Integration of flexible multibody systems dynamics and virtual commissioning simulations of a machine tool

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EXTENDED ABSTRACT

1 Introduction

Digitalization of production processes is a key aspect of Industry 4.0. Companies are increasingly using digital simulations to develop and test new ideas as an effective way to improve competitiveness in the market. The so-called Digital Twins of mechatronic systems are conceived to comprehensively replicate the overall functioning of complex devices, machines, and even industrial plants. Through the integration of the physical behavior with automation-related aspects (automatic hardware and control logic), these advanced models can be used from the early-stage optimization of mechanical design and virtual implementation of control procedures [1, 2] to real-time operations management and in-service failure predictions [3]. The additional efforts required at the design stage for the development of advanced models are supposed to result in a significantly smaller time-to-market of new machines. Indeed, the prediction of possible functioning troubles (and their consequent solution) would cut the duration of the commissioning phase (i.e. all the steps required from the completion of machine assembly to its entry into service). The latter is known to be particularly and time-consuming, above all for debugging the preliminary program codes and/or their adjustment to face unexpected events caused by the actual and unforeseen dynamic behavior of mechanical parts. The so-called Virtual Commissioning, i.e. the part programs' verification performed on virtual models of machines prior to their realization, is just conceived to minimize the occurrence of critical issues in the final testing stage of the physical system.

Within this context, simulations of elastodynamic models may prove particularly relevant in the field of machine tools, which are susceptible to vibrations and dynamic loads possibly detrimental for the machine operational functioning. Elastodynamic simulations make it possible to predict the dynamic behavior of machine tools for different operational conditions and possibly reveal the need to optimize the mechanical design and/or to properly tune the control programs (thanks to Virtual Commissioning), in order to enhance the final machining precision and thus to guarantee proper quality standards. Such highly advanced techniques of modeling and simulation are not widely used yet, mainly due to the significant effort required in the early design stages, to the specific industrial requirements for their implementation [4] and – to the authors' best knowledge – the actual lack of commercial software able to integrate in a whole the simulation tools required for the optimization of both the mechanics and automation sides.

This paper focuses on the development of the flexible multibody model of a machine tool to analyze its mechanical behavior and dynamic response featured at different operational conditions. The model, validated by experimental tests' data, is conceived to predict the elastodynamic behavior of the machine when operating at high speeds and considering both the compliance of flexible parts and the backlash in kinematic joints possibly due to wear. The combination of the simulation results with a Virtual Commissioning simulation is intended to provide a comprehensive and effective tool for supporting the design process (Figure 1a). The methodology, that might be applied to other similar case studies, would provide a holistic approach for the overall analysis and/or design optimization of mechatronic systems.

2 Results and discussion

A specific *transfer* type of machining center (Figure 1b) used for the production of locks' components has been used as case study. The transfer machine, whose specific design and functioning is customized according to the customer's specifications, is composed of multiple stations fixed to the basement that sequentially perform machining operations on the workpieces fixed to a moving rotary table. Each station hosts one or two operative units, that are 3-axes CNC milling machines (Figure 1c) based on the same architecture and featuring only slight differences. A parametric flexible multibody model of the single operative unit was developed through the software *ADAMS* (Hexagon – MSC Software, USA) to simulate the mechanical behavior of the system including elastodynamic effects. Flexibility is indeed a crucial parameter for machine tools since tolerances on the final product depend on the actual motion of the tool (possibly subjected to vibrations) with respect to the theoretical motion law (based on rigid-body dynamics assumptions). To this aim, starting from a preliminary rigid-body model, some kinematic joints were replaced by general forces to take into account stiffness, damping, and the relative positions of the components involved in the motion power transmission. Experimental tests were performed to validate the model: through the comparison of the numerical results with the experimental data, the parameters used for the model definition were properly updated. In particular, the values of stiffness, damping, and friction parameters of the components involved in the case study were repeatedly modified in order to achieve the best fit. In Figure 1d, reported just as a simple example, there are three curves showing the required torque to accomplish a specific displacement along the Y-axis. Initially, using parameters taken from the commercial components datasheets, the simulation results were found to be incongruent with respect to the experimental test data, whereas the curve obtained after the model parameters updating shows a clearly improved similarity.

After the mechanical model of the single operative unit was verified and validated, the results obtained from the elastodynamic simulations are intended to be exploited for a more complex evaluation of the overall transfer machine, for example using motion laws optimized from the mechanical point of view to assess whether they meet the requirements of the overall production cycle time of the product. To this aim, some Virtual Commissioning software were evaluated and tested: *Eureka* (Roboris, Italy), specifically designed for machine tools, has been highlighted as advantageous for this purpose as it effectively meets the needs of the case study, by enabling direct verification of Part Programs, allowing the direct evaluation of machining operations on the visualized finished product, and proving more favorable for future developments with respect to alternative software.

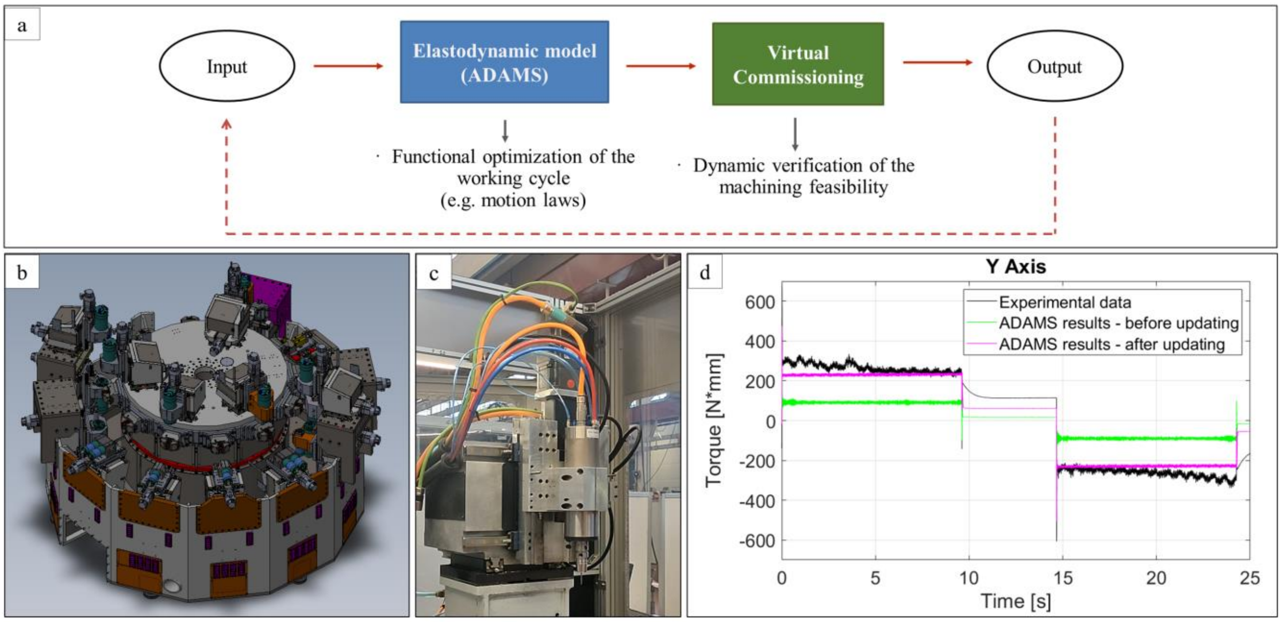

Figure 1: a) Scheme of the methodology; b) transfer machine tool; c) operative unit; d) comparison among experimental data and simulated results.

3 Conclusion

The paper presents the development of the elastodynamic model of a 3-axes milling machine unit, which is the fundamental working module of a CNC transfer-type machine tool. Simulations corresponding to different working conditions were performed to analyze the impact of dynamic effects on its mechanical behavior when operating at high speeds, due to the compliance of the power transmission components and backlash in joints. The elastodynamic model was validated through experimental testing, in particular by comparing numerical results and experimental measurements in terms of spindle motion laws and driving torques of actuators.

By incorporating the elastodynamic modelling framework and the Virtual Commissioning simulation into a single holistic approach, a powerful tool can be developed for the overall analysis and design optimization of complex mechatronic systems: this is the goal of the work currently in progress.

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