# Reliability of concentrated contacts due to a synergetic loop between experiment and simulation

Michael Gless[1)*], Anette Schwarz[1)]

[1)] ContactEngineering.de Stuttgart

## 1. Introduction

Due to low frictional losses and high efficiency rolling contacts are used in drives, transmissions, gears and bearings.

During operating under mixed lubrication micro contacts between asperities of the contacting surfaces are responsible for high local stresses and friction forces. Consequently, a reduction of the overall lifetime is expected. In highly loaded rolling contacts, surface fatigue is an unavoidable life-time-limiting failure mechanism.

This paper investigates the adaptability of the Weibull-statistics based rolling bearing fatigue life model according to Ioannides and Harris [1] for the lifetime prediction of rolling contacts under mixed lubrication.

Fatigue endurance tests performed in a newly created two disks test rig showed and optimized the most important influences.

Comparisons between experiment and simulation show the ability of the model to describe the influence of load, residual stresses and roughness profiles to the overall lifetime of highly loaded rolling contacts.

## 2. Goals and motivation

Focus of this paper is the integration of additional design and verification loops into development process.

Main advantages are
- understanding required functions and evaluation of influences for chosen design
- software in the loop (SiL) based optimization
- dependent on design stage appropriate models (analytical models vs. FEM) and also adequate testing
- early design verification loops to decide evidence based to achieve reliable robust design from the initial stage
- parallelization of work on component levels
- a frontloading of improvements and therefore verified design quality
- speed up of development process, to fulfil functions and increase reliability

## 3. Reliability engineering

System and its components have to fulfill required functions under environmental conditions over requested lifetime.

The V-shape model (Figure 1) helps to visualize development process steps. Specification of system functions leads to required functions for sub-system and definition of requirements.

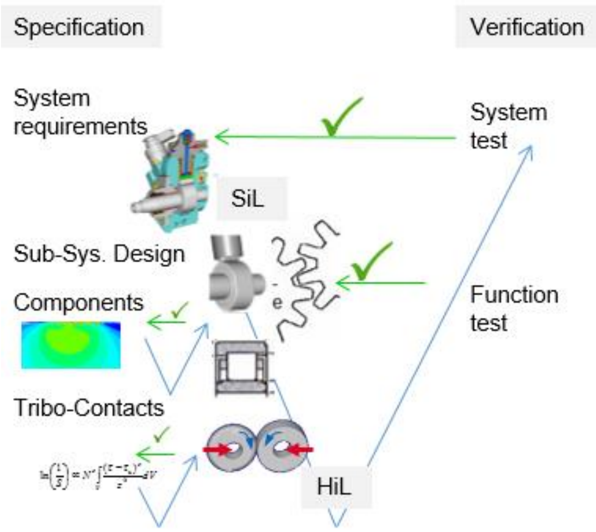


Figure 1: Development processes according V-shape Models and simulations (SiL) of design and verifications loops on different levels.

On design level we can evaluate and rate design parameter influences, interaction and there effects on functions and reliability requirements (Figure 2).

| → functions and requirements<br>↓ variables and influences | Loud-cycles without failure due fatigue |
|---|---|
| **Design-parameter, design and manufacturing** | |
| Geometry and tolerances | $L \sim p^{-8} \sim \tau^{-8}$ |
| Diameter and tolerance | $L \sim d^{4}$ |
| Length of contact and tolerance | $L \sim l^{4}$ |
| Topographie, roughness, texture, running-in | L = f(macro-, micro-topo.) |
| **Load + operational conditions** | |
| load | $L \sim F_N^{-4}$ |
| friction force | $L \sim \tau^{-8} \approx \tau_{xy}^{-8} \approx (\sigma_x \mu)^{-8}$ |
| Residual stresses (e.g. annealing, treatments, run-in) | $L \sim \tau^{-8}$ |

Figure 2: Matrix of design parameter of a roller bearing contact and evaluation/rating of influences there effects on functions and reliability requirements (schematically with only a few examples for illustration)

This paper is focused on influences load, residual stresses and roughness.

## 3. Simulation and life prediction model

### 3.1. Analytical models or low resolution models

In first levels approach analytically models are preferred. Advantages are fast approaches and an overall overview of most important parameters and how their influence functions, to find most important contributors.

### 3.2. FEM and post processing models

After a first design is found FEM-models and post processing routines supports further investigations. The damage accumulation model proposed by Ioannides and Harris [1] or ISO 281 [2] for the prediction of lifetime of rolling bearings has been applied to predict rolling contact fatigue.

## 4. Verification

### 4.1. Verification of contacts on tribometer e.g. two-disc test rig

Experimental investigations and determination of life time data were carried out on a new developed two-disc test rig [3].

### 4.2. Verification of design on component level

Verification of design on component level were carried out on test bench. Verification on component level can build synergies with end of line tests and appropriate monitoring techniques applied.

### 4.3 Validation of System/on system level

After passed test on tribometer and component level validation of system ensures product meets system level functions and requirements as well.

## 5. Results and discussion

The fatigue under rolling stress could be determined with the help of the stress-based fatigue life model and simulation. The test results confirmed the expected influence of the stresses on fatigue life.

### 5.1. Influence of load

As expected in fatigue life tests, the typical characteristic of a Wöhler curve is also found in rolling contact. The same failure mode (fatigue) and lifetime model allows the transferability of the time-accelerated tribometer experiments under increased stresses.

### 5.2 Roughness/textured surfaces

Roughness and lubrication state have a significant influence on the determined lifetimes (Figure 4). At low lubricating film parameters $\Lambda<0.3$ surface roughness at the low film thicknesses significantly reduces the lifetime and increases distributions. The shorter lifetime in mixed friction are caused by the high local stresses of the roughness contacts. The results show the great importance of surface quality under mixed friction conditions.

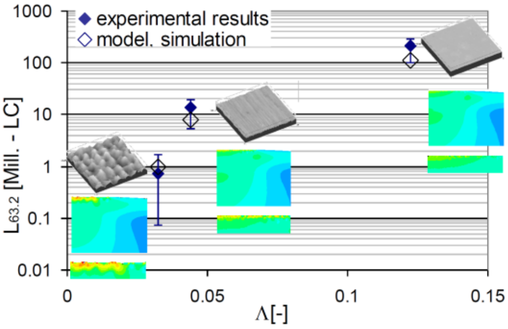


Figure 4: Influence of roughness/textured surfaces on lifetime of investigated roller contact.

### 5.3. Residual stresses

Measured residual stresses are considered in stress based model. The expected increase in fatigue life due to the applied residual compressive stresses was confirmed by the experiments (Figure 5). In addition, compressive residual stresses reduced the lifetime distribution.

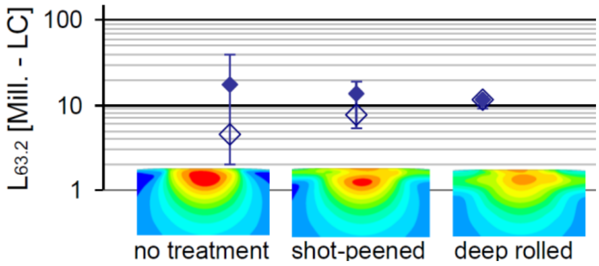


Figure 5: Influence of residual stresses on lifetime of investigated roller contact.

### 6. Conclusion

Rolling contact fatigue is a complex phenomenon of high interest for industry. In this paper reliability engineering is discussed. Development processes according V-shape model with additional verification loops on different levels are shown.

The damage accumulation model proposed by Ioannides and Harris (ISO 281) for the prediction of lifetime of rolling bearings has been applied to predict rolling contact fatigue.

Fatigue endurance tests performed in a newly created two disks test rig showed the positive influence of mechanically introduced residual stresses and smoother surfaces. Verifications between experiment and simulation show the ability of the model to describe the influence of residual stresses and roughness profiles to the overall lifetime of highly loaded rolling contacts.

Models (SIL) and verifications in different levels help to archive a reliable design from the initial stage. Furthermore prediction models help to investigate influences on function and to increase reliability.

### 7. References


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[5] Goergen F. at al. RWTH Aachen/WZL Exp. und rechnerische Analyse von Zahnflankenermüdungsschäden konventioneller und neuartiger Zahnradwerkstoffe