The interaction of a lubrication gap with a sealing

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ABSTRACT

In the present paper the interaction between the sealing and the oil in the lubrication gap between the sealing and a reciprocating piston rod is studied. On one hand the pressure $p(t, x)$ in the lubrication gap causes a deformation of the sealing and on the other hand the deformation of the sealing influences the shape of the gap and therefore the pressure distribution (see Fig. 1). The purpose of the investigation is to determine a shape such the net flux of oil through the lubrication during one oscillation cycle vanishes and that a lubrication gap reducing the wear of the sealing is maintained.

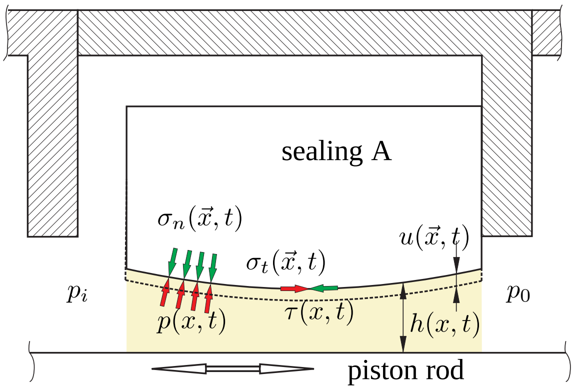

Fig. 1) The lubrication gap

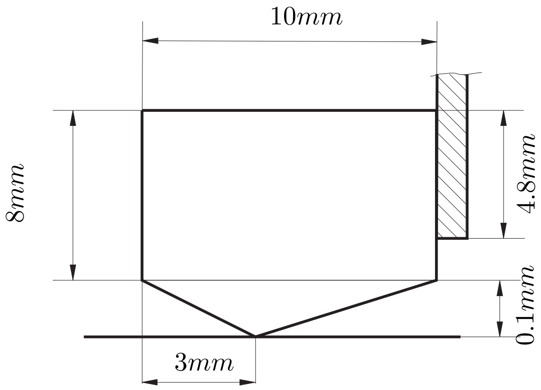

Fig. 2) Cross section of the undeformed sealing

The sealing can be considered as an elastic ring around the reciprocating piston rod. It is located in a chamber and it is pressed due to the internal pressure p_i which is larger than the ambient pressure p_0 towards the right wall of the chamber.

Thus the governing equations are the equations for an elastic body and the Reynolds lubrication equation for the oil flow in the gap. They are coupled by the kinematic and dynamic boundary conditions. Due the axis symmetric situation the the governing equations can be simplified. Inertia effects can be neglected in the fluid and the solid sealing as well. Thus a time derivative in the governing equations appears only in the continuity equation.

The equations for the elastic deformations are rewritten as boundary integral equations and a boundary element method (BEM) is applied [1] . Instead of deriving the the boundary element method for the axis symmetric case directly, a BEM for the 3-dimensional situation is considered which is reduced to the axis symmetric case by a symmetry transformation. The boundary conditions for the elastic deformation follow naturally from the geometric situation. A the right wall the displacement in both directions is set equal to zero. At all other boundaries the pressure acting on the sealing is given.

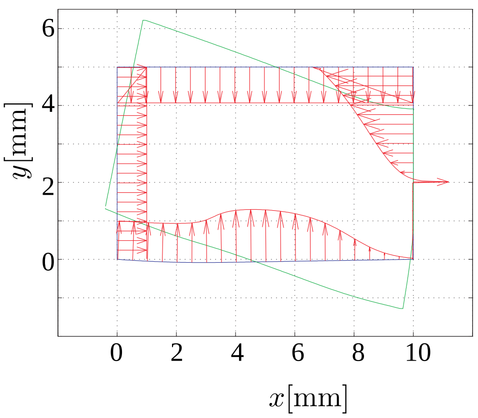

Fig. 3: Deformation (green, not to scale) of the sealing and stresses at crank angle $\varphi = 0$ (red)

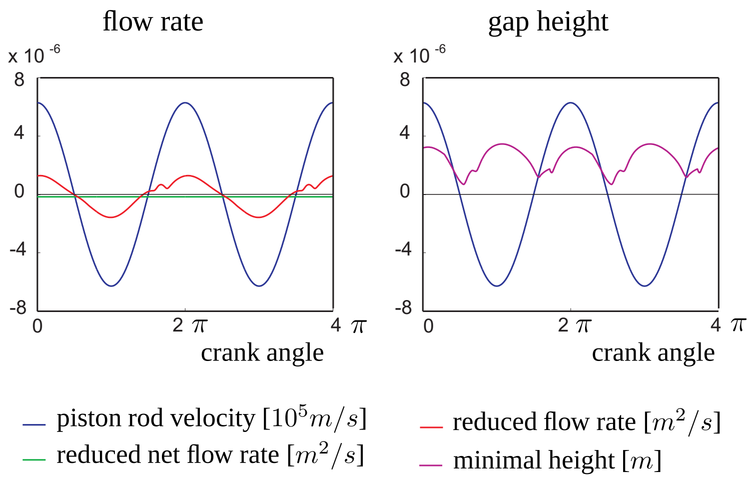

Fig 4: Flow rate and minimal gap height

The Reynolds' lubrication equation have to be supplemented with additional models for the cases of cavitation and contact. To avoid that the pressure in the lubrication gap drops below the vapor pressure a fictive density function $\rho' = \rho'(p')$ which depends only on the (scaled) pressure is introduced.

In order to avoid numerical problems if the gap width becomes too small a minimum gap width h_* is introduced. In a region where the gap width would drop below h_* the coupling conditions gap/sealing are changed. The gap width is kept there at is minimum value h_*. As a consequence the stress in sealing is there different form the pressure in the gap. Since this contact regions are very short with respect to time and length they influence the results only marginally.

Figure 2 shows an example of a sealing geometry for reciprocation piston rod sealing. The shape of the lubrication gap must have a convergent part for both directions of the rod motion to maintain the lubrication gap. Therefore the gap must have a convergent and a divergent part. However, in the divergent part the pressure may drop below the vapor pressure and cavitation can occur.

In Figure 3 the deformation of the sealing and the stresses at the surface of the sealing are shown when the piston rod velocity has its maximum outward velocity (to the right)

In both diagrams of figure 4 the blue line indicates the piston rod velocity. The violet line marks the minimal height of the lubrication gap, the red line the reduced flow rate at the right end of the lubrication gap and the green line the time averaged reduced flow rate. As shown in the left diagram of figure 3 the time averaged reduced flow rate is slightly negative. So there is a net mass flow from the outside to the inside against the pressure difference $p_i - p_0 > 0$ and therefore the sealing is, in a time averaged sense, leakage free.

However, it turns out that the averaged net flow is very sensitive to parameter variations and material properties like the viscosity of the oil. Since the viscosity of the oil is temperature dependent the net flux through the gap may change during operation.

References

[1] G. Beer, I. Smith, and C.Duenser, The Boundary Element Method with Programming

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