Measurement Setup for the Experimental Lifetime Evaluation of Micro Gears

G. Lanza[1], B. Haefner[1]
[1]*wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT), Germany*

benjamin.haefner@kit.edu

Abstract

Micro gears are crucial parts of micro transmissions for various applications in industries such as medical, automotive and industrial automation that require highest precision. In order to enhance the lifetime prediction of micro gears, an experimental approach is to be developed at the Karlsruhe Institute of Technology to model the influence of geometric shape deviations and the material structure of micro gears on their lifetime. For this, a highly precise experimental setup is required to conduct abrasive experiments under clearly defined conditions. In this article a suitable experimental rig is presented.

1 Introduction

Nowadays, micro transmissions are used in combination with micro motors in manifold industrial applications such as dental drills or hexapod micro positioning systems for wafer processing. Micro gears, defined as gears with a module < 200 µm [1], are parts of micro transmissions, in which the gear quality is critical to the functionality of the transmission. To ensure proper operation of the micro gears, a reliable prediction of their lifetime is crucial. Lifetime evaluation is particularly important for micro gears, as the influence of their geometric shape deviations on their load-carrying capacity is significantly higher in comparison to gears with larger modules. This is a consequence of their manufacturing processes, which are not capable of producing micro gears with the same relative accuracy as larger gears.

The lifetime of micro gears is to be evaluated by an experimental approach at the Karlsruhe Institute of Technology. After geometric measurements, a pair of micro gears is systematically worn under realistic, clearly defined conditions, until a defect of one of the micro gears can be detected. For the lifetime experiments and deduction of the lifetime model, a highly precise measurement setup is required to wear micro gears up to an estimated torque of 1 Nm and a rotational speed of 3000 rpm. In particular, accurate positioning of the micro gears to each other and stable locations of their rotary axes have to be guaranteed within the range of few micro meters.

2 Literature review

A literature review shows that various rigs have been developed for different gear experiments. However, only very few deal with gears with very small modules. Beier developed a rig for lifetime experiments of assembled planetary gear transmissions consisting of planetary gears with a module of 400 µm [2]. Braykoff designed a test rig for gears with a module down to 300 µm to analyze their load-carrying capacity [3]. However, only the experimental setup developed by Hauser is applicable for micro gears, which was demonstrated for a module of 169 µm [4,5]. Precise positioning of the micro gears is realized by a 5-axes manipulator and air bearings. However, as the rig was designed for single-flank working tests, it is only applicable for a low torque load of < 50 mNm, which is not adequate for the desired lifetime experiments.

3 Measurement setup for the lifetime evaluation of micro gears

The developed measurement setup shown in figure 1 provides the functionality to systematically abrade various types of pairs of micro gears under clearly defined, variable conditions. The rotational speed, the torque as well as the center distance of the micro gears can be precisely adjusted. Hence, the measurement setup is both accurate and flexible with regard to different kinds of micro gears. It, however, is restricted to cylindrical gears, which are by far the most common type of micro gears.

Variable rotational speed is provided by a synchronous motor (up to 5000 rpm), while a hysteresis brake is used to adjust the torque (up to 3 Nm). Both rotational speed and torque are measured by means of a sensor (relative uncertainty < 1 % for speed, < 0.1 % for torque). Feedback control is implemented to guarantee constant experimental conditions of the speed and the torque.

The bearings of the brake and the sensor are joined by a coupling (cf. figure 1). The sensor as well as the motor is connected to a shaft. The micro gears to be used in the lifetime experiments are manufactured with a small integrated shaft. Thus the gears can be precisely clamped to each of the general shafts by an integrated collet chuck (cf. figure 2). A high precision collet chuck, which is also used in micro milling machines for high accuracy machine tools, is inserted into a grinded conic hole at the top side of the shafts and fixed by a clamping nut (true running accuracy < 2 µm).

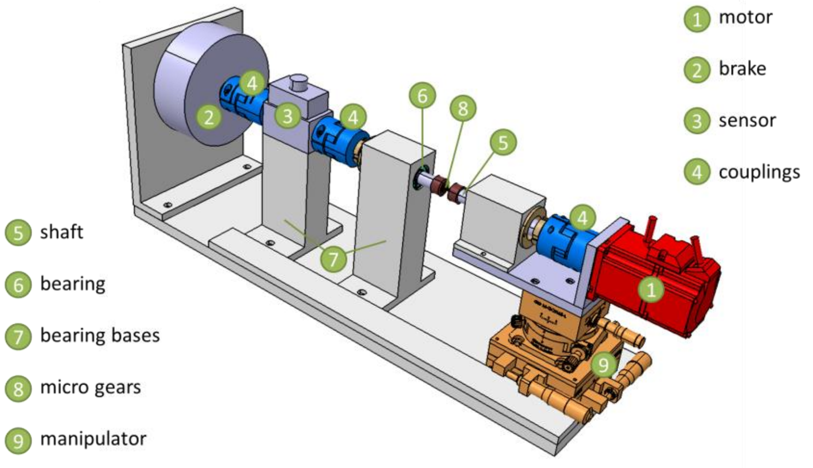

Figure 1: Overview of the measurement setup

Each shaft is grinded and mounted by means of two high precision spindle ball bearings which are fixed into grinded holes in the bearing bases as illustrated in figure 2. Consisting of ceramic balls, the bearings have a very high stiffness and wear resistance. Both bearings are preloaded in a duplex bearing (DB) arrangement to enhance their running smoothness (true running accuracy < 2.5 µm) by means of a locking ring, a distance sleeve, a clamping lid, a clamping sleeve and a groove nut.

In order to adjust the center distance of the micro gears to each other and to align their rotational axes in parallel, the motor and the respective bearing base are mounted on a 4-axes manipulator. It consists of two lateral units (positioning accuracy < 3 µm) and an angular unit as well as a goniometer on top of those (cf. figure 1). Further positioning units are not necessary for the adjustment of the gears in lifetime experiments. The rig can be mounted to a coordinate measuring machine so that the center distance and the axial orientation of the micro gears to each other can be determined precisely (length measuring error < 2.4 µm) by measuring the grinded shaft cylinder between the bearing and the collet chuck (cf. figure 2). Based on this, the manipulator system can be adjusted.

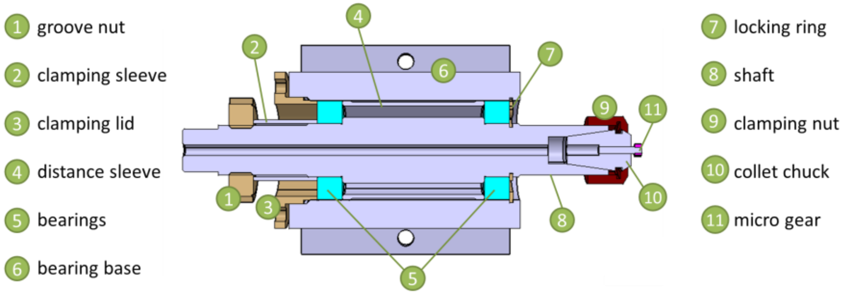

Figure 2: Bearings, shaft and gear fixing concept in the measurement setup

4 Summary and outlook

In this article, an experimental setup to conduct abrasive experiments of micro gears under clearly defined conditions was presented. Speed, torque and the alignment of the gears to each other can be controlled precisely. Besides, suitable concepts for the fixing of the micro gears and the bearings of the shafts have been developed.

Currently, the rig is physically assembed and a mechanism to detect the time of the gear defect is developed. Upcoming, the lifetime experiments will be started in order to deduce the aforementioned lifetime model of micro gears dependant of their shape deviations and material structure.

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