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Measuring Load on Linear Guides in Different Load Scenarios Using an Integrated DLC Based Sensor System

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Summary:
The integration of a load measurement system into a linear guide is both a challenging and promising topic. This work focuses on evaluating a model for the load distribution in linear guide bearings for establishing a sensor system using a direct strain measurement method based on a piezoresistive Diamond Like Carbon (DLC) layer, capable of determining the up to five degrees of freedom load state of the bearing. We observe good matching between the theoretical model and the measured sensor data, demonstrating the capability of the sensor system in different load scenarios.

Keywords: Load Determination, Linear Guide Bearings, Industry 4.0, Piezoresistive DLC, Load Distribution Model

Background, Motivation and Objective

Linear guides are standard machine parts that constrain movement of connected machine parts to a linear, translational one. For machine tools, profiled rail guide cylindrical roller bearings are heavily employed. Integrating a sensor system that is able to determine the load vector acting on the linear guide, without affecting its mechanical characteristics, would allow both for better remaining lifetime predictions as well as improving accuracy in manufacturing. In [1] we presented a load measurement system based on local strain measurement using piezoresistive, DLC based sensors. The sensors are placed in a group of three sensors on each of the four raceways of the runner block and measure the strain introduced by loading the rolling elements above the sensor elements.

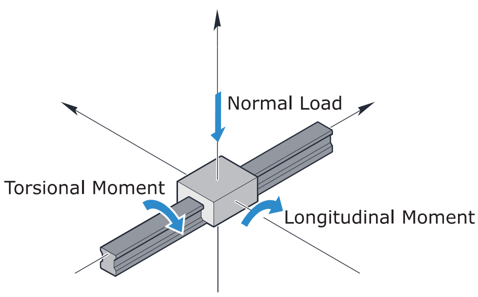

Fig. 1. Linear Guide with Load Modes (based on [2])

Until now, we have only shown principal functionality by comparing to a normal load in one direction and uniform local load distribution and mainly focused on addressing non-idealities for measuring the local load. The objective of this work is to show compliance to a simplified model for mapping the different external loads (fig. 1) to local loads. This enables the sensor system to capture the load scenarios accurately. Additionally, **direct** empirical evaluation of the model assumptions is possible for the first time. This is valuable insight for different research areas in mechanical engineering.

Description of the New Method or System

In order to reduce complexity, the most foundational assumption made is that the **runner block and the rail are rigid**, i.e. all deformation occurs at the rolling element contact, [3] calls this the classical model. For the non-linear load-deflection relationship of the rolling elements, a profiled, **slice based model** with 41 slices has been used with a profile as defined in the DIN 26281 norm [4] where each slice is assumed to act like proposed in [5]. This nonlinearity also prohibits linear superposition of the local loads introduced by different external load components. Therefore, an iterative procedure, based on the one described in [3], is employed until local loads agree with external defined loads. Preload is introduced in linear guides by design using oversized rolling elements and changes when loading the bearing [2]. This effect is modelled as part of the iteration process. Since the sensors measure strain, rolling element load has to be converted into **resulting strain** at the sensor position. For this, the method in [1] based on a partial Fourier transformation, has been extended to cover torque, i.e. differently loaded neighboring rolling elements. The solving procedure remains the same. This model allows the sensor system to relate measured sensor data to the external load state, as shown below.

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Results

Experiments have been performed loading two runner blocks type SNS size 45 from Bosch Rexroth, equipped with the sensor system. Normal loads are ranging from 0 kN to 100 kN, torsional moments from 0 Nm to 1900 Nm and longitudinal moments from 0 Nm to 1150 Nm, each applied in both directions. The sensor signal is dependent on the relative position of rolling elements, so the runner blocks have been moved 1 mm between repeating measurements. The amplitude can be defined as the difference between maximum positive and negative signal at a certain load over the positions. The shape of the load dependent signal is of more interest than absolute values. Therefore, amplitude curves have been normalized to their maximum value.

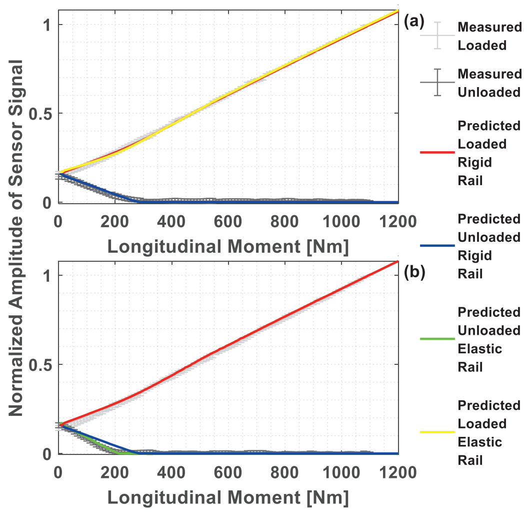

Fig. 2. Sensor Amplitude vs. Longitudinal Moment. (a) Upper Raceways, (b) Lower Raceways

Error bars represent three standard deviations calculated from the obtained curves. For longitudinal moments, fig. 2 shows good agreement of model predictions with measured values, especially when loading the lower raceways. The preload liftoff point, after which the unloaded raceways do not carry any load, happens at lower moment when loading the upper raceways. This could be explained by increased elastic yield of the rail, which is more flexible at the upper raceways. Modelling this linearly shows good improvement, as seen for the elastic rail curve. Fig. 3 shows torsional moment, where the variation of the preload liftoff point is found to be less significant, and the curves match well in both cases. Fig. 4 shows normal loading. Here variation in preload liftoff occurs, but the model fits well for loading the upper raceways. The variation again can be explained by elastic behavior of the rail, but has to be combined with further modeling that shifts the preload liftoff to higher loads, which is left open for further research. One possibility is the inclusion of changing contact angles with an elastic runner block.

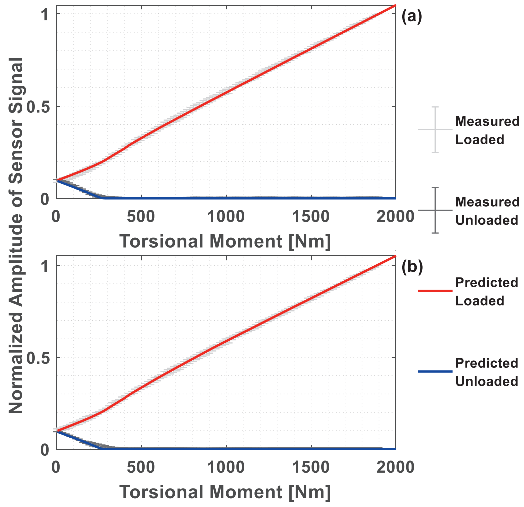

Fig. 3. Sensor Amplitude vs. Torsional Moment. (a) Lower Raceways (b) Upper Raceways

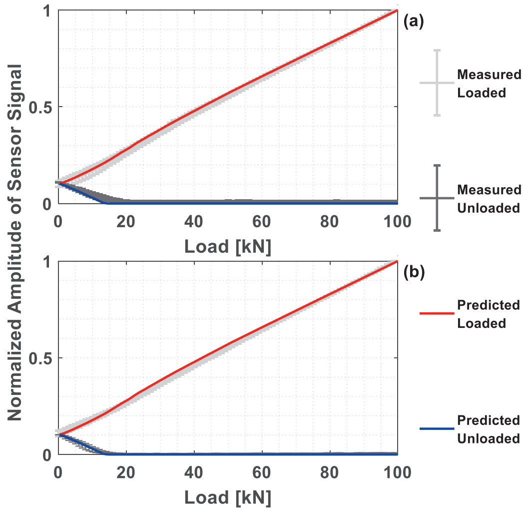

Fig. 4. Sensor Amplitude vs. Normal Load. (a) Upper Raceways (b) Lower Raceways

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