

Cast Monolithic Hydrostatic Journal Bearings

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Abstract

In this work a self-compensating hydrostatic journal bearing design, which eliminates all but one precision-manufacturing step, was manufactured and tested. Novel manufacturing methods for different sizes are introduced. The bearing sensitivity to manufacturing errors was analyzed computationally using statistical methods. These results were used to show that the introduced manufacturing methods are more cost effective than the traditional precision manufacturing methods for hydrostatic bearings, even when the performance variation is taken into account. Manufactured bearings were tested and the experimental results were compared with theoretical results and satisfactory agreement was achieved.

The bearing geometry is shown in Figure 1. The surface geometry on the internal surface achieves compensation and the bearing is able to carry load without any external restrictor devices, hence the name surface self-compensating hydrostatic bearing. This type of bearing generally achieves similar or slightly better performance as a bearing with fixed compensating devices (for example orifices or capillary tubes). Also, the bearing system is simplified since only single hydraulic line is needed and the number of parts is reduced. The only problematic question has been, how to manufacture the surface geometry, shown in Figure 1, on the internal surface of the bushing and how accurately they should be manufactured.

In order to manufacture the internal surface geometry, different casting and molding methods were explored. The most convenient and economically viable methods, especially for small quantities, are processes where the mold is broken after the part material has cooled. Such methods are, for example, sand casting and investment casting. Sand casting, in this case, requires a special core box to make the sand core with the desired geometry. Investment casting requires patterns for each produced part and due to the part geometry traditional pattern making methods were not applicable. Rapid prototyping methods offered the required versatility to produce the investment

casting patterns. These methods were selected for producing two different size prototype bearings..

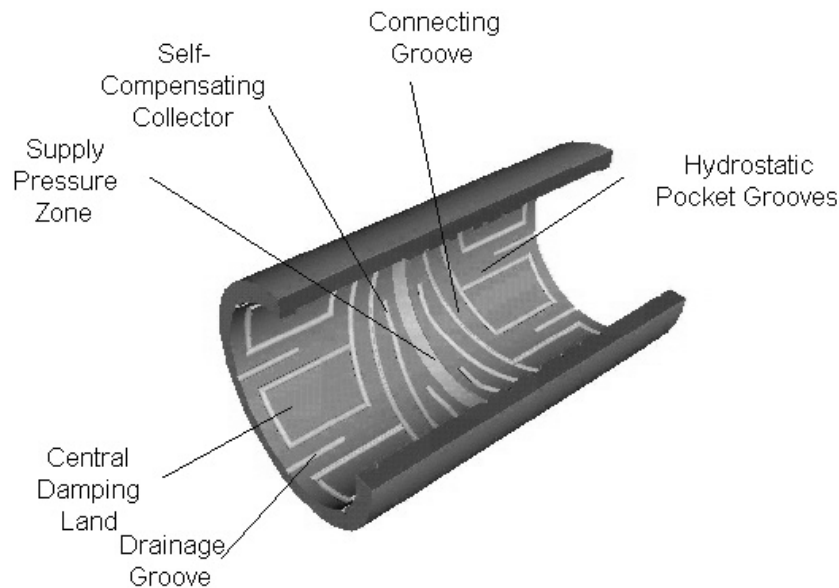


Figure 1 Cut open view of the bearing

The actual dimensional variation was measured from the manufactured parts. This information is used to determine the effect of manufacturing errors to the bearing performance. This was done by statistical methods (Monte-Carlo method). The distribution of the manufacturing variation was determined to follow Gaussian distribution by Chi-square test. Trends were searched with run test, but none were found. The static bearing performance is modeled with a hydraulic resistance network, where the bearing geometry is lumped into equivalent hydraulic resistances. The hydraulic resistance is calculated with the assumption of one dimensional, fully developed, highly viscous flow between two flat plates. If the area which is lumped into a single hydraulic resistance is small enough, the assumptions are very accurate.

The dimensional variation introduced by the manufacturing method is modeled by assigning each of the land widths a probability density function (pdf). This is obtained from measuring the bearings or estimated if the variation is not known. After pdf's are defined, Monte-Carlo method is used to compute the bearing force histogram. From this data it is possible to define the bearing

output (usually force) pdf. In the case of the 6" bearing the measured data will be used to perform the analysis. The standard deviation and the mean offset are $\sigma = 3\%$, $\Delta\mu = 4\%$ respectively. These correspond to approximately 0.2mm errors, which is a reasonable number for this size casting. Figure 2 shows the distribution at $ecc=0.1$ together with the overlaid normal distribution with the computed mean and standard deviation. Table 1 summarizes the results at different eccentricities.

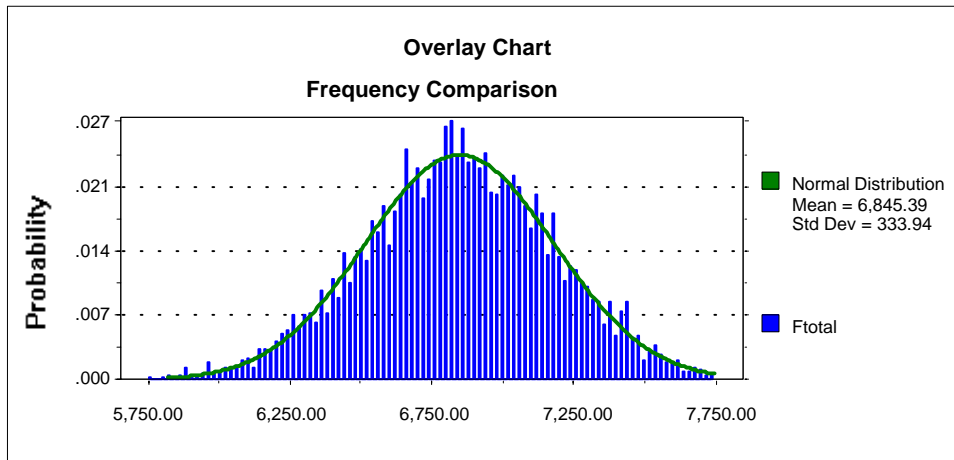


Figure 2 Bearing force distribution with $ecc=0.1$, $\Delta\mu = -4$, $\sigma = 3\%$ of groove width

TABLE 1 Summary of the results for $\Delta\mu = 4$, $\sigma = 3\%$ of the land widths case

Eccentricity	$F_{nominal}$	μ_F	σ_F	$\phi_{nominal}$	μ_ϕ	σ_ϕ
0.1	6832	6843	328	-28.1	-28.1	2.9
0.2	13139	13146	314	-28.2	-28.3	1.4
0.3	18563	18567	288	-28.5	-28.5	1.0
0.4	22966	22974	266	-28.8	-28.8	0.7
0.5	26387	26398	251	-29.1	-29.1	0.6

It was attempted to derive a variable that would combine the effects of manufacturing quality with the cost of the particular manufacturing method. This was done by integrating the computed pdf together with a quadratic cost function to calculate the mathematical expectation for the cost. This single number can then easily be compared between different manufacturing methods to determine the most cost effective. The power of this method is that it automatically takes the cost and

the accuracy of the manufacturing methods into account. The values of this number for the two methods introduced here varied between 1.3-2 times the manufacturing cost, depending on the calibration of the cost function.

Bearings were also tested and good agreement between predicted and measured results was achieved. As an example the initial stiffness (taken as a linear fit at 500N) results for the 6" bearing are presented in Table 3.

TABLE 2 Initial Stiffness at 250 psi

Measure	Value	Unit
Predicted Initial Stiffness	1770	N/ μm
Measured Initial Stiffness	1915	N/ μm
Difference	7.6	%

The combined radial and tilting error motion trace for multiple revolutions is shown in Figure 3. The maximum deviation from LSC is $0.20 \mu m$ and the mean deviation $0.05 \mu m$. This test was run at 6 rpm and there are 10 revolutions in the error motion trace.

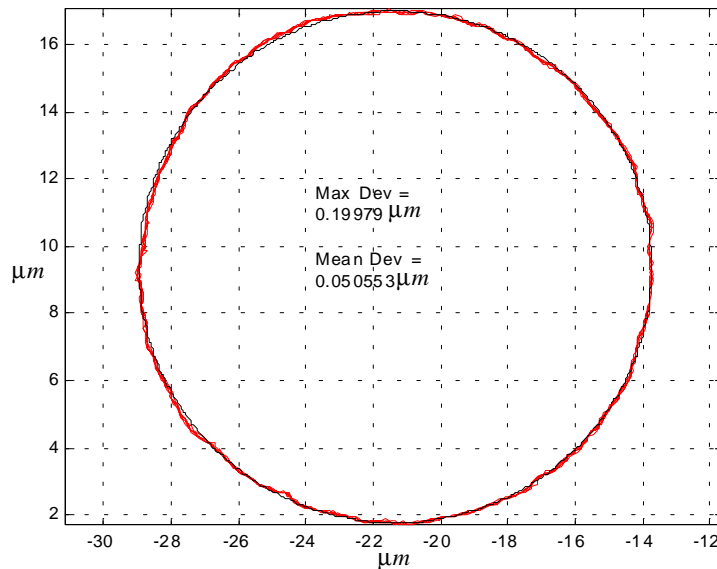


Figure 3 Error motion for multiple revolutions