tag{16}$$

By integrating (18) on obtain the expression of hydrostatic pressure distribution on the entire width of the guide way as follows:

$$p^2 = p_j^2 + \left(p_{atm}^2 - p_j^2\right) \cdot \frac{x}{b} \tag{17}$$

By integrating of the relation (19) for the entire surface of the guide way and subtract the load that occurs due to external pressure, the carrying capacity can be obtained as follows:

$$P = 2b\left[\frac{2\left(p_j^3 - p_{atm}^3\right)}{3\left(p_j^2 - p_a^2\right)} N_i l - L p_{atm}\right] \tag{18}$$

Where: N_i – number of orifices, *L* – the guide way length, *l* – distance between two orifices. The pressure p_j, depends on the porous restrictor resistance and on the thickness of gap. The guide way stiffness can be calculated by applying the following relation:

$$J = 8bN_i l \cdot \frac{k_0 p_j \left(p_j^4 - 3p_j^2 + 2p_j\right)}{h\left[p_{atm}^2 + K_0 + \left(3p_j^4 - 2p_j^2 - 1\right)\right]} \tag{19}$$

where: $K_0 = f(p_j)$, $K_0 = f(p_a/p_{atm})$ – represents a functional parameter as a function of the supply pressure.

5. IMPLEMENTATION OF THE MODEL AND RESULTS

Availability and existence of multiple hardware devices, computers and mathematical simulation software, allows the testing and execution of the simulation operations even for very complicated systems. For different load levels and different dimensions of the porous restrictor as a function of the supply pressure p_a, a series of values for the thickness of film lubricant is obtained. From the analysis of the results presented in Figure 5 it can be concluded that for a certain value of the external loading of the guide way, the thickness of the lubricant film must be constant. From the results show in Figure 6, it can be remarked the sensitivity of the film thickness h with the increase of the external loading.

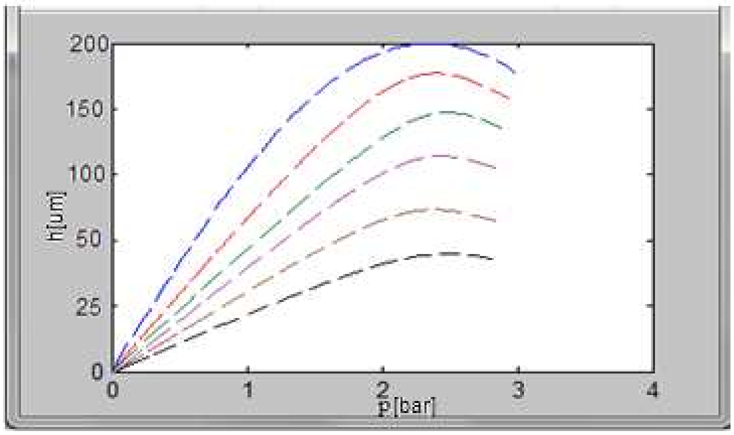

Fig. 5. Variation of the film lubricant thickness h as a function of supply pressure, p_a.

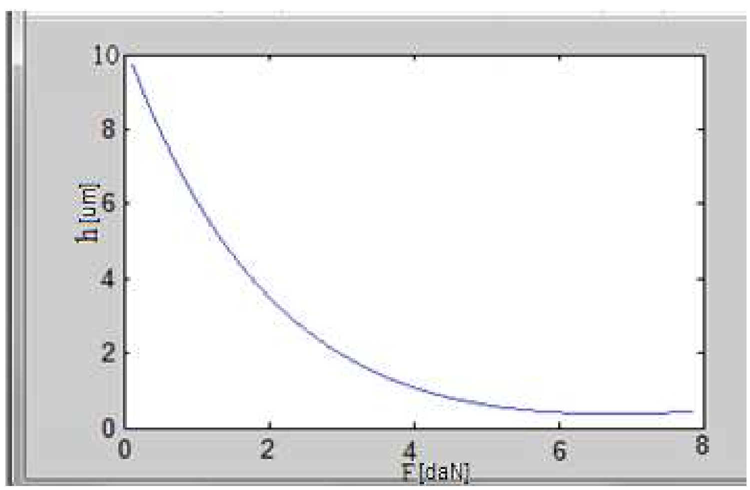

Fig. 6. Variation of the film thickness h, as a function of external loading, *F*.

6. CONCLUSIONS

This paper shows the possibility for use of porous restrictor on the hydrostatic guide ways. A mathematical model was developed that describing the behavior of a porous restrictor as part of a simple hydrostatic guide way. The result was obtained by implementing of the equations in Matlab2009b software. From the characteristics obtained after model implementation it is remarked that the increase of the external loading leads to the decrease, in the unwanted manner, of the film thickness *h*.

The modification of the porosity due to clogging of restrictor will influence the constant k_p and will change the geometric constant of the restrictor. The pumping power is directly proportional to the supply pressure and

carrying capacity as well. The conclusion may be made that a high pumping pressure is recommended in order to obtain a high carrying capacity, but this will lead to considerable pumping effort, so a costlier pumping group.
By analyzing the Figure 6 it may be noticed that there is the disadvantage of the decrease of the film relative thickness upon the load increase; however, in this case the maximum relative rigidity is superior to that of supply through capillary pipe. It may also be noticed that for several variation intervals of h, the rigidity of the hydrostatic guidance supplied through a porous restrictor is higher than the rigidity given by the capillary pipe, at relatively higher flows.

With reference to the optimization of the supply pressure – Figure 5, it may be asserted that on low speed guidance its value can be decreased in order to decrease the pumping power, if at the same time the total surface will decrease; in case of high speed guidance, a low friction power can be obtained if the friction surface of the thresholds will be decreased, even though p_a is high. The correlation of the supply pressure with the threshold friction surface is, on the other side, imposed by the carrying capacity that has to be provided. It is preferable in conclusion, that p_a is as low as possible, thus contributing to the decrease of the pumping power and regime temperature.

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