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Model Based Evaluation of Integrated DLC Based Sensor System for Load Measurement on Linear Guides

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Summary:

Having an accurate model of the load distribution in linear guides is crucial for both simulative purposes and accurate sensor based load measurement. In this work, such a model is employed to predict sensor signals of an integrated, Diamond Like Carbon (DLC) based sensor system directly beneath the raceways, in different load scenarios. Measurements were found to match the theoretical model predictions well. This both allows for model verification by direct load measurements as well as demonstrating the capability of the sensor system to successfully retrieve the applied load.

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

Background, Motivation and Objective

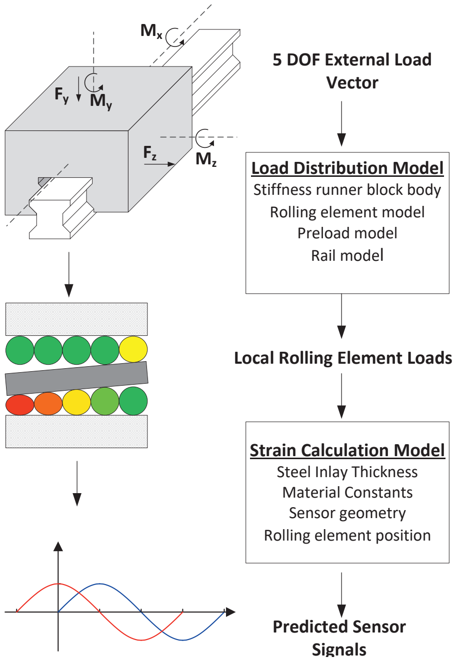

Fig. 1 Sensor signal calculation scheme

There are widespread efforts to integrate load measurement features in machine tools, e.g. for process monitoring [1]. Solutions such as a sensory spindle exist [2] but are highly specialized to the component at hand. Integrating load measurement into a standard machine part in the force flux, such as linear guides which provide a translational bearing, would significantly reduce required engineering efforts and cost. In [3] we presented an integrated strain sensor system based on Diamond-Like-Carbon (DLC), which is placed directly beneath the raceways, i.e. the place of load transmission. For evaluating sensor system performance, and in deployment for retrieving the applied load from the sensor signals, a model for the mapping of external loads to sensor signals has to be defined, as sketched in fig. 1. In [3], we have shown good agreement of the sensor signals with both strains obtained via finite element method simulation and an analytical strain calculation model, predicting strain depending on the local load on rolling elements beneath the sensors, i.e. the second step in fig. 1. The result is shown in fig. 2 for the difference signal between two neighboring sensors over different relative positions of the closest rolling element. The load distribution model, used for predicting those local loads dependent on an external five degrees of freedom load vector, is yet to be verified in the context of load measurement and at the center of this work.

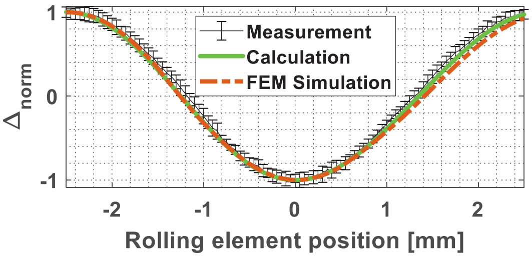

Fig. 2 Normalized difference signal Δ_{norm} for movement under constant load

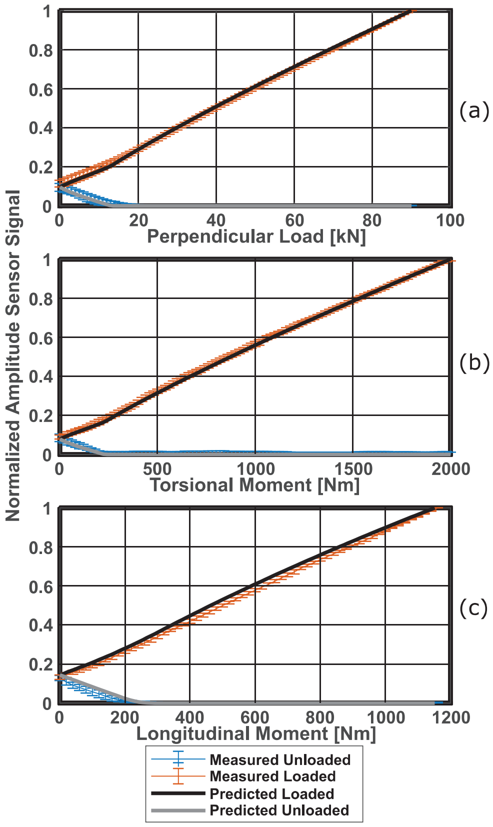

Fig. 3 Comparison of measured and calculated sensor signal amplitudes. (a) Perpendicular loading (b) Torsional moment (c) Longitudinal moment

Description of the New Method or System

The load-displacement relationship of the rolling elements is nonlinear. This prohibits linear superposition of the individual load components' effects. The load distribution model therefore establishes a mapping of the internal loads to the external loads, and then uses Gauss-Newton iterations until the discrepancy falls below a threshold. The core procedure is based on [4]. First major model assumptions have to be addressed. The runner block and the rail are assumed to be ideally rigid, i.e. all deformation only occurs at the rolling element contacts. A profiled, slice based model with 41 slices as in ISO/TS 16281 [5] where each slice is modeled according to [6] is employed. Preload is introduced in linear guides by design using oversized rolling elements and changes when loading the bearing. As load on some raceways increases by external loading, the other experience reduced load. This effect is integrated into the model by calculating the preload as a function of the load on rolling elements being less loaded then at a preload-only state, and is thus integrated into the iteration procedure. The calculated local loads are then used in the strain calculation model to predict the resulting sensor signals.

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 90 kN, torsional moments from 0 Nm to 2000 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 experiments have been repeated at 13 positions, moving the runner block 1 mm in between. From this an amplitude is calculated, indicating the maximum sensor signal at a certain load. Sensor signal here refers to the difference of the relative resistance change between two sensors of a group, which is more robust to e.g. temperature changes [3]. Fig. 3 compares amplitudes normalized to the maximum value, from calculations and repeated measurements, for two sensor pairs per raceway, measurements ± one standard deviation. The measurements agree well with the predictions for both loaded and unloaded raceways. Note that for all predictions the same parametrization of the model has been used. The biggest discrepancy is found at unloaded raceways at longitudinal moments, see fig. 3(c), where the preload vanishes slightly faster than predicted.

The good overall consistency demonstrates the sensor systems capability to estimate the external load vector and for the first time allows for direct verification of the load distribution model.

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