Simulation Driven Engineering for Machine Tools

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Summary:

Simulation in product development for machine tools and manufacturing machines was supported by service provider specialists like Siemens “Mechatronic Support” or “Planlauf” during the last 20 years. Only such specialists were able to represent the different disciplines in one simulation model:

- drivetrain
- control
- control theory
- measurement
- mechanics (coming from the manufacturer)

Over the last 20 years this simulation model was improved in the manner that today there is a virtual prototype, which can be seen as a digital twin regarding tasks like **dynamic behavior at the Tool-Center-Point** (TCP). Manufacturers of machine tools and manufacturing machines are driving to be more independent from such system - service provider specialists. Dr. Binde Ingenieure GmbH supports manufacturers in their ambition and discloses which problems can be **solved only with the tool NX Simcenter 3D**.

We aim to show machine tool manufacturers how to integrate the drivetrain into simulation, identify the mechanic with the help of transfer function/frequency response, realize a force shock excitation at the TCP and simulate dynamic compliance at TCP.

Keywords:

machine tool, dynamic behavior, response simulation, drive train, tool center point, transfer function, frequency response, dynamic compliance, NX Simcenter 3D

1 Dynamic behavior as a quality feature of machine tools

Dynamic behavior is an important quality feature of machine tools. Issues in dynamic behavior are overshooting, contour failure, machining marks or low productivity. To improve dynamic behavior of machine tools it is necessary to combine smart designed mechanics with a fitting drive train and an optimal adjusted control system.
To reach an optimal solution faster and more cost efficient dynamic response simulation is a good tool. Important load cases for dynamic response simulations are:
- frequency Response of the Speed Controller Plant
- frequency Response of the Mechanics
- dynamic Stiffness / Compliance
- force shock at Tool Center Point

2 Simulation model of the machine tool

The dynamic behavior of the machine tool can be represented with a simulation, using the tool NX Simcenter 3D. To create a simulation model the most necessary information are already available. These information are:
- 3D CAD data
- material properties
- stiffness values of guides, bearings and ball screw systems
- moments of inertia of motors, clutches and ball screw systems

In this article we use a principal example: a machine tool with one axis (*Fig. 1*). The main parts of this machine tool are:
- machine bed with 4 mounting feet
- drivable slide (x-direction) with linear guidance
- clamping surface for workpiece with Tool Center Point Workpiece (TCPW)
- main spindle for milling with Tool Center Point (TCP)

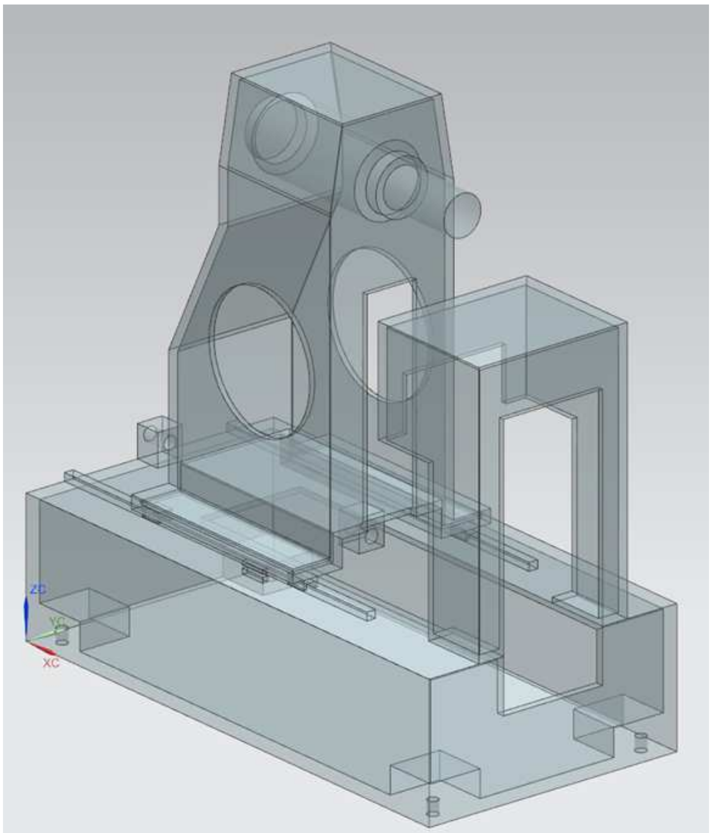

Fig. 1: Principle example: machine tool with one axis

In NX Simcenter 3D we created a FEM-model of the machine tool using solid-, spring-, rigid- and mass- elements. The guidance and the bearings will be modeled using spring- and rigid- elements. The drive train will be modeled using mass- and spring- elements. The physical ball screw system will be replaced by the model of the drive train. The model of the drive train will be linked to the bearing point at the machine bed and to the bearing point at the slide using a manual coupling. The abstraction of the drive train from mechanic model to equivalent simulation model is shown in *Fig.2*.

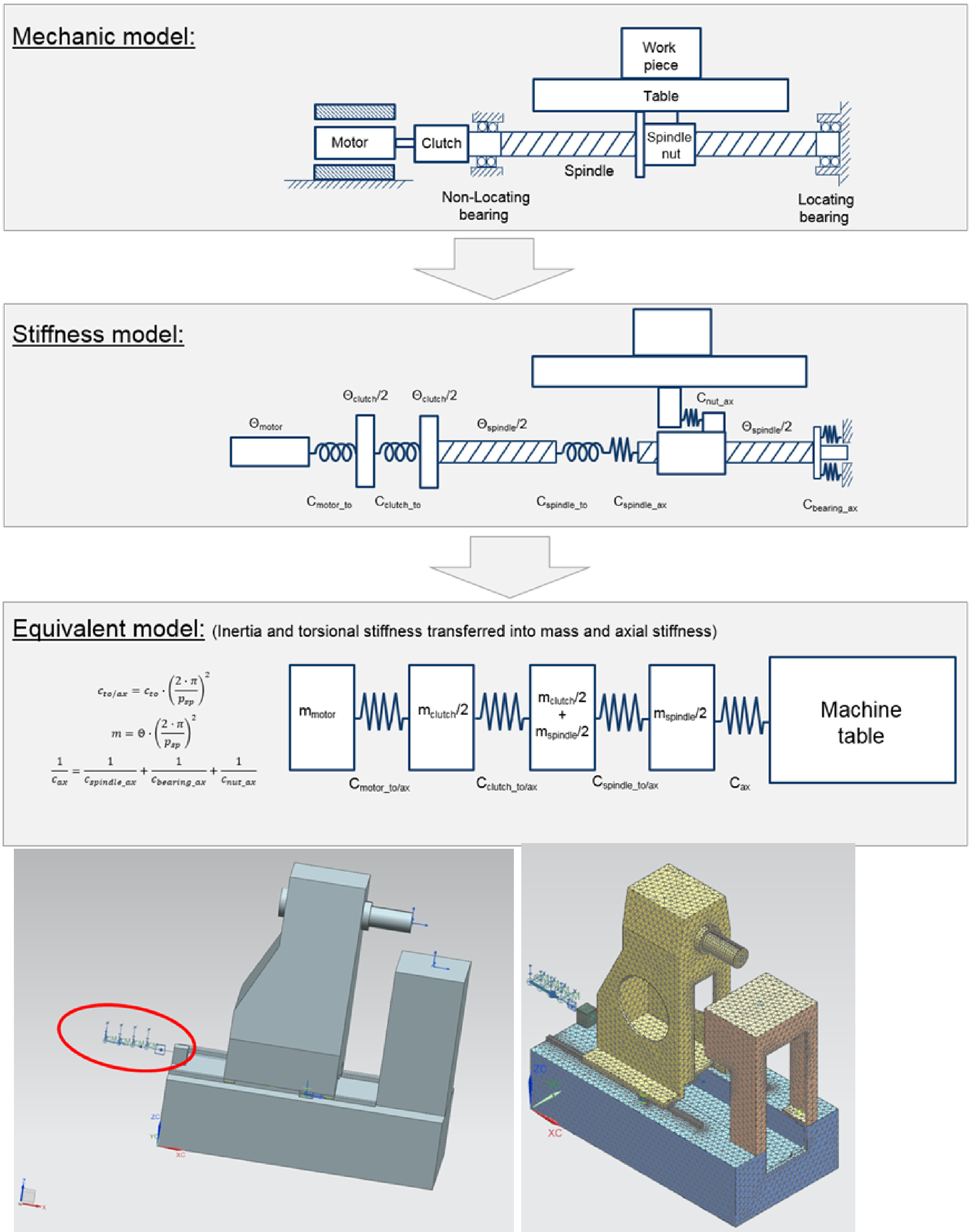

Fig. 2: Abstraction of the drive train

Input- and Output-nodes are defined at these positions: motor and motor measurement system MMS, direct measurement system DMS (moving and fix), Tool Center Point (TCP and TCPW).

3 Simulations with NX Simcenter 3D

3.1 Frequency Response of the Speed Controller Plant

The frequency response of the speed controller plant is determinated between the force at the motor (excitation) and the velocity at the motor measurement system (response).

- input: force at the motor
- output: velocity at the motor measurement system (MMS)
- transfer function: between velocity at the motor measurement system MMS and force at the motor

From the XY-plot of the frequency response of the speed controller plant (*Fig.3*) we can derive the following information:

- zeros and poles
- lowest eigenfrequency determines controller gain factor for the closed position loop
- fingerprint of the machine tool (Blocked rotor Eigenfrequencies and Resonances)
- classify the machine tool

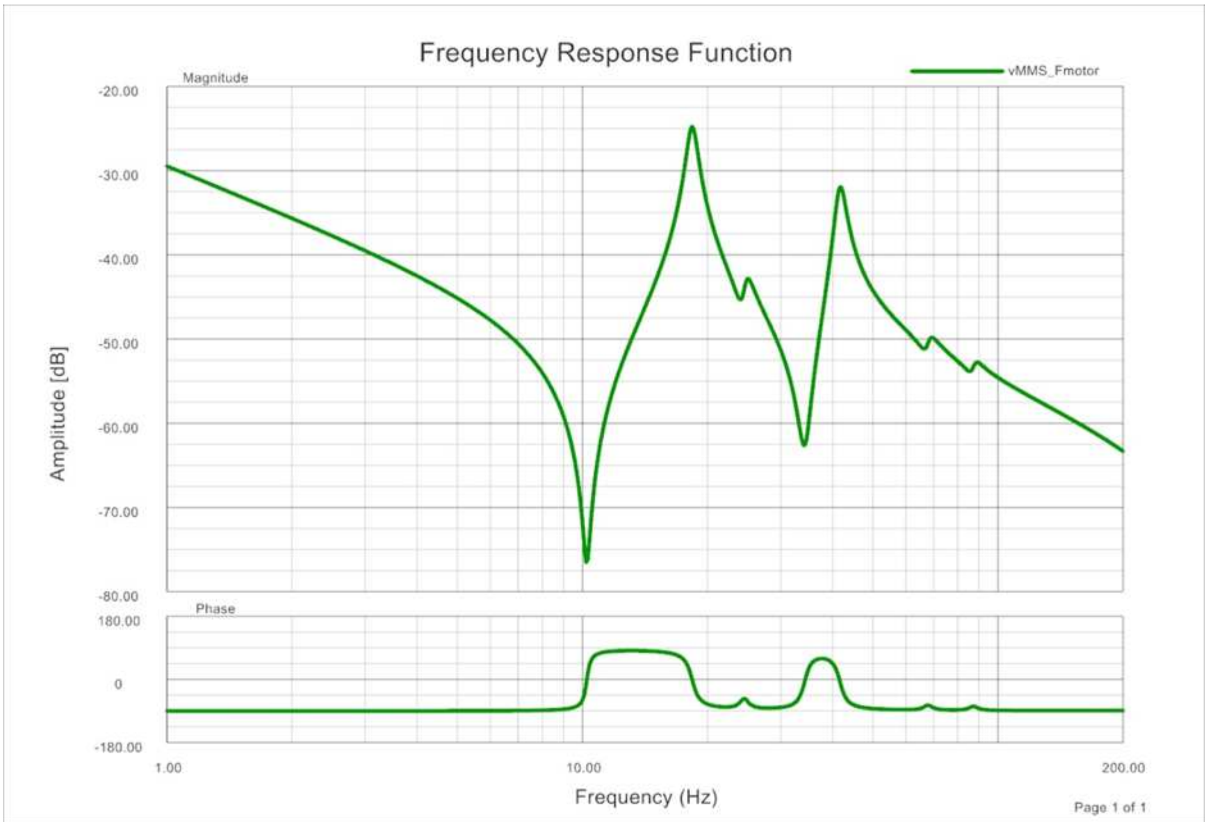

Fig. 3: XY-Plot Frequency Response of the Speed Controller Plant

3.2 Frequency Response of the Mechanics

The frequency response of the mechanics is the transfer function between the velocity at the motor and the velocity at the direct measurement system (DMS).

- input: force at the motor
- output: velocity at the direct measurement system DMS (relativ moving and fix)
- transfer function: from the frequency responses v_{MMS} / F_{motor} and v_{DMS} / F_{motor} the frequency response v_{DMS} / v_{MMS} will be created

From the XY-plot of the frequency response of the mechanics (*Fig. 4*) we can derive the following information:

- which mode limits the machining at the TCP
- important indication for the positioning behaviour

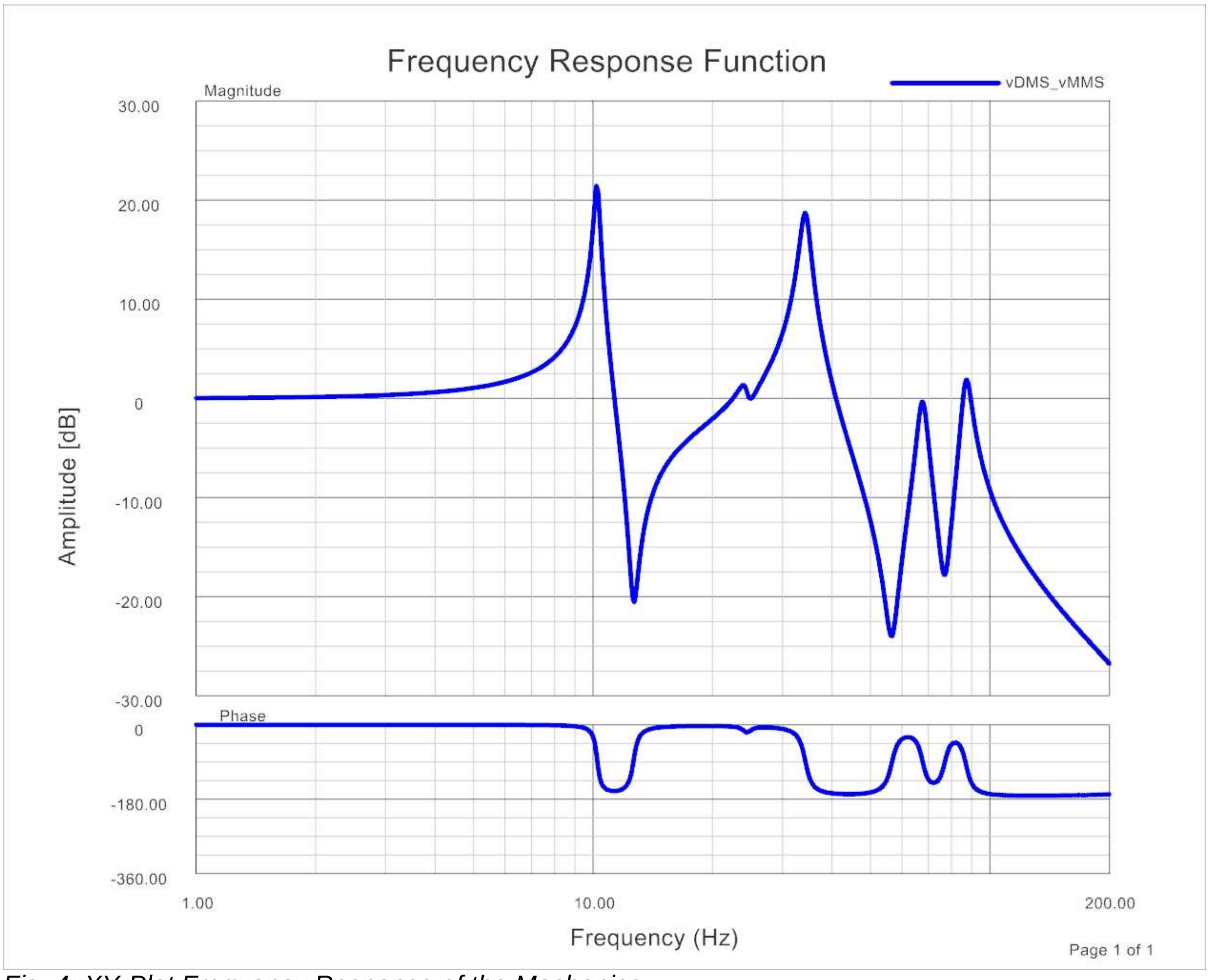

Fig. 4: XY-Plot Frequency Response of the Mechanics

3.3 Dynamic Stiffness / Compliance

The dynamic stiffness is determinated between the force at TCP (excitation) and the displacement at TCP (response).

- motor: fixed (simplification, equivalent to an ideal controller)
- input: force couple at TCP and TCPW
- output: displacement at TCP/TCPW
- transfer function: between force at TCP and displacement at TCP

From the XY-plot of the dynamic compliance (*Fig. 5*) we can derive the following information:

- XY-plot stiffness vs. frequency
- shows frequencies where the machine has a lower stiffness than the statically stiffness
- enables statement regarding technical feasibility of the concept
- enables statement regarding the machine tool if it has enough dynamic stiffness for the application or not

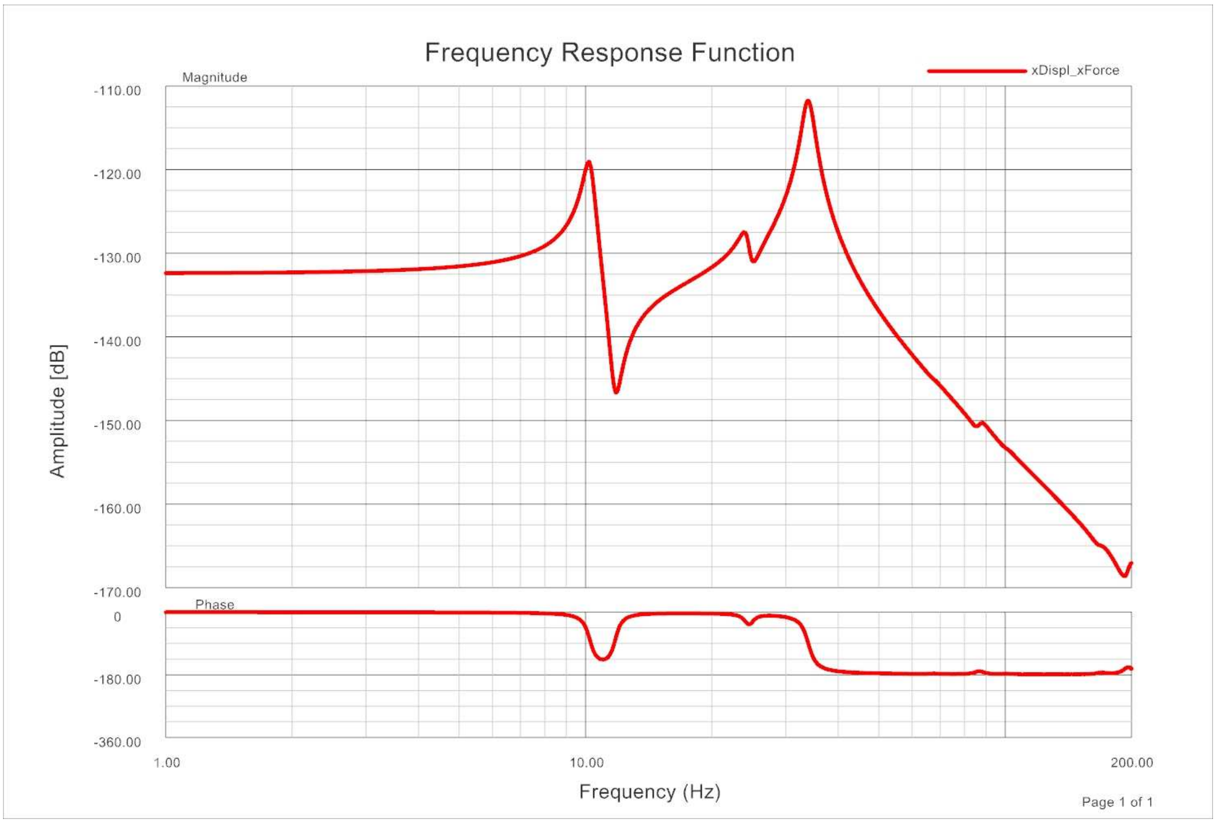

Fig. 5: XY-Plot Dynamic compliance

3.4 Transient response to force shock at Tool Center Point

An excitation with a force shock at TCP generates as response vibrations at TCP.

- motor: fixed (simplification, equivalent to an ideal controller)
- input: force couple (transient force shock) at TCP and TCPW
- output: Displacement at TCP/TCPW

Important fact:
- ramp-up time and force level determine which eigenmodes will be excited

From the XY-plot of the transient response to force shock at TCP (*Fig. 6*) we can derive the following information:
- transient behavior of the machine after initiation a shock force at TCP
- which frequencies will be excited at TCP side and at TCPW side
- can be used as indication for machining marks

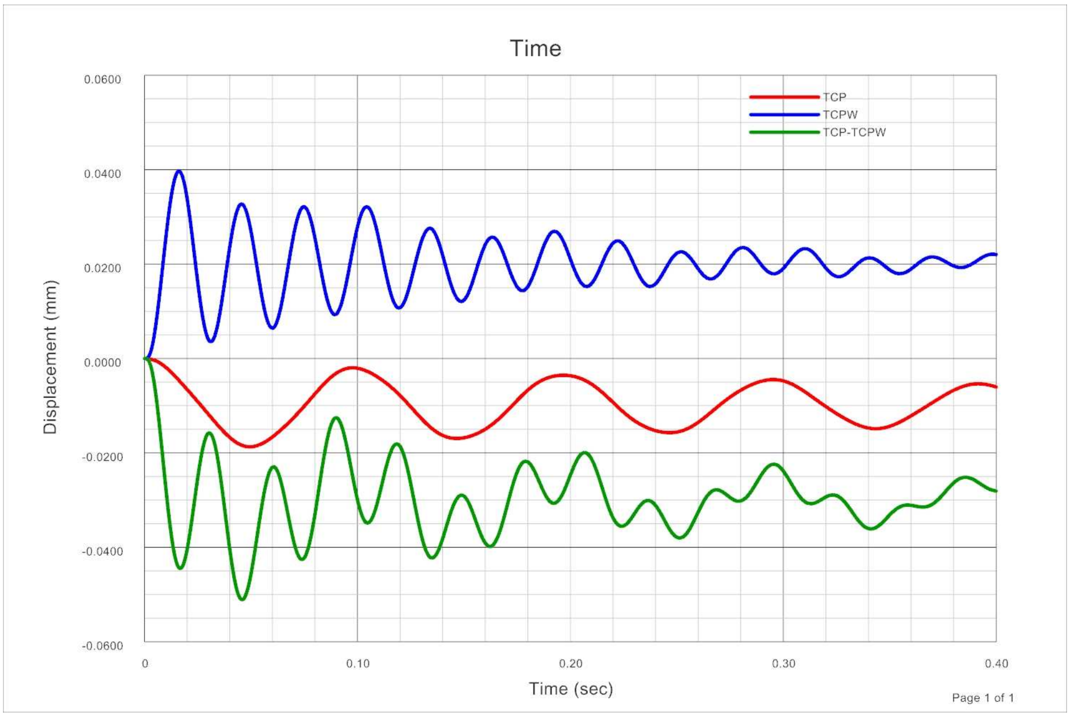

Fig. 6: XY-Plot Transient response to force shock at Tool Center Point

4 Summary

In this article we gave an overview about the possibilities of dynamic simulation of a machine tool. These possibilities are identifying the mechanic with the help of transfer function/frequency response, realizing a force shock excitation at the TCP and simulating dynamic compliance at TCP. With this kind of simulation the mechanic behavior of the machine tool can be analyzed without involving the control system into the simulation. The simulation results can be used in the development process of a machine tool to reach the predefined mechanical requirements.

5 References

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