Design of Hydrostatically Balanced Bearings of Radial Piston Pumps by the Use of FE Computation with Interaction of Multibody and EHD Simulation

Dr.-Ing. Tino Kentschke

MOOG GmbH, Hanns-Klemm-Strasse 28, 71034 Böblingen

Abstract

In the actual MOOG R&D projects a new computation software tool was used for the verification of bearing capacity of pre-designed geometries of hydrostatically balanced bearings of radial piston pumps RKP in prototype phase. This software tool combines multibody computation and elasto-hydrodynamic theory (EHD) with a sequenced solution of Newton's Equation of motion and Reynolds Equation of flow. The computation considers both geometrical boundary conditions such as bearing clearance and surface roughness of the contact partners and operational conditions such as relative velocity, forces resulting from pressures, friction coefficients and fluid viscosity. Local deformations of surfaces resulting from multibody computation are directly used as boundary conditions for the solution of the Reynolds Equation of flow. The results of the computation for the bearing geometry are for example the distribution of bearing gap width, the local bearing pressures and, if mixed friction occurs, the local contact pressures. For verification of the software the model of a proven bearing with accordingly substantial knowledge regarding operational and wear behaviour was set up and calculated.

KEYWORDS: piston pumps, tribology, slide bearings, computation, EHD

1. Introduction

To ensure reliable functionality and to reduce friction losses, the forces on highly loaded bearings in hydraulic pumps are hydrostatically balanced. In this case the generated pump pressure in combination with adequate dimensioned geometrical design features is used to reduce of the acting force in the friction contact down to an optimal value regarding lowest friction and volumetric losses.

In the dimensioning of a balancing feature the geometric data of the feature itself can be calculated with values of the acting external force, the pressure drop in the bearing and with experience and knowledge regarding the tribological load capacity of the used material combination of the parts. After this calculation procedure prototype parts and components are manufactured, qualified in test procedures and if necessary optimized.

In bearings with high relative velocity, for example the control journal – cylinder block bearing of an internal pressurized radial piston pump (RKP) (**Figure 1**), additionally the arising hydrodynamics have a significant impact on the deriving bearing gap geometry. Furthermore the local and time variable deformations of the contact partners resulting from varying pressures and forces lead to significant impacts on the bearing behaviour.

The individually available algebraic dimensioning approaches for these hydrostatically balanced bearings do not consider these hydrodynamic effects or deformations. In former times after prototype testing a higher number of loops of parts geometry optimization with new prototype tests was necessary, until sufficient results were obtained.

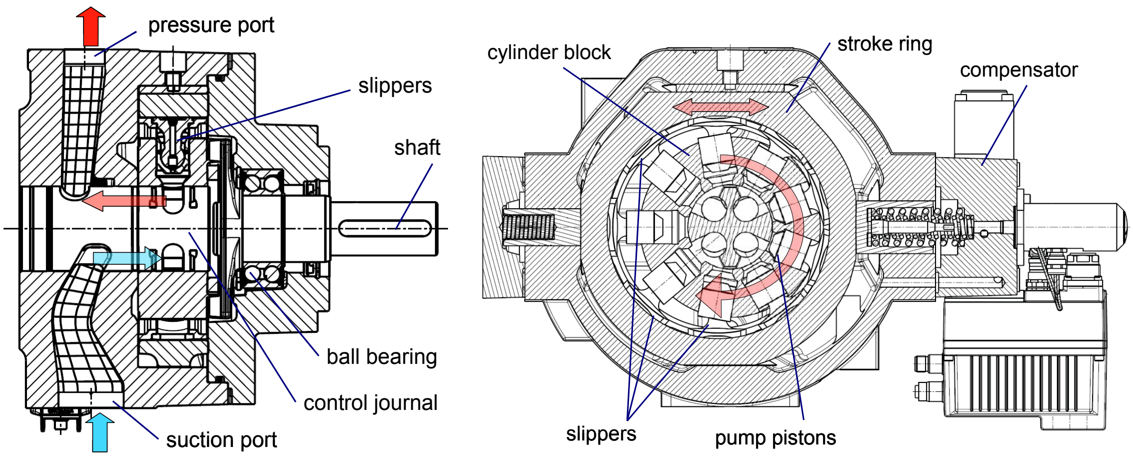

Figure 1: Schematic of Operation of a MOOG-RKP /1/

To reduce the time effort and the inherent prototype and test costs in the development of new products, MOOG now uses a new software tool. With this tool a computation and an evaluation of the complex running behaviour of bearings with consideration of hydrostatics, hydrodynamics and deformation is possible. Thus the predictive accuracy before prototype manufacturing and test is largely improved.

As an example in this paper the results of the computation of a control journal – cylinder block bearing of a RKP are shown.

2. Control Journal – Cylinder Block Bearing of MOOG Radial Piston Pump

In the pump operation of a MOOG RKP the rotatory driven cylinder block and the fixed control journal create a slide bearing (**Figure 2**).

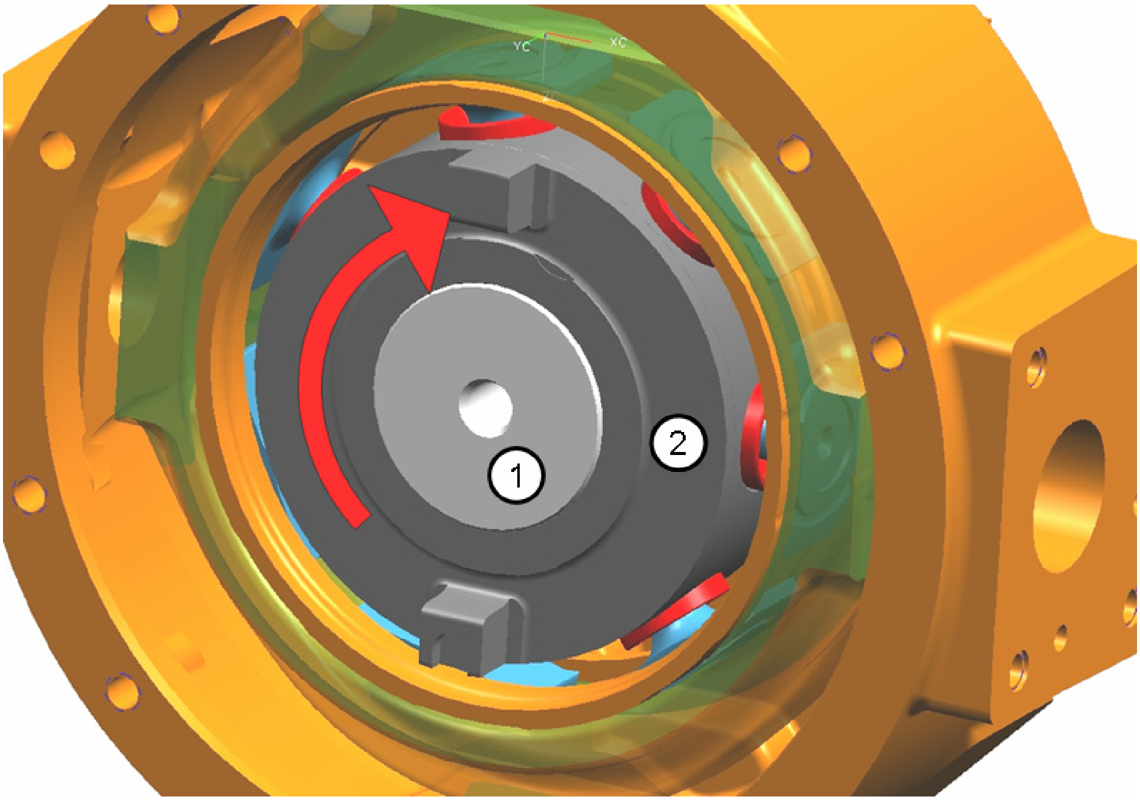

Figure 2: Control Journal (1) – Cylinder Block (2) Bearing of a MOOG-RKP

This slide bearing must be capable of withstanding the relative velocities and pressure forces generated by the pump pistons. To achieve this, a large proportion of the pressure force is hydrostatically balanced over a suitable design of balancing grooves in the control journal (**Figure 3**). The acting force in the friction contact is reduced by this amount.

For the dimensioning of this balancing feature an algebraic calculation approach exists, using the ratio of the pressurized faces of cylinder block and control journal. Using this approach and experience, a pre-calculation of that balancing design is possible.

Additionally the real bearing behaviour is significantly affected by velocity-dependent hydrodynamic effects, by local and global structure deformations and by its interactions. For a meaningful estimation of these influences a powerful, computer aided, numerical simulation tool is necessary.

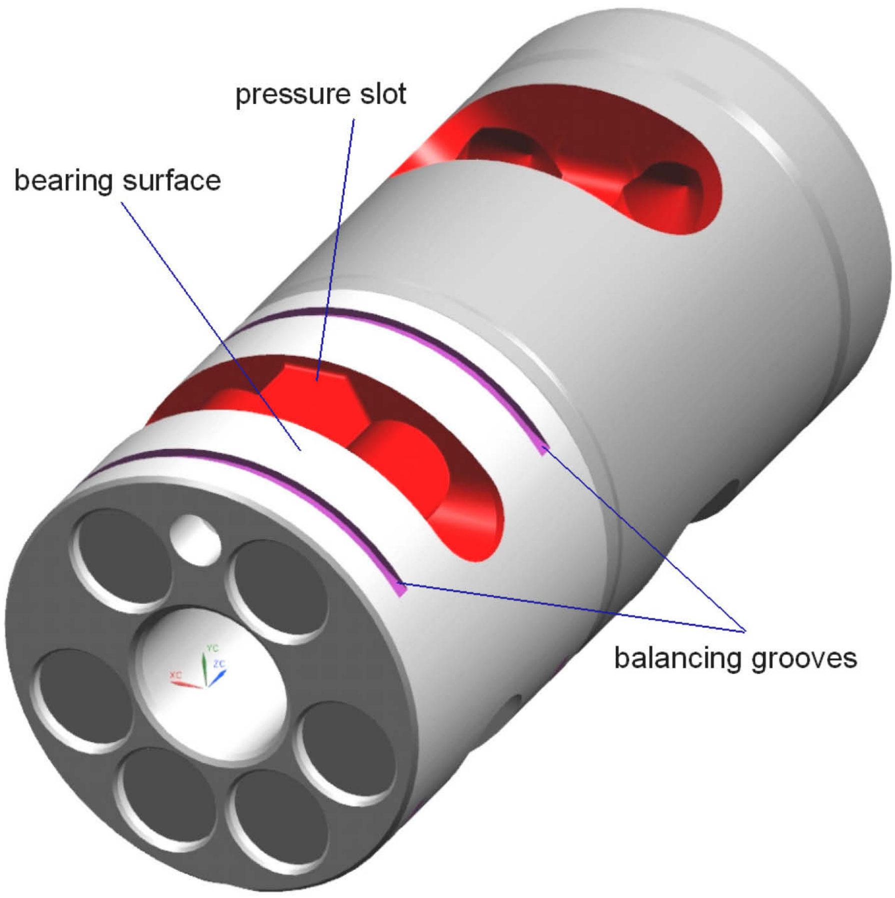

Figure 3: Control Journal of MOOG-RKP with Balancing Feature

3. Algorithm, Parameters, Computation Results

3.1. Software Algorithm

The commercial FE simulation tool is typically used in automotive industry for computation of slide bearings in structures of combustion engines. This tool allows an analysis of structure dynamics of cylinder block and control journal with consideration of the elasto-hydrodynamic coupling of the bearing.

The tool couples the subdomains multibody systematics, structure dynamics and hydrodynamics and enables a hydrodynamic and structure dynamics evaluation of the whole considered system and its occurring interactions /2/.

The software algorithm consists of a stepwise solution of Newton's Equation of motion in the time domain. With consideration of the acting boundary conditions at start of computation the local accelerations are calculated. Then these accelerations are used in an integral calculation to determine positions, deformations and velocities. These quantities are the boundary conditions for the following solution of the Reynolds Equation in the hydro bearing surface. The resulting reactions on the structure (state of motion of bearing, hydrodynamic bearing forces) together with the other loads (pressure forces, drive forces, internal structure forces, vibrational forces) are the basis for the solution of Newton's Equation in the next time step.

Based on typical FE meshes cylinder block, control journal and pump housing are modelled as elastic structures (**Figure 4**).

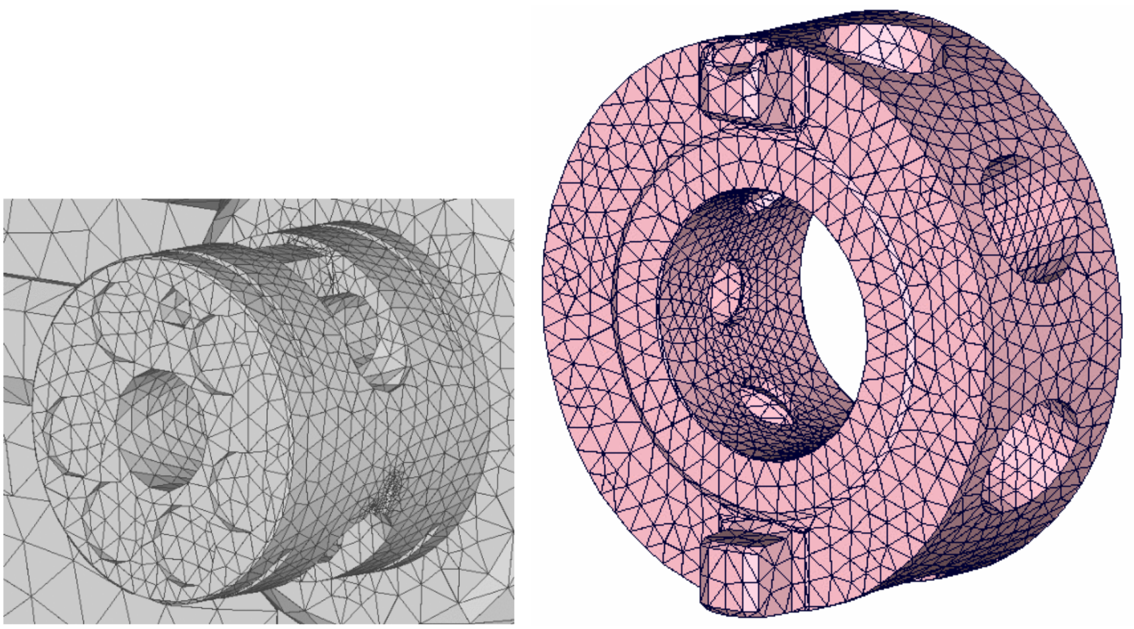

Figure 4: FE-Models of Pump Housing with Control Journal and Cylinder Block

The coupling of the elastic structures of cylinder block and control journal is realized by hydrodynamic lubricating film forces in the bearing. Therefore an EHD substructure (hydro mesh with plane elements) is created on the bearing surface (**Figure 5**). This is practicable, because in Reynolds Equation a constant pressure over the gap width is considered. For a reliable mapping of deformation states and pressure distribution the hydro mesh is typically meshed much finer than the volume geometries of cylinder block and control journal. The picture at the right hand side in **figure 5** shows the gap situation for concentric position of cylinder block on control journal.

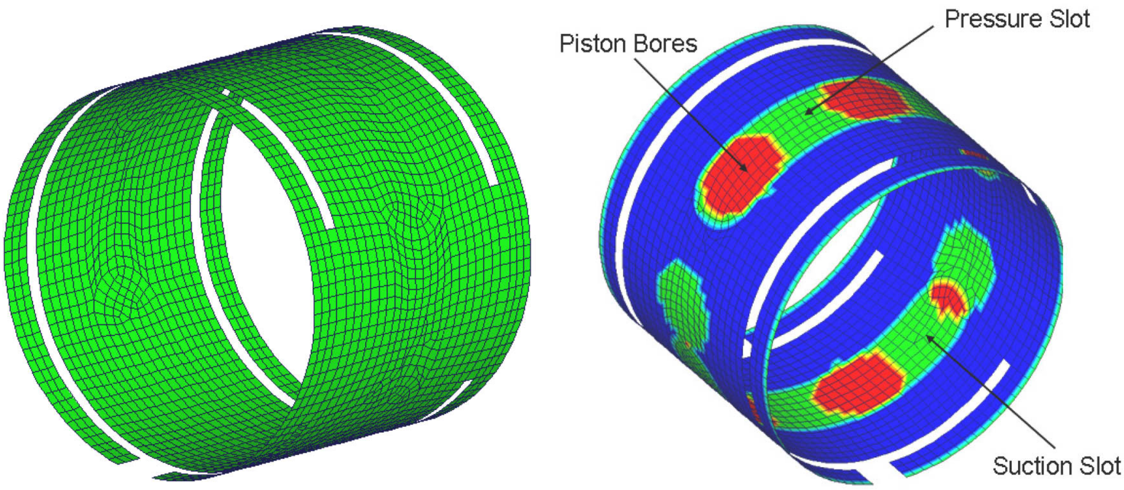

Figure 5: Hydro Mesh as EHD Substructure – Concentric Gap Situation

3.2. Parameters and Boundary Condition Needed for Simulation

For the computation of the bearing model different parameters and boundary conditions are required, describing the contact and also the behaviour of the parts. In this simulation the following inputs were applied:

- bearing clearance
- surface roughness of contact partners
- Coulomb's solid friction coefficient
- viscosity
- material density of control journal and cylinder block
- rotational speed (applied with rotational drive in the barycentre of cylinder block)
- piston pressure characteristic (depending on rotation angle)
- pressures in suction and pressure channel and in pump housing
- fixation of housing geometry

3.3. Computation Results

After post-processing the following outputs of computation amongst others can be plotted:

- movement and tilting of the bearing parts due to deformation, pressure and motion excitation
- local, rotation angle dependent gap width in the bearing
- local pressure characteristic in bearing gap
- local contact pressure characteristic when mixed friction occurs
- hydrodynamic dissipation

These quantities allow a comprehensive description of the expected running behaviour and functional capability of a control journal – cylinder block bearing of a RKP. In the following pictures the results of such a computation are shown. **Figure 6** shows an overview of the range of animated simulation results.

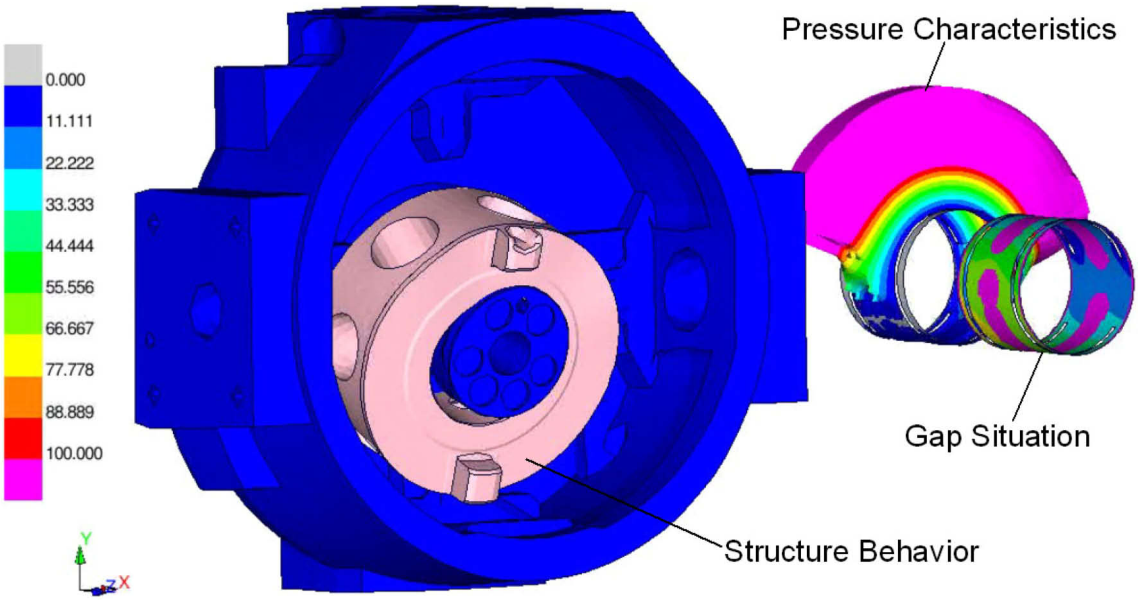

Figure 6: Overview of Simulation Results

Figure 7 shows a plot of the local maximum pressure in the bearing gap. The highest maximum pressure inside the marked area is mainly determined by the hydrostatic pump pressure (280bar). A small hydrodynamic proportion is overlaid.

Figure 8 shows an evaluation of the distribution of the smallest bearing gap. The marked field contains the minimal smallest gap on the front side of the bearing at the 1 o'clock position. This results from a slight cylinder block tilting during pump operation with high pressure.

Figure 9 shows the calculation result compared to a real control journal failed in the test stand, which underlines the practise relevant quality of the simulation results.

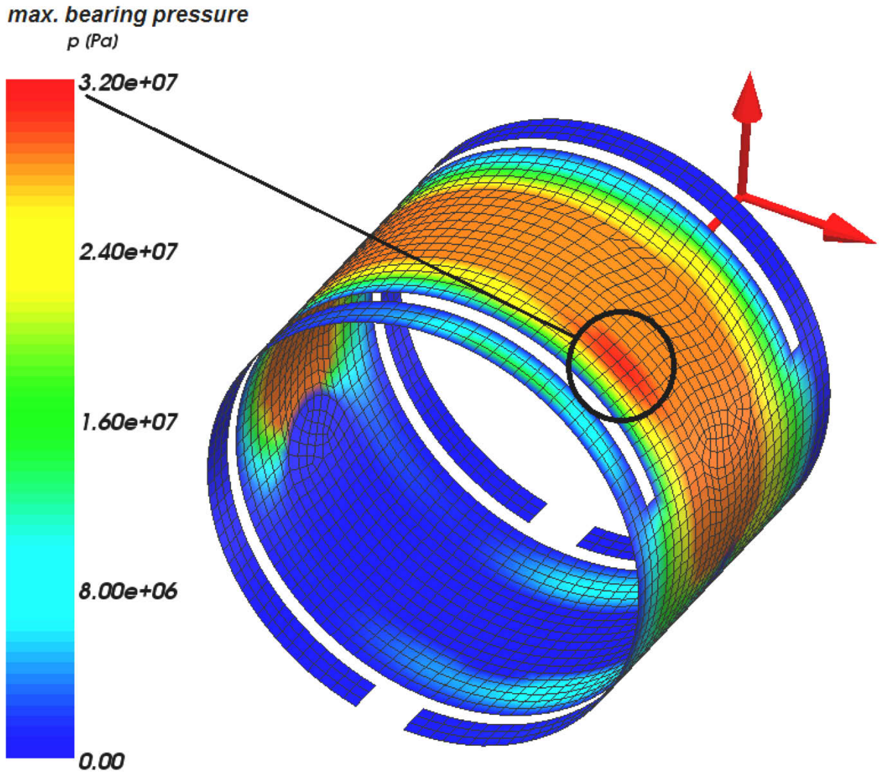

Figure 7: Maximum Pressure in Bearing Gap in Operation

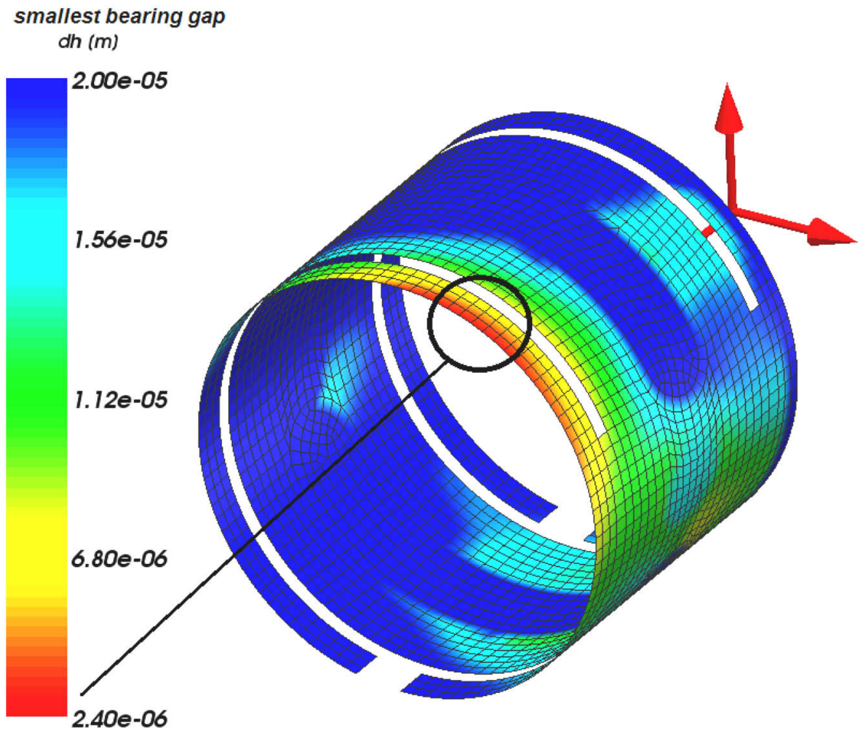

Figure 8: Smallest Bearing Gap Situation in Operation

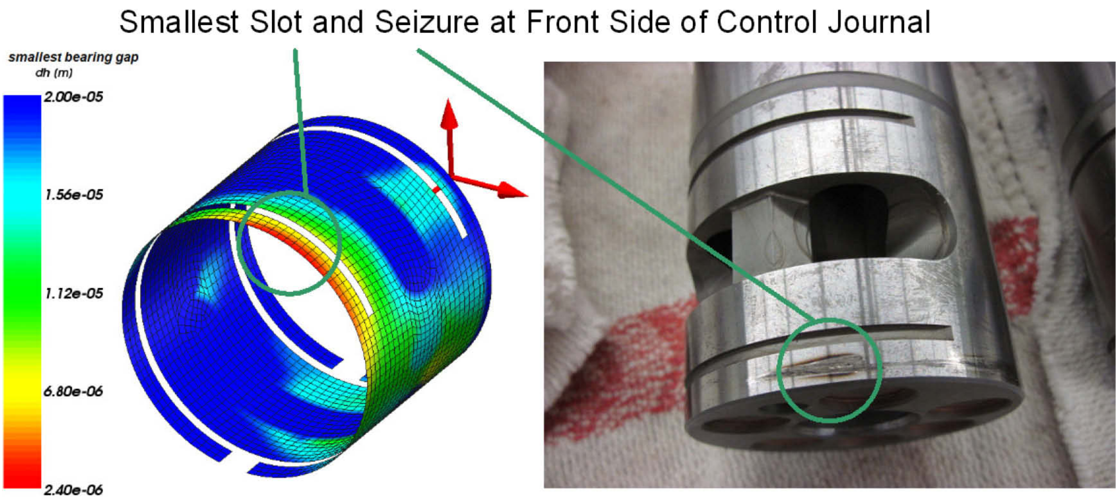

Figure 9: Comparison of Simulation and Real Failure Result

4. Conclusion

With the new software tool the running behaviour of a control journal – cylinder block bearing of a MOOG RKP could be modelled and analysed with good quality computation results.

Based on these results a targeted optimisation of the bearing geometry, especially the hydrostatic balancing feature, with regard to functional reliability is possible before expensive production and test of prototypes. Furthermore the computed gap geometry allows a prediction of the leakage behaviour, so that an optimisation approach regarding volumetric efficiency can be easily checked with this tool. In addition the model can be used for a quick pre-estimation of the influence of geometric tolerances on running behaviour of the bearing. Since the viscosity is used in the computation model the influence of changing fluid temperatures or also the use of different kind of fluids can be easily checked with a simple parameter variation.

5. References

/1/ Catalogue Radial Piston Pump, RKP-II, MOOG GmbH Böblingen, http://www.moog.com/literature/ICD/Moog-Pumps-RKP-Catalog-en.pdf , Germany, 2011

/2/ Knoll, G.; Lang, J.; Schönen, R.: Strukturdynamik von Kurbelwelle und Motorblock mit elasto-hydrodynamischer Grundlagerkopplung, Publication of Ingenieurgesellschaft für Strukturanalyse und Tribologie mbH (IST), Aachen, Germany, 2000