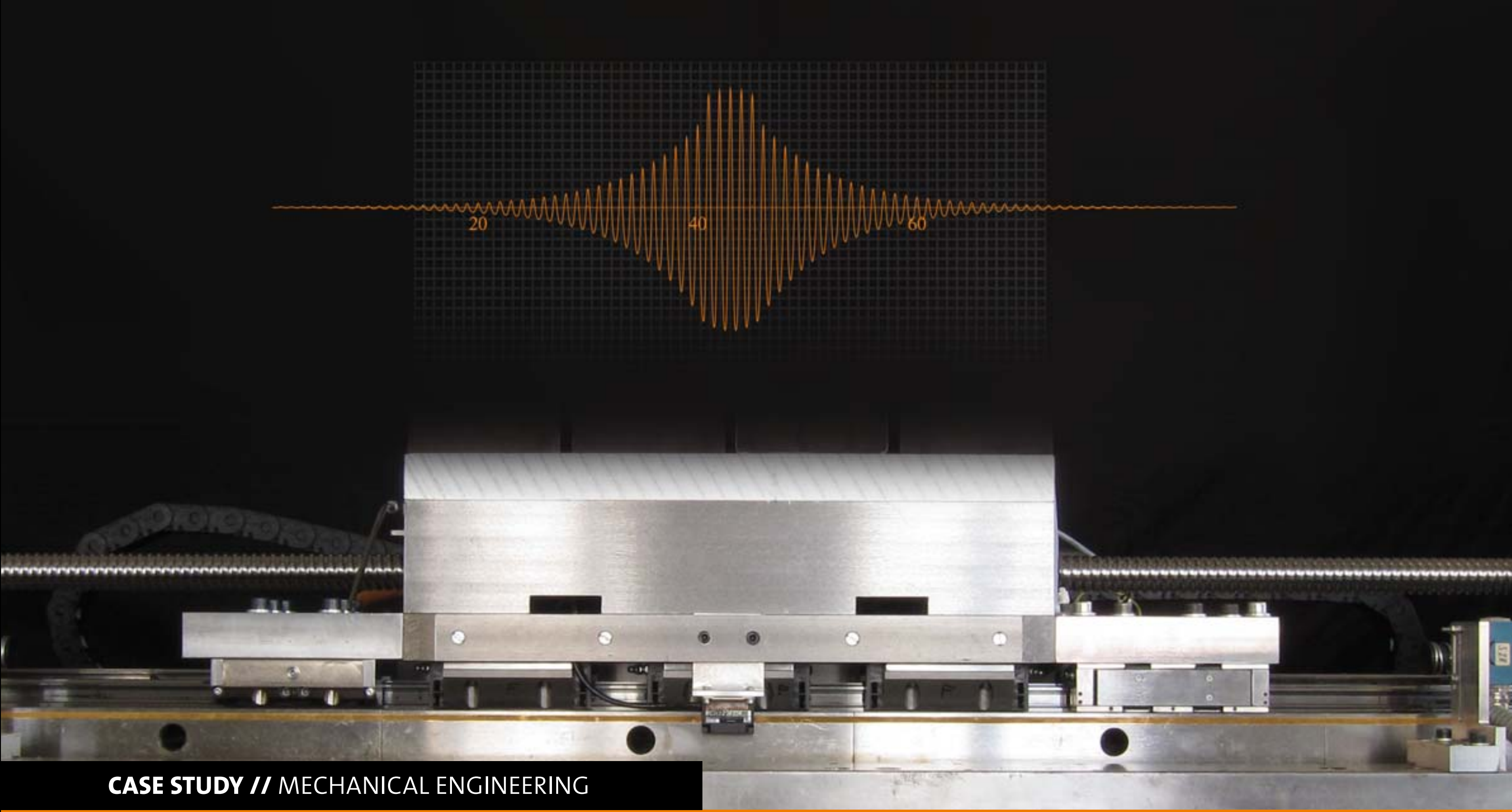

MODEL-BASED PARAMETER IDENTIFICATION: CAUSE AND EFFECT

Model-based condition monitoring with ANSYS and optiSLang enables an understanding of correlations between the properties of individual components and their effects on the behavior of a machine.

To assure acceptable machining tolerances and the quality of work pieces in the long run, it is necessary to monitor machine tools during the operating mode. Basically, there are three different strategies which can be categorized as “run to break”, “time-based preventive maintenance” and “condition-based maintenance”. The objective of the last approach is the permanent analysis of component properties during the period of operation.

In most cases, condition monitoring is based on the analysis of the vibration amplitudes measured by external acceleration sensors at various spots of the machine. This project presents a new approach that determines the physical characteristics of individual machine components based on the analysis of the machine vibration and system model.

The generation of an appropriate algorithm for the condition monitoring of a particular system requires a comprehensive knowledge of potential failure modes. In the case of a spindle nut drive, the abrasion of the runway is the most common problem. The erosion of the runway profile impairs the tribological properties of the contact surface and, as a consequence, reduces the prestress between balls, nut and spindle. Furthermore, the loss of prestress reduces the total stiffness of the feed drive system causing a change of the system’s eigenfrequencies. Therefore, an analysis of the eigenfrequencies of the feed drive can lead to determination of the stiffness in different subcomponents.

Analysis using a simplified model

During the SIOCS project “Simulation-based parameter identification for online condition monitoring of a ball screw” at the ISW (Institute for Control Engineering of Machine Tools and Manufacturing Units) of Stuttgart University, calculations of the eigenfrequencies and the following analysis of the component stiffness were conducted by using a FE (Finite Element) model of a ball screw. In the first phase, a simplified 2-D FE model (Fig. 1, see next page) was developed with less than 50 degrees of freedom. The first eigenfrequency corresponded to the axial vibration of the axis and the second one characterized the torsional vibration of the spindle. Besides the table mass and the motor inertia, the simplified model also included the stiffness and damping parameters of nut, bearing and coupling. The correlation between the stiffness values and the first two cal-

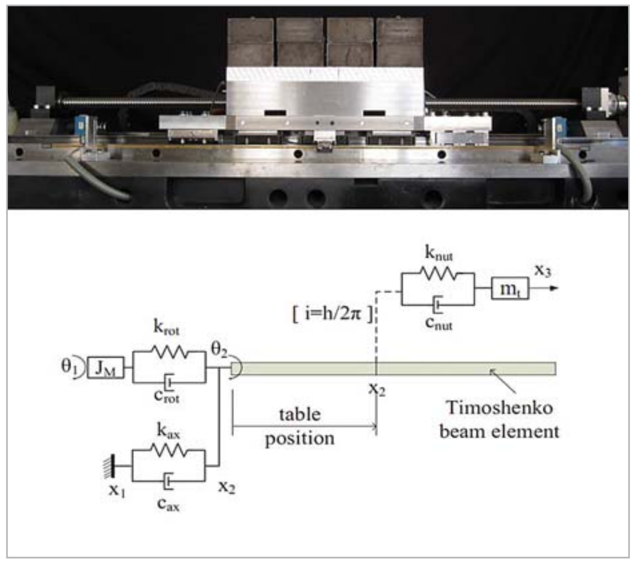

Fig. 1: Experimental set-up of a ball screw axis at the ISW and the corresponding simplified model

culated eigenfrequencies of the simplified model was analyzed afterwards. To obtain the stiffness parameters based on the measured eigenfrequencies, an optimization process was performed using optiSLang. The objective function was defined based on the difference between measured and simulated eigenfrequencies. An extra analysis by means of neural network demonstrated that the correlation between inputs (eigenfrequencies) and output parameters (stiffness) could be determined more robustly via optimization algorithms.

The initial identification of stiffness parameters indicated that, based on the measurement of only two eigenfrequencies, no appropriate stiffness value for the nut could be identified. In order to clarify the correlation, a sensitivity analysis of the model was performed using optiSLang inside ANSYS Workbench. During this sensitivity analysis, different stiffness parameters, as well as the table mass and position, were considered. Furthermore, additional eigenfrequencies were analyzed for calibration of model parameter. The results indicated that neither the first nor the second eigenfrequency was considerably affected by the stiffness of the nut. An additional study was conducted to find a physical vibrational parameter, which is affected by the nut stiffness parameter. The study outcome pointed out that the first eigenmode (machine table movement) is mainly affected by the nut's stiffness. The sensitivity analysis identified three output parameters, which were decisive for the identification of the stiffness parameters of the ball screw drive. Fig. 2 shows the indication represented by optiSLang's Coefficient of Prognosis (CoP) and Metamodel of Optimal Prognosis (MOP) as a result of the sensitivity analysis.

After the modification of the objective function by adding the eigenmodes, as well as the implementation of the correctional factors, the identification of the model parameters was conducted. An Evolutionary Algorithm (EA) was applied as a model-based identification algorithm and the stiffness parameters could already be identified after about 200 iterations.

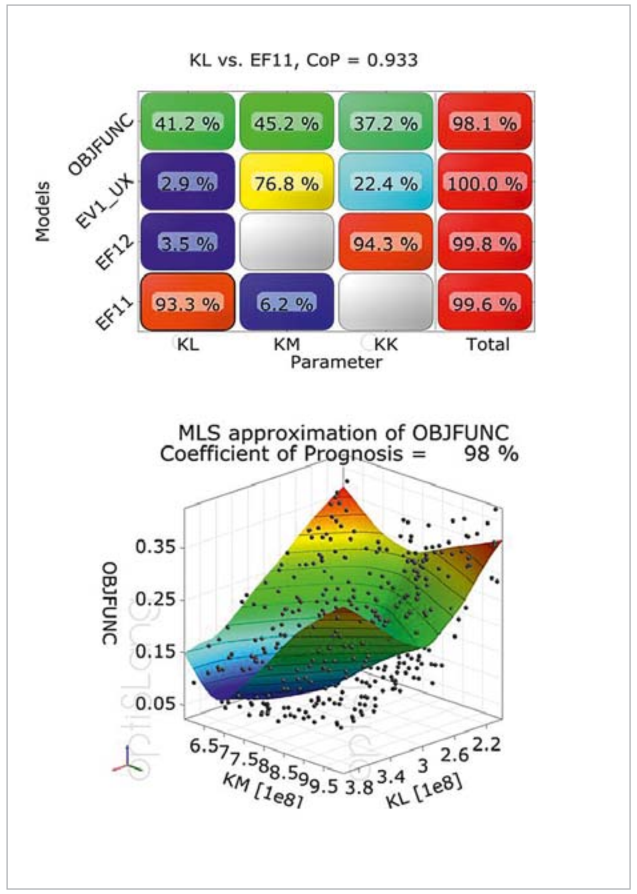

Fig. 2: CoP (left) and MOP (right) based on the sensitivity analysis in optiSLang

Accuracy of the algorithm

Fig. 3 illustrates how the proposed SIOCS approach was verified on the basis of the simulation input data. The simplified 2-D model of the ball screw was used to calculate the frequency response of the rotational velocity control. Based on the curve fitting in the Bode plot, the transfer function of the system could then be identified. The eigenfrequencies and eigenvectors were calculated afterwards, using the generated algorithm. By providing the eigenfrequencies and eigenvectors as inputs of the identification algorithm, the stiffness parameters of the ball screw model were determined and the accuracy of the algorithm could be evaluated.

Conclusion and benefit

As a result of the project, the following conclusions can be drawn: The expected correlation between system parameters and characteristics of the machine could not be determined at the beginning of the project. Only the additional consideration of the system's first eigenmode, as well as the inclusion of a wider range of parameters and system responses identified by the sensitivity analysis with optiSLang, could explain the phenomena. The correlation matrix showed the interaction between the model parameters and the machine performance. This approach enables an evaluation of the monitored component states by the identification of their real vibration behavior. As a benefit, this allows an optimal adjustment of operating time and maintenance intervals to the current condition of the machine tool.

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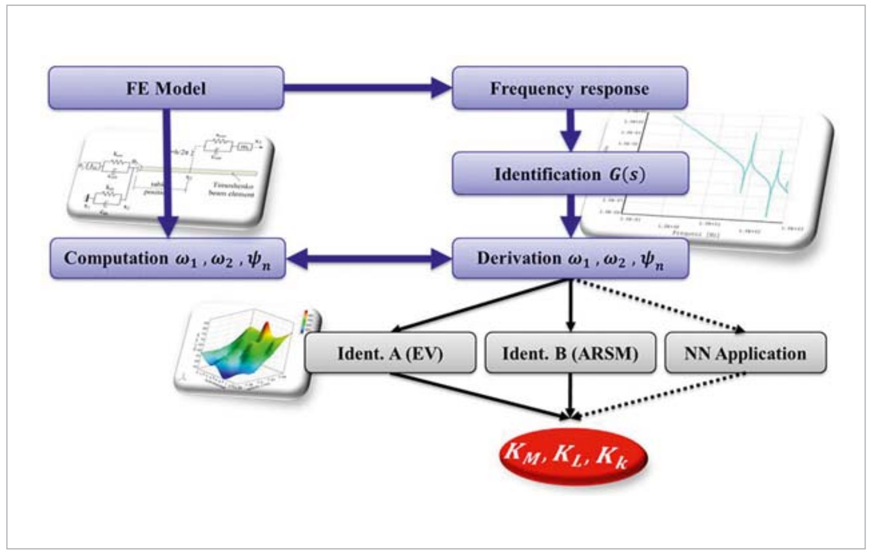

Fig. 3: Workflow of the stiffness parameter identification of a ball screw drive system based on the calculated eigenfrequencies and the second eigenvector