Modeling of machining operations based on the Virtual Machine Tool concept

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The Twin-Control European project [1] aims to develop a simulation system that integrates the different aspects that affect machine tool and machining performance, including lifecycle concepts, providing better estimation of machining performance than single featured simulation packages.

The focus of this paper is on the dynamic modeling of the machine tool including its Computer Numeric Control (CNC), and its interaction with the machining process. To properly simulate modern machine tools in machining condition, which show close interaction between the dynamic behavior of the mechanical structure, drives, and the CNC, it is crucial to build models that represent the flexibility of all components and their interactions [2]. To answer such requirements, we use 3D MBS and FEA methods for mechanical aspects, and 1D modeling for the CNC. This paper introduces an integrated methodology that combines MBS capabilities in a nonlinear FEA solver called SAMCEF Mecano [3][4]. It enables accurate modeling of the machine by considering FEA models of the components connected together by a set of flexible kinematical joints. Particular models are implemented to deal with drive-trains and motors dynamics.

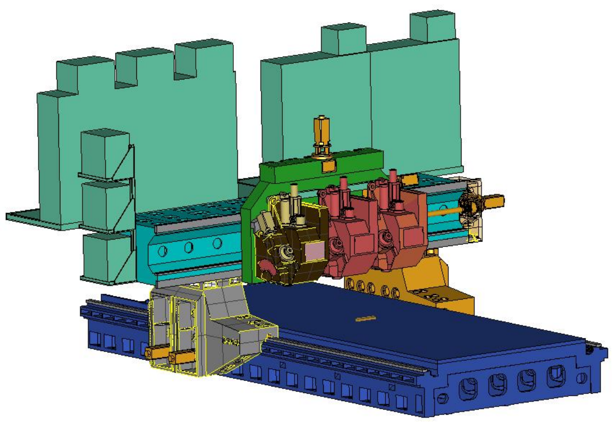

Fig. 1: Multybody model of a five axes machine tool with multiple spindles

To fully capture the dynamic behavior of the machine, force interactions between the cutting tool and the workpiece are also considered in this model. The process for obtaining cutting forces is illustrated in Fig. 2.

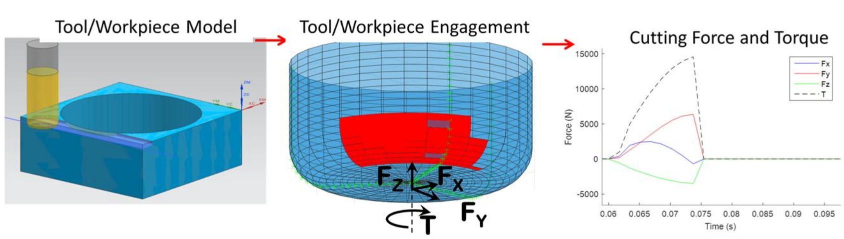

Fig. 2: Process of obtaining cutting forces

First, the motions of the machine structure are coupled with workpiece CAD files to define how the tool is engaged in the workpiece at any point of the CNC program. Calculation of tool-workpiece engagement is based on a mixed discrete-continuous representation of the stock material, also known as the tri-dexel model [5]. The resulting tool workpiece engagement data is then applied to a mechanistic cutting force model [5] to determine cutting forces that are applied to the machine structure model.

A strong coupling between the mechatronic model of the machine tool and the machining simulation tool is implemented. Practically, a specialized cutting force element has been developed. It considers the dynamics of the tool tip combined with the tool work-piece engagement determined from Module Works CAD/CAM for toolpath generation and simulation. The resulting relative dynamics of the tool with respect to the workpiece is use as input to generate cutting forces. Those are applied on the machine model at the spindle tip and workpiece clamping levels. To fulfill equilibrium at each step of the time integration process a Newton-Raphson iterative scheme is used, where cutting forces are updated and the associated iteration matrix is generated at each iteration.

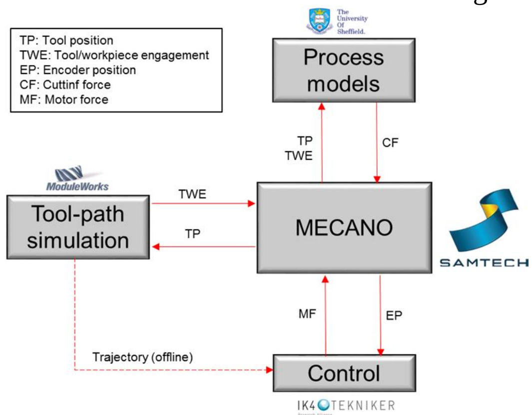

Fig. 3: Coupling scheme

To illustrate this technology, a 5 axes machine is considered. A Fagor CNC controls the motors of the different axes to follow the desired trajectories with minimum errors. In the model, all frames are fully flexible, as the rails and screw drive trains, which are represented by sets of flexible slider elements. The control loops are modelled in MATLAB/Simulink, translated into a dynamic library that is associated to a specific control element used to manage the coupling between 1D models and the full flexible 3D model. The use of such digital twin model will be demonstrated on some machining operations required to manufacture of the following demonstration piece.

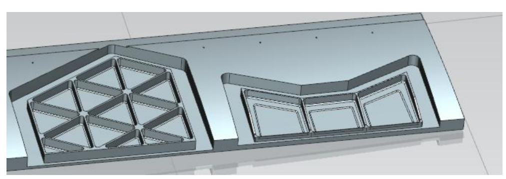

Fig. 4: Manufactured workpiece

Acknowledgments

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References

[1] Twin-Control website (http://twincontrol.eu/)
[2] M. Ghassempouri, E. Vareilles and C. Fioroni. « Modelling and simulating the dynamic behavior of a high speed machine tool", *Samtech Users conference*, 2003.
[3] M. Géradin and A. Cardona. "Flexible multi-body dynamics: a finite element approach", *John Willey& Sons*, 2001
[4] Samtech. "SAMCEF V18.1" *User manual.* 2017.
[5] Moduleworks website (http://www.moduleworks.com)
[6] Y. Altintas, "Manufacturing Automation; Metal Cutting Mechanics, Machine Tool Vibrations, and CNC Design", *2nd Edition, Cambridge University Press*, 2012.
[7] F. Cugnon, M. Ghassempouri, M. Armendia, "Machine tools mechatronic analysis in the scope of EU Twin-Control project", *Nafems world conference, Stockholm*, 2017
[8] F. Cugnon, L. Berglind, D. Plakhotnik, E. Ozturk, "Advance Modeling of Machine Tool Machining Process", *Eccomas thematic conference on multibody dynamics, Prague*, 2017