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# SURFACE FATIGUE AROUND A POINT ASPERITY WHICH PASSES A CYLINDRICAL ELASTOHYDRODYNAMIC CONTACT

## NSCM-29

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## 1 INTRODUCTION

Highly loaded contact surfaces will eventually fail due to surface induced rolling contact fatigue (RCF), often called pitting or spalling, where small pieces of surface material are chipped off. In 1935 Way[1] did a thorough experimental investigation of pitting and found some fundamental prerequisites for when the damage occurs, in particular the requirement of lubrication. Hannes and Alfredsson showed in 2010[2] that pitting like damage can be caused in dry conditions by an asperity of the same height as common gear surface roughness. To understand the damage mechanism, it is of great interest to understand how the lubrication affects the loading of the asperity.

The geometry of the problem was simplified to an elastic cylinder with an asperity against a flat surface, see Figure 1. A coordinate system was placed in the middle of the contact and the asperity was defined as rotational symmetric cosine wave with a wavelength $W$ and an amplitude $A$ at the time depending position $X_d$ from the contact centre at the $X$,$Y$ origin.

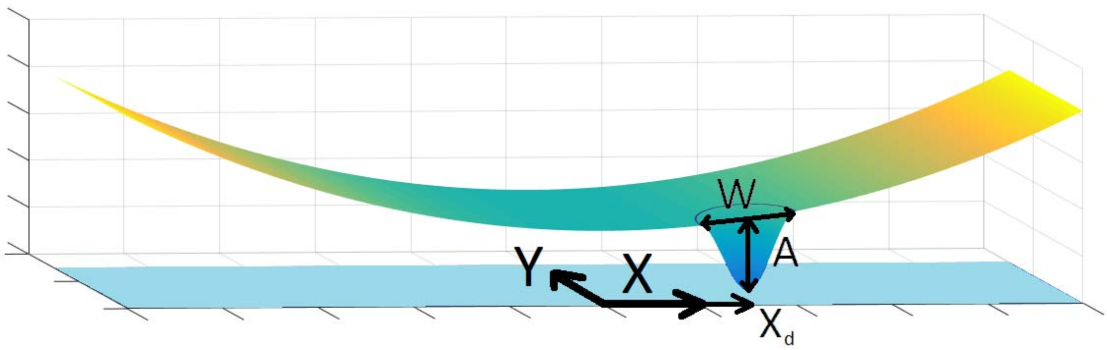


Figure 1. Simplified geometry of the lubricated gear contact reduced to a cylinder with an asperity against a flat surface.

In heavily loaded contacts the elastic deformations are much greater than the thickness of the lubrication film. These contacts are called Elastohydrodynamic lubrication (EHL) contacts. To solve EHL contacts the elastic deformation is coupled to the fluid dynamic simulations and a load balancing equation is used to determine the height of the lubrication. Furthermore, the viscosity of the lubricant changes with several orders of magnitude due to the high contact pressure. The high viscosity combined with rolling makes the problem weakly coupled in the transverse rolling direction. The coupled problem is described with Reynolds equation for the lubrication, Love's equations for the elastic deformation of the surfaces and the Boussinesq potential function for the stresses. Findley's multi-axial fatigue criterion was used to evaluate the fatigue load cycle on the surface to estimate if the load cycle may cause fatigue damage.

## 2 NUMMERICAL SETUP

To achieve a reliable numerical solution, the EHL problem was solved using the Finite Difference Method (FDM). The code follows that of Huang[4] which has the same structure as Venner and Lubrecht's setup[5]. An overview of the numerical scheme is presented in Figure 2.

To yield a starting point for the time dependent simulations the problem was first solved for a time independent case with flat surfaces. In the time independent simulation the load balance was evaluated for the lubrication height. This, global lubrication height, was then kept constant for the time dependent simulation. To yield faster convergence of the load balancing equation the problem was first solved on a course grid. The grid was thereafter refined multiple times until a solution is obtained for the specified fine grid size.

To avoid oscillations the relaxation parameter for the pressure update was initially set to low values. If the solution was converging the relaxation parameter was increased to decrease the computation time. To update the pressure, Reynolds equation was used to generate a residual which was minimized with a combination of the Gauss-Seidel and the Jacobi iteration scheme. The choice of scheme depended on the properties of the contact. In the inlet and outlet region Reynolds equation is of nearly elliptical character, while in the high pressure region the high viscosity reduces the equation to one of transport characteristics. Line relaxation was used to improve the convergence of the pressure iterations. The time derivative was implemented with the Crank-Nicolson scheme to yield second order accuracy.

Thereafter the elastic deformation was evaluated with Love's equations for surface loads on an elastic half plane. If the two bodies came in contact the pressure of the contacting nodes was increased with the aid of simplified estimations of the pressures effect on the elastic deformation. When no contact remained the remaining parameters of the problem was updated based on the new pressure estimation.

The convergence was then evaluated and the pressure estimate was deemed good if the difference with the past guess was small enough. When the whole time dependent problem had been solved, the Findley criterion was evaluated for each node and for all possible damage planes.

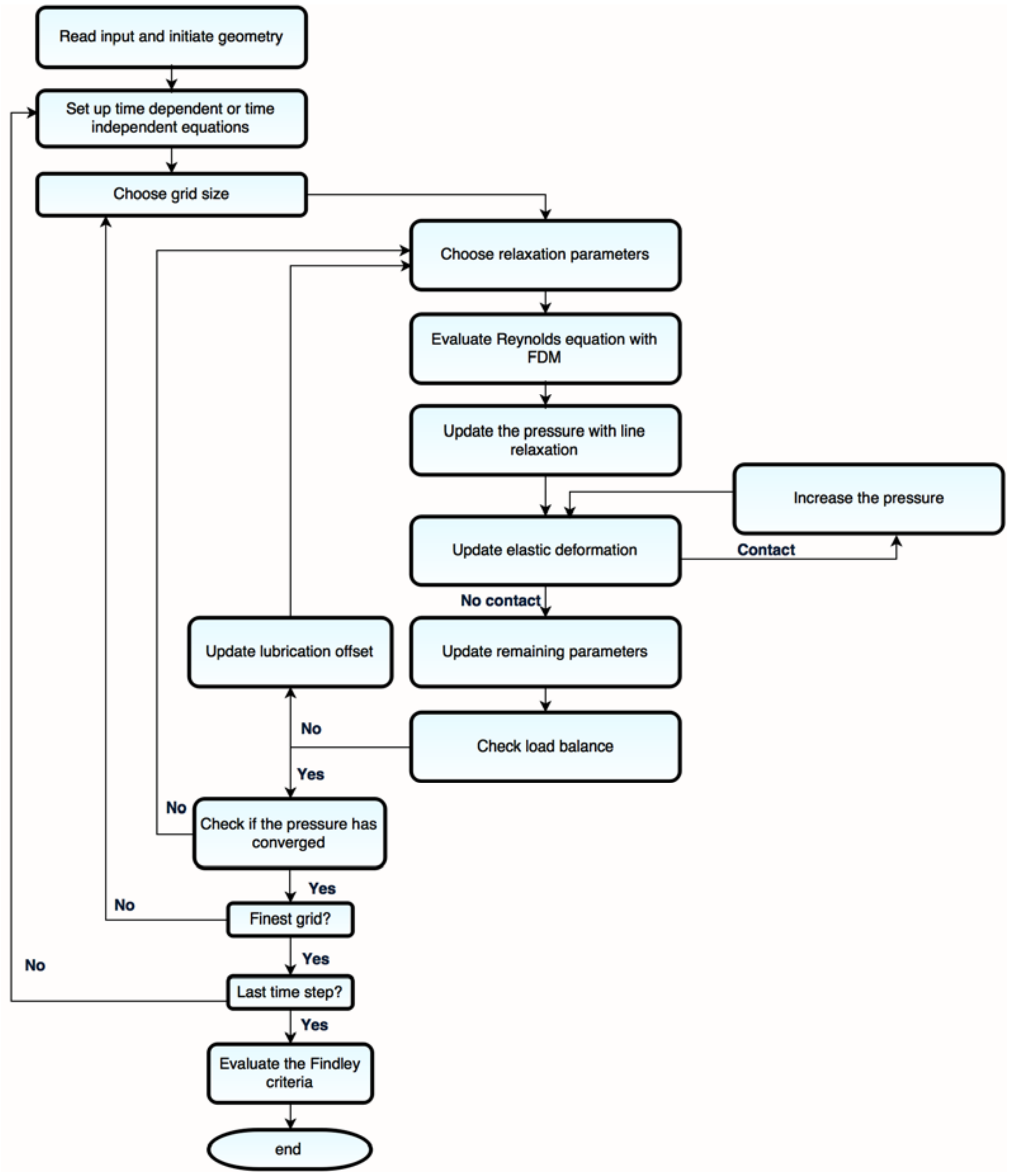


Figure 2. Schematic workflow of the EHL program.

## 3 RESULTS AND CONCLUSIONS

The FDM solution gave the cylindrical EHL contact pressure including the pressure on the asperity as it passes through the EHL contact. The contact pressure and the film thickness along the centreline are presented in Figure 3. The figure shows three instances: the time independent solution before the asperity has entered the contact, when the asperity has just entered the contact and when the asperity is at the rolling contact centre. Figure 4 presents the fatigue damage from evaluation of Findley's criterion.

The FDM code in Figure 2 was capable to produce stable time dependent solutions for contact pressure, asperity deformation and film thickness. It captured the local lubrication behaviour around the asperity as it passed through the cylindrical EHL contact, see Figure 3. The fatigue damage analysis in Figure 4 showed that local fatigue damage may develop at the asperity when it passed through the cylindrical EHL contact. The accumulated fatigue damage at the most loaded material point at the asperity was in the range where fatigue can be expected.

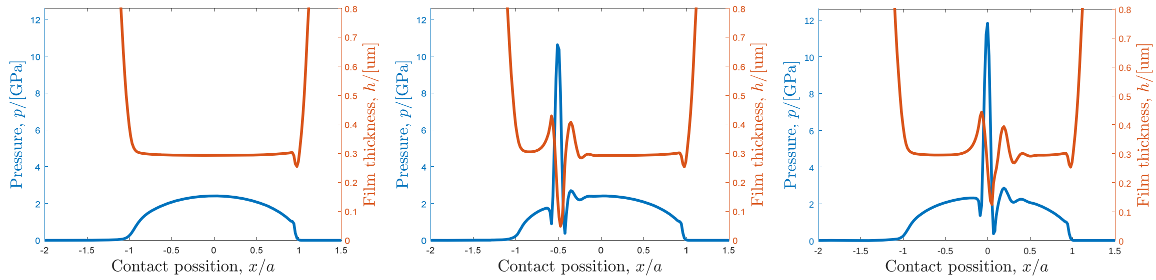


Figure 3. The contact pressure in blue and the film thickness in red for the contact centreline when an asperity of width 50 μm passes through the contact.

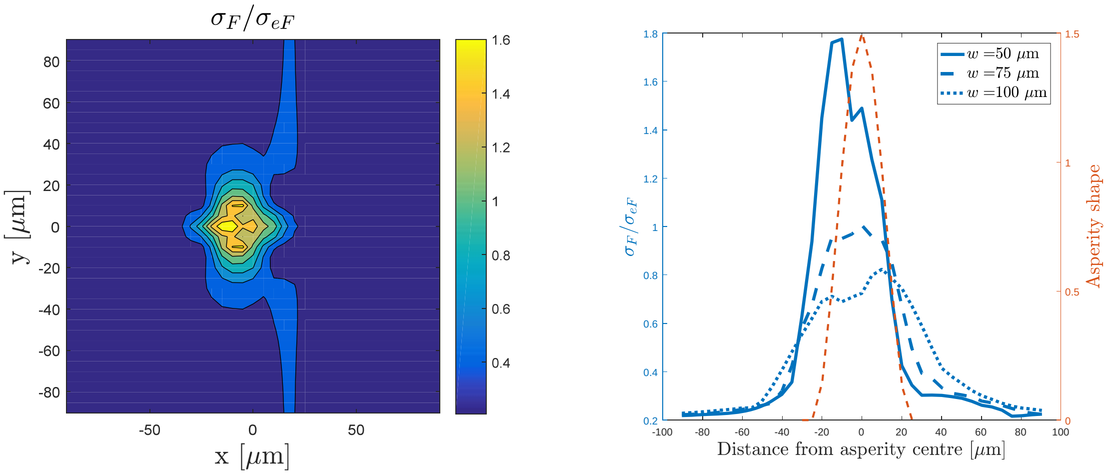


Figure 4. Findley's criteria divided with the fatigue limit of the material for the surface near the asperity. To the left is a surface view around an asperity of width 50 μm. To the right it the Findley results of the centreline presented for three different asperity widths.

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