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APPLICATION OPTIONS OF ROLLER AND HYDROSTATIC BEARINGS IN MOTOR SPINDLES

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Abstract: Due to higher requirements for accuracy appearing in machining, hydrostatic bearings have begun to be used in the motor spindles of high precision machine tools. These types of bearings have much better static stiffness and damping ratio, than rolling element bearings, but their rotational speed capability is strictly limited. This paper deals with the examination of hydrostatic bearings applications at high-speed machine tool spindles.

Keywords: *hydrostatic bearings, damping capability, rotational speed*

1. INTRODUCTION

Plain-bearing is one of the main variant of bearing technology. The surfaces of shaft and bearing slip on each other by the help of evolving oil film or grease, which are in accordance with the necessary requirements. Hydrostatic bearings pertain to the plain-bearings. In the hydrostatic bearings, the oil films are evolving by excess pressure developed by an external pump, so as to ensure the non-contact operation and load support capability. The main goal is that the flow rate must be nearly independent to loads, constantly. Under bearing loads, the clearances between shaft and inside bearing surface are changing too. To compensate this effect, orifices or capillaries must be maintained in front of the bearings recesses [1], [2].

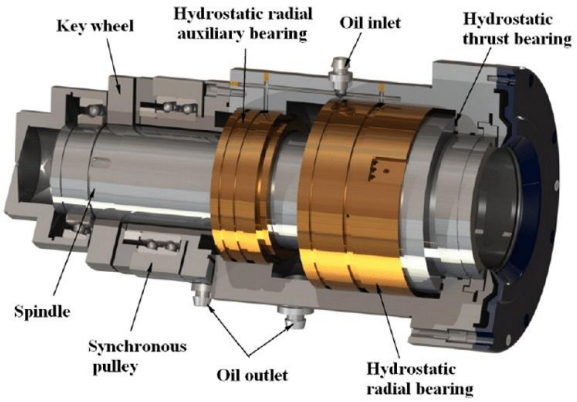


Figure 1. Motor spindle supported by hydrostatic bearings [3]

2. APPLICATIONS

These bearings are capable of the most support assignments, however due to expensive auxiliary arrangements, the economical operations are only potential, where ball bearings cannot be used and furthermore the fluid frictions are not provided by any other methods.

Moreover, hydrostatic bearings are widely mounted to high precision instruments and machine tools *(Figure 1)*. The main reason is, that the high bearing stiffness and low friction are primary requirements of these devices. Large-sized machines are also supported by hydrostatic bearings in case of the auxiliary arrangement's costs are much lower, than the machine price or the installation of ball bearings is uneconomical. The gradual application spreading is due to high stiffness and the significant damping capability are well combined, with which the surface roughness can be improved. The bearing design is almost optional: plain, spherical, cylinder and the combinations of these shapes can be chosen. The static stiffness and load support capability of hydrostatic bearings are independent from the fluid's viscosity (only from fluid pressure, and flow resistance at feed restrictor and the surface of oil film), so non-Newtonian fluids and gasses could be used [1], [2].

3. COMPARISON OF BALL AND HYDROSTATIC BEARINGS

In motor spindle applications, beside of the conventional ball bearings (steel or ceramic ball designs), most commonly hydrostatic bearing mountings are being used. So it is worth to make a comparison between these bearing designs in accordance with machining respects.

3.1. Load support and Stiffness

At hydrostatic bearings, the loads dissipate on a larger surface. That is why, compared with ball bearings (depends on the performance of external pump), these bearings support twice more. Their self-adjusting abilities derived from operating principle, so they are able to keep the original bearing centre-point. Moreover, in stable operating territory, load support capability does not depend on rotational speed loads *(not like hydrodynamic and rolling bearings, Figure 2).*

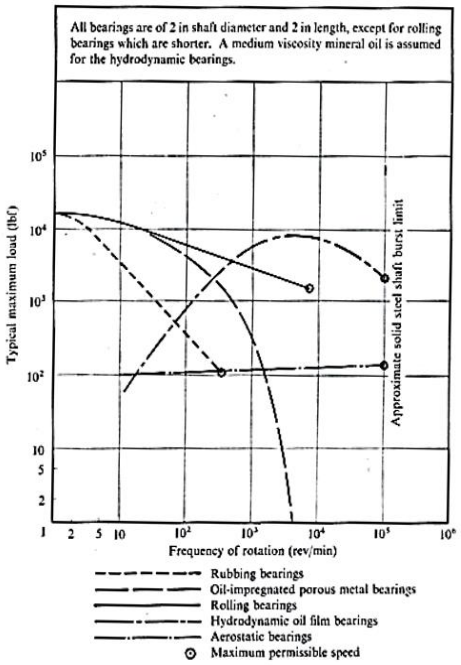


Figure 2. Bearing designs comparison in function to load capacity and rotational speed [5]

Ceramic balls have 50% larger modulus of elasticity, than steel balls, with that 20% larger rigidity can be reached, increasing the stiffness. In case of hydrostatic bearing, it can be achieved N/nm stiffness range and contact-deformation effects are not absent [4–6].

3.2. Accuracy and damping ratio

Ceramic balls have much better surface roughness, with that reducing the vibration and shaft swings. Accuracy of hydrostatic bearings depends on the manufacturing tolerances of bearing parts. Maximal rotational accuracy can be reached between 50 μm and 0,1 μm *(Figure 3).*

Hybrid bearings has also better damping ratio than steel bearings. The thin oil film in hydrostatic bearings produces excellent damping in either directions: through compressibility of fluid film in normal direction and fluid shear rate at tangential direction. Damping ratio is particularly important coefficient, when the main goal is the manufacturing of really low surface roughness *(mirror surfaces).* The productiveness can be improved, because the polishing operation could be negligible in most cases [4–6].

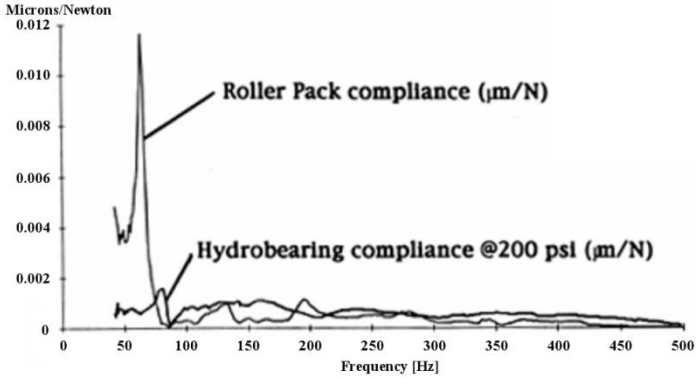


Figure 3. Comparison of bearing compliances at 200 psi ≈ 14 bar, in function to frequencies [8]

3.3. Friction and thermal properties

Though by using hybrid ceramic bearings, the coefficient of friction and channelling effect can be reduced, these bearings have strictly limited service life. On the other hand, due to parts in the hydrostatic bearings slip on each other through a fluid film, friction is nearly zero and wear will not occur.

At ball bearings, due to heat produced by friction, additional external cool and lubrication systems need to be installed. Because of fluid pressure, energy is induced into the hydrostatic bearing. The oil oozes out slowly from the bearing into a drip pan. In the pan, the pressure and flow rate are nearly zero, so all initial energy turns into fluid shear. This energy dissipates as heat. The rise in temperature

of oil also depends on heat produced by the machine. With this effect taking into account, it is worth using the possibly lowest pressure and flow rate at hydrostatic bearings. The fluid shear also generates heat in the bearing clearances at high speeds [4–6].

3.4. Rotational speed

By hydrostatic bearings only fluid friction are developing in fluid films during movement. In this case, the flow is laminar. However, at high speeds hydrodynamics effects occur, which tend to change the flow from laminar to turbulent. This occurrence leads to vibrations and shaft deflections, that finally results total bearing failure. For compensating this disadvantage, several research has made so far. With patterned *(ribbed)* internal bearing surfaces, the dynamic stiffness can be improved. Moreover, using of non-Newtonian fluids *(electro- and magnetic-rheological fluids)* results better controllable real-time balance [7].

Table 1
Maximal speed capabilities at different bearing designs [5]

Bearing type	Estimated maximum speed (dN factor)
Steel ball bearings	1 000 000
Ceramic ball bearings	2 000 000
Hydrostatic bearings	1 000 000

The table shows the achievable maximum speed capabilities of different bearing designs. For the characterization of speeds, dN factor is prefer being used, because the bearing rotational speed (*N- 1/min)* significantly connects with its diameter *(d-mm).* The allowable rotational speed of steel ball bearings are nearly equal to the hydrostatic bearings. The density of ceramic balls is only 40% of those in conventional steel bearings. If hybrid ceramic bearings are installed in motor spindle, then the centrifugal force will be reduced at the adjusted preload, so this bearing design are highly recommended at high-speed applications [4–6].

3.5. Reliability and costs

Roller bearings have limited service life, the long term collapse is typically output by bearing runway fatigue or the termination of appropriate lubrication. The bearing life time is being significantly reduced if the operating temperature rises or the machine load is too high. The roller bearings are especially sensitive to the contaminations, so the assembly must be performed in the possible cleanest environment. During operating, labyrinth seals and air-cleaner instruments are usually adopted to prevent the cooling and cutting wastes getting into the bearing. The lubrication effect of ball bearings, exposed to humid environment for a long time, greatly deteriorates in case of grease lubrication. Machine collisions usually cause bearing runway deformations *(brinelling),* if the loads are heavy during

impact. Most parts of roller bearings rotate at high speeds, which can generate noise during specific environment. The noisy spindle is the result of bearing malfunctions, in such cases the bearing replacement must be performed as soon as possible.

The features of hybrids bearings assist to reducing wear, meanwhile improving corrosion-resistance and lubrication life. In addition to high service life, lower vibration state and noise level can be reached with silicon-nitride balls.

Hydrostatic bearings are non-contact bearings, so they have infinite service life in theory. However, during operations the appropriate filtration of lubrication fluid is indispensable. The fluid constantly flows from gaps, thus greatly prevent to get contaminations into hydrostatic bearings. Most cases, the part is closed hermetically so as to estop of the lubrication fluid pollution. If the sealing is damaged and polluted by coolant, then the lubrication oil must be exchanged periodically.

The parts of high precision ball spindles have strictly geometric tolerances *(0,002–0,003 mm shaft diameter tolerances)* which cause higher manufacturing cost. Installation of these bearings requires highly skilled workmen and additional mounting costs *(parts heating for fitting).* Ball bearings are very sensitive to contaminations: the installation and operating environment must be clean. Supporting optimal operating, bearings must be chilled and lubricated by auxiliary equipment. Newly installed roller elements of ball bearings with grease lubrication must be run in protractedly and carefully. In the course of the gradual increase of spindle rotational speed, grease can distribute properly among roller elements in the bearing *(Figure 3)*. Due to higher prime costs, hybrid bearings were not able to spread widely, but owing to different manufacturing improvements, their purchase prices are much lower nowadays.

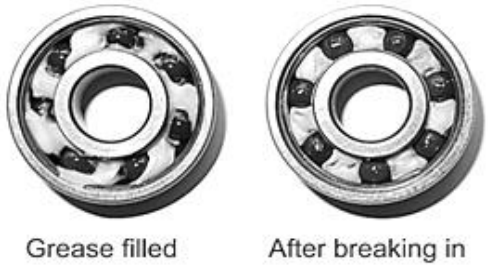


Figure 4. State of the hybrid bearings lubrication before and after breaking in [9]

On the other hand, tolerances of hydrostatic bearings are significantly higher. Because of the simple construction, the installation into the motor spindle requires less time. The lower tolerances cause higher clearances between the shaft and internal bearing ring, so heating is not necessary at mounting. Because of hydrostatic bearing features, the maintenance cycles are fewer, and take less time against ball bearings. The main operating costs are derived from the auxiliary

equipment: external pump, filters, valves, cooling units, pressure switches as well as hydraulic tanks and batteries. The maintenance of these instruments must be regular, because of their limited service lives [4–6].

4. CONCLUSION

The application of hydrostatic bearings could replace ball bearings in motor spindles, however the rotational speed limitation, derived from turbulent flow, does not allow widely. It is worth making additional researches because they have excellent damping capabilities which are necessary for high precision machining. A turbulent flow model should be set up to examine the hydrodynamic phenomena. Moreover, the application of controllable fluids could be considered to reach better real-time balance.

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