Experience with SimulationX for University Education in the Field of Mechatronics of Machine Tools

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Abstract

This article describes the conception and performance of a university lecture without presenting scientific research results from a pedagogical point of view. The program SimulationX has been succesfully used to try to increase the attractivity of a complex subject matter. It is shown how the simulation software can help to combine different contents of teaching. This example describes how natural oscillations of a feed axis can be reduced by using redundant piezo-based auxiliary drives.

Kurzfassung

Der Artikel beschreibt die Konzeption und die Durchführung einer universitären Lehrveranstaltung, ohne aus pädagogischer Sicht wissenschaftliche Untersuchungsergebnisse darzulegen. Mit Hilfe des Programms SimulationX wird erfolgreich versucht, die Attraktivität eines komplexen Lehrstoffes zu erhöhen. Es wird gezeigt, wie sich mit der Simulationssoftware ein Bogen über verschiedene Lehrinhalte schlagen lässt. Mit dem hier beschriebenen Beispiel wird demonstriert, wie mit dem Einsatz redundanter piezobasierter Zusatzantriebe Eigenschwingungen einer Vorschubachse reduziert werden können. Der Artikel geht besonders auf den methodischen Aspekt der Modellaufbereitung für die Seminararbeit in einem PC-Pool ein.

Problem

Even long before the conversion to bachelor/master programs, the necessary contents of teaching for Mechanical Engineering studies were argued about: general knowledge versus specialization or, best of all, both combined. Students can select from a broad range of courses or modules with the goal to collect credit points. This broad offer often affects the depth, which should actually increase toward the end of the studies. The students of today do not all come just from one single field of studies. Here, machine developers and production engineers represent the smallest contrasts. Thus the task arises to concept an attractive lecture which also unites very different ways of studying. If the requirements are

set too high, however, as for example, 40% of the time dedicated to self-study in a master program or extensive papers, the subject will not be chosen.

The subject Machine Tool-Mechatronics

The subject Machine Tool-Mechatronics arose from the idea to directly convey current findings of machine development (e.g. parallel kinematics, active materials) to the students. The research or user point of view quickly exposed the large scope of knowledge to be taught. No matter how this subject is generally defined – sometimes it is noted that machine tool making of today is always mechatronics – solid basics in different (education) subjects are necessary. Furthermore, the field of study should also be interesting for those who approach a subject more from the user point of view than from theory. Thus the authors focused on the independent motto “Recognizing contradictions (conflicts of goals) and solutions” as educational objective.
Considering the curriculums and lecture contents in the main fields of study of the institution, the lecture starts with the mechatronic feed axis as a review and specification of the known subject matter. The conflict of goals “Accuracy versus high dynamics” is introduced here and continues throughout the complete lecture. The operation of SimulationX is introduced by a seminar in the PC-pool. After shortly dealing with important basic elements and functions using the example of a simple single-mass-oscillator, the model of a feed axis is considered. The description of this design conflict is followed by a chapter on parallel kinematics. Drive redundancy is introduced as a further topic. In optional exercises on this topic, the students are recommended to use simulation software, such as MathCAD. The chapter adaptronic touches the aspect of material innovation in modern machine development. The piezo actuators, which are explained in detail in this chapter, are used in the following chapter for redundant auxiliary or fine positioning drives. The highlight of the lecture is the simulation of the principle of the piezo-based axial vibration compensation for feed drives during the seminar, using SimulationX and thus completing the lecture.

Motivation for Using SimulationX

When using a simulation tool for an exercise, the study frequency should be increased compared to a conventionally conducted exercise. In order for the student to keep a critical view on the results delivered by the PC, the first eigenfrequency in the seminar is also established analytically as a comparison. Experience shows that active cooperation in the PC-pool is distinctly higher than it is during the standard exercise.

Main Element of a Machine Tool: the Feed Axis with Ball Screw Drive

The introduction of SimulationX can take approx. 45 minutes. The same time is available for dealing with the actual feed axis. The model with indirect path measuring system, according to [1], is downloaded completely by the students. The first exercise focuses on the behavior in the time range. The velocity

amplification is to be increased until the axis is unstable. Points of discussion are: What is the velocity amplification? What does stable mean, where do you put the limit? Afterwards the movable mass is increased and the behavior of the system is evaluated again.
The frequency behavior is established using the calculation of the first eigenfrequency. How can the result be achieved by different means? The comparison between simulation and calculation when the axis is reduced to a single-mass-oscillator is supposed to show that the purpose of a simulation model also determines its specification. The friction element and the related values are also of interest in this context. A model extension is necessary for establishing the frequency behavior itself.

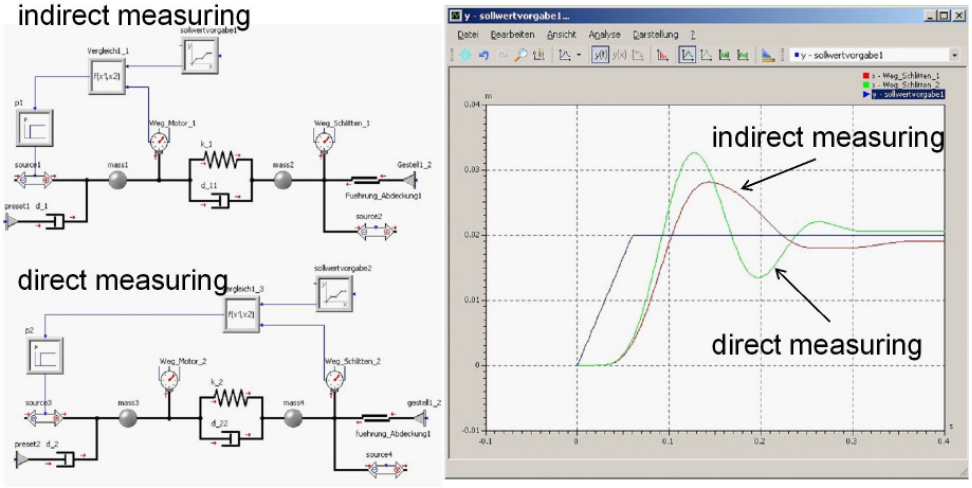

Figure 1: SimulationX-model and comparing positioning of the tool slide with direct and indirect path measuring system

For the comparison of the indirect and the direct path measuring system a minimal model with two masses (tool slide and motor mass carrier) was established (Figure 1). The students have to appropriately link the given elements, which are provided with parameters. By comparing the behavior of the transient oscillation the advantages and disadvantages of both variants can be discussed.

The lecture script contains further exercises which can be solved using SimulationX, as the PC-pools are available for the students for self-study. For example, in order to understand the frequency behavior an exercise on the damping principle was created.
The question “Is there a solution for the conflict of goals accuracy versus dynamics?” remains unanswered, but will be dealt with in the final seminar at the end of the semester.

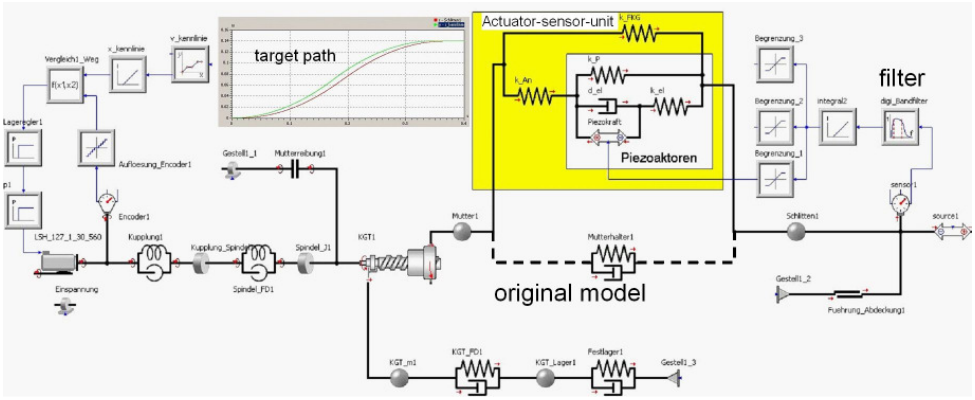

Figure 2: SimulationX-model of the feed axis with built-in actuator-sensor unit

Teaching Model Compensation of Axial Vibration

The second example, the compensation of axial vibration (Figure 2), is based on a piezo-based auxiliary drive, the so-called actuator-sensor-unit (ASU), which is arranged between screw ball nut and tool slide [2].

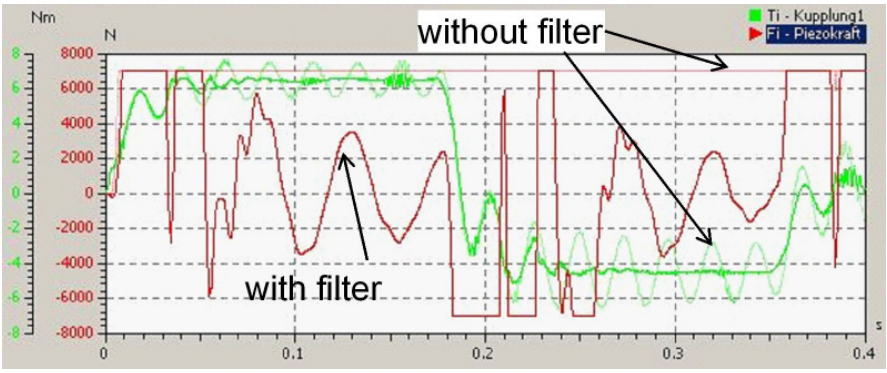

Figure 3: Comparison of coupling moment and piezo force with and without a band filter

The seminar begins with a review of the model of the feed axis, explanation see above. In a second file the individual elements with the set parameters of the ASU are made available to the students; these parameters have to be arranged according to the specification in the script. The functional test is performed within the frequency range. The smaller modifcations of the models are not mentioned here. The frequency response is compared with and without actuator-sensor-unit.

The resilience of the mechanical structure becomes larger during passive operation. It is only by integrating a sensor signal and controlling the piezo actuator that the amplitude of the first eigenfrequency be can decreased. Thus it works to significantly increase the damping in the mechanical structure. Then the students are asked to investigate the improved time behavior, i.e. the orginial positioning process is investigated. For an analysis, additional parameters such as the motor moment and the piezo actuator stroke are used (Figure 3). It can be seen that the ASU remains without effect. In seminars so far no student has been able to find the correct solution in terms of a filter for the sensor signals. After integrating this filter, the drive behavior of motor and piezo actuator can easily be compared.

Teaching Concept

At the moment the lecture series is limited to 15 double periods per semester. A PC-pool is reserved for three lectures. In addition to the seminars mentioned above, the principle of magnetic bearings is demonstrated by SimulationX. A first test showed that an exercise without a noticeable result, that means a course of a graph, is not attractive and that the students' cooperation is lost. The pool has a maximum of 10 available licenses. If one license drops out, 4 students may sit in front of one screen. The start models are in a file that is publicly available. In order to ensure the attention of all participating students for 90 minutes, essential intermediate results of the exercise model can be provided according to the progress of the seminar. In this context it is always important that every modification of the model is reflected in a visible modification of the simulation result. The detailed documentation of the script has proved successful in reducing random trials or intuitive approaches. At the end of the seminar exercise it has to be evaluated whether the start model will be used multiple times or whether it will be better for gaining knowledge if the model is continuously developed.
The combination of lecture, seminar and PC-exercise tries to sharpen the sensitivity of the students for simulation systems and their results. The worth of this teaching concept lies in the comparison of calculation formula that have been known for years, estimated to cover more than 80% of the cases of application, and new simulation methods which can be used appropriately to exploit new development potentials.

[1] Arndt, H.: Auslegung und Bewertung von Vorschubantrieben mit Spindel-Mutter-Systemen. TU Dresden, Institut für Werkzeugmaschinen: 2000
[2] Neugebauer, R.; Pagel, B.; Bucht, A.; Wittstock, V.: Control Concept for Piezo-Based Actuator-Sensor-Units for Uniaxial Vibration Damping in Machine Tools. In: Production Engineering Research and Development, Vol. 4 (2010), 4, S.413-419, DOI: http://dx.doi.org/10.1007/s11740-010-0237-2