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Laboratory practice energy efficient production

The students understand the challenges of energy efficient production by using a research oriented learning approach

Introduction

About 30 % of the electrical power in Switzerland and Europe is used by industry. Therefore, there are pan-European ambitions to reduce the consumption of electric energy in industry. Due to the high precision requirements in the manufacturing sector a large fraction of the energy consumption is required for the thermal stabilization of the equipment such as machine tools or metrological instruments and machines. Particularly, the heat losses generated by the components have to be removed out of the structure by investing power into the cooling system. In contrast to other industry sectors such as robotic, automotive and aircraft industry, in manufacturing systems small temperature changes can already result in critical dimensional errors. In the scope of the three lab courses the students have the unique opportunity to deal in detail with the on-going challenges of energy efficient production. The teaching concept is goal and method oriented to strengthen the critical thinking of the students. Thus, the first learning objective is to understand the problem of energy efficient production and the correlations within this field. The remaining learning objectives are method oriented and include how to analyse complex relations within engineering tasks, how to model them and how to derive measures from engineering models and implement them in real machine tools.

Teaching concept

The teaching approach which is used for these lab courses combines theoretical explanations and applied exercises at the forefront of research. The structure of the lab courses includes recent research findings in the field. The theoretical explanations support the students to get expertise on the topic of energy efficient production while the applied exercises improve their engineering and implementation skills. In the following sections the teaching structure of the three lab course is explained.
The Green Machine Tool: How Does Energy Efficient Production Work?
The course starts with a theoretical discussion and analysis of the life cycle of machine tools. It continues with an applied part where the students get to measure the energy consumption of a machine tool during the use-phase. The students perform a power measurement according to ISO 14955-2 [1] on a five-axis machine tool. The power measurement system is especially designed for this lab course as a further development of the already existing measurement system of IWF, developed by Gontarz et al. [2] and applied to the Mori Seiki NMV 5000 DCG by Züst et al. [3]. During the measurement the energy consumptions of several machine tool components are measured at different operating states. The obtained data is used in order to calculate the energy consumption of each component in relation to the total power. In the last

part of the course, the connection between energetic losses and the accuracy of the manufactured product is explained, providing the connection with the next course unit.

The Deformed Machine Tool: How Do Heat Losses Cause Manufacturing Errors?

This course analyses the thermal chain of causes, which describes the physical fundamentals leading to thermal deformations of the machine tool. Due to the long time constants of the thermal behaviour of machine tools, the experimental investigation is performed on a test bench, which reacts much faster. The test bench, especially designed for this course, consists of an aluminium structure to ensure measurable thermal displacements with small time constants. An online visualization of the measured temperatures and temperatures displacements is provided so that the students can immediately evaluate the changes due to different configurations of the heat sources. Allowing the students to interact with the test bench provides an understanding of the relations between the configuration of the heat sources, the temperature field and the TCP displacements. The course continues with developing and validating a physical FE model of the test bench. After the validation of the model, the students can try different load case scenarios faster than in the measurement setup of the test bench. This demonstrates the benefits of physical modelling to the students, as different design modifications or load cases can be evaluated in a more efficient way than performing measurements directly with the physical prototype. The simulation and measurements on the test bench are furthermore extrapolated to understand the thermal behaviour of machine tools. In the last part of the course, the students propose different alternatives on how to improve the thermal behaviour of machine tools. This provides an outlook to the next course unit where the online compensation of thermal errors is explained in detail.

The Machine Tool 4.0: How to make precision manufacturing energy efficient?

This course focuses on the online compensation of thermally induced position and orientation errors of a rotary axis. Two different approaches are followed, namely physical and phenomenological compensation models, both introduced by Gebhardt et al. in [5] and [6] respectively. First the students create their own thermo-balance compensation model by establishing the heat transfer equation for each considered body of the machine tool. The resulting TCP displacements are then calculated using simplified geometrical information about the bodies. Using experimental data of the machine, the students test the accuracy of the created thermo-balance model. In the next part of the course another compensation approach is presented, phenomenological models. The students are provided with over 90 hours of measurement data, i.e. thermal errors and temperatures, from the machine tool Mori Seiki NMV 5000 DCG. The students feed measurement data over 60 hours in a phenomenological compensation model for each considered error type to obtain the model parameters and use the remaining 30 hours to test the resulting models. Afterwards, the students use the Fanuc Control (Interface FOCAS 2) of the machine tool and a measurement PC as cyber physical system to implement their compensation model in the machine tool. The course also outlines the potential of increasing the accuracy of the compensation models when large volume of data is available, which is facilitated by the new trend towards Industry 4.0.

Analysis of student learning

The developed lab courses provide the students a research oriented learning approach, in which the students apply new and already acquired theoretical skills to current research questions. Thus, the course structure is developed in a strongly interactive manner which enables a direct observation of the stated learning objectives. The different exercises including the measurement results are directly presented and discussed by the students during the lab course, so that the supervisor can directly assess their learning progress. This enables a high- level interaction between the bachelor students and the supervisor and enforces the learning success of the students. Furthermore, the extensive practical application of the elaborated solutions supports the supervisor to evaluate the fulfilment of the learning objectives. Finally, the students demonstrate their learning progress by including their findings into a report template.

Lessons learnt

The first runs of the lab courses showed, that the strong interaction between theoretical and practical elements in the context of current research questions results in a high motivation of the students. Furthermore, the students appreciate the connection between technical and social challenges of the given exercises. The three lab courses indicate that this teaching concept is an excellent opportunity to integrate current research findings and the required research methods into teaching. For the students this lab course provides the opportunity to familiarize with machine tools, which allows them to access this knowledge in future courses related to production and machine tools. This lab course is sustainable in two different ways. First, the lab courses create awareness for the scientific and social challenge of energy efficient high precision manufacturing. Second, the lab course is sustainable for the improvement of their academic skills because they familiarize with methods by applying them to a specific problem. The concept of these lab courses can be easily transferred to other fields of research as an innovative concept for research oriented learning and teaching of application competence.

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