Finite element analysis of micro gears for the prediction of their lifetime

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Abstract

Micro transmissions are very important systems in manifold applications, e.g. in the medical or automotive industry, which enable movements at very small available space. Micro gears are crucial parts of these transmissions. At the Karlsruhe Institute of Technology a methodology for their lifetime prediction is to be developed, which specifically integrates the measured shape deviations of the micro gears. This article outlines how the influence of the shape deviations of the micro gears on their reliability can be modelled by means of the finite element method (FEM).

1. Introduction

Micro transmission today are used in combination with micro motors in manifold industrial applications such as active prostheses, dental drills or movable automotive components such as LCD monitors. Micro gears, defined as gears with a module lower than 200 µm [1], are critical components to the desired functionality.

For the reliable operation of the micro gears, a valid method for their lifetime prognosis is crucial. Yet, existing approaches developed for the reliability analysis of macro gears, particularly the calculation of the load capacity according to ISO 6336 [2], are very imprecise for the specific case of micro gears, as shown by Braykoff [3]. A reason for this is that the influence of the geometric shape deviations of micro gears is significantly higher in comparison to gears with larger modules. This is a consequence of the larger shape deviations of micro gears relative to their part size due to their manufacturing processes. Thus, in this article an approach is described by means of which the influence of the measured gear quality on the lifetime of the gears can be determined.

The article is structured as follows. In section 2 the general approach for quality dependent reliability prediction is summarized. Section 3 details the methodology focussing on the determination of the characteristic loads of the micro gears by means of the finite element method, while sections 4 concludes with a summary and an outlook on future research.

2. Lifetime prediction of micro gears dependent on manufacturing quality

The presented methodology for the lifetime prediction of micro gears dependent on their manufacturing quality is based on an experimental approach. Figure 1 shows an overview of the methodology. According to this, samples of pairs of micro gears are systematically worn under realistic, clearly defined conditions, until a defect of the gear pair can be detected. These experiments can be conducted by means of a highly precise experimental setup [4]. Before the experiments as well as at certain intermediate times interrupting the experiments, the geometry of the micro gears is measured by means of a micro CMM with very low measurement uncertainty. The measured data points serve as an input for a finite element analysis of the pairs of mirco gears. As a result of the finite element analysis the characteristic loads of the micro gears such as the tooth root stresses of each tooth can be determined.

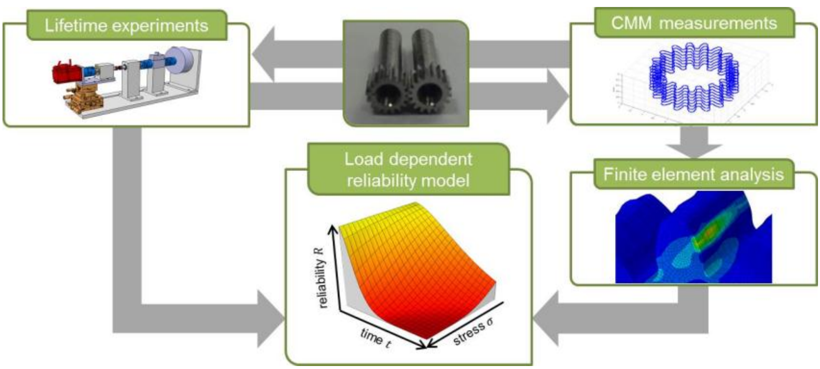

Figure 1. Overview of the methodology.

Based on the determined loads by the finite element analysis as well as the failure times of the micro gears at the lifetime experiments a load dependent reliability model can be developed for the micro gears. By means of this, the lifetime of a pair of micro gears of a specific gear type can be predicted based on the measured shape deviations of the micro gears. A more detailed description of the general approach of the load dependent reliability model can be found in [5].

3. Determination of characteristic loads

Each gear worn within the abrasive experiments is measured by means of a Zeiss F25 micro CMM, for which a maximum permissible error of MPE_E = (0,25 + L/666) µm is specified. Thus, a measurement uncertainty of less than 1 µm can be realized for the data points, which is required for the aforementioned areal characterization method. The areal contours of the gears are determined by very fine scans in profile direction. The resulting point clouds can be converted into spline surfaces based on Non Uniform Rational B-Splines (NURBS) by means of the software Matlab [6]. These spline surfaces can be converted into volumetric CAD models by means of CAD software such as CATIA V5. In the following finite element analysis the geometric models of both gears of a respective gear pair are combined.

For a realistic simulation of the mechanical loads of the gear pair, the material structure of the gears as well as the experimental conditions of the abrasive experiments (e.g. relative position of the gears to each other, rotational speed, torque) have to be applied to the finite element model. The latter can be determined by CMM measurements of the experimental setup and a speed and torque sensor [4]. Figure 2 shows an exemplary result of a finite element simulation of a pair of micro gears, for which the geometric models were generated from the measured surface structures.

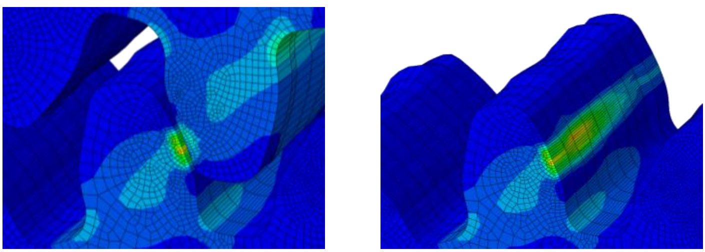

Figure 2. FEM simulation of micro gears based on their measured geometry.

4. Summary and outlook

Existing approaches for the reliability prediction of micro gears are very imprecise, because the shape deviations due to their manufacturing processes are not considered in an adequate way. Thus, in this article a methodology is presented by means of which the influence of the geometric shape deviations of a pair of micro gears on their lifetime can be modelled in a more realistic way. According to this approach the the gear surfaces are measured with a measurement uncertainty of less than 1 µm and the resulting geometric models are applied within finite element analysis to determine the mechnical stresses at the teeth of the gears. Besides the failure times of the micro gears, which are an output the lifetime experiments, the resulting stress data of the finite element analysis are the main input for the load dependent reliability analysis of the micro gears [5]. Future research at wbk will focus on a detailed elaboration of the presented methodology as well as its verification by means of the conduction of lifetime experiments, gear measurements and FEM simulations of the characteristic mechanical stress.

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