Calculation of Rigid Body Dynamics in a 2.5-axis HSM Process

Motivation & Objectives
High-speed machining (HSM) is characterized by high dynamic demands due to frequent and high velocity changes and high instantaneous power consumption.

Existing models of machine tool rigid body dynamics are mostly restricted to kinematics, without taking into account the realistic feed velocity profiles. The tool engagement conditions are not included and there is no interaction with the tool path. A comprehensive model of MT rigid body dynamics in a HSM process still does not exist. Control-related constraints, as well as many electromechanical constraints of MT drives, have not been modeled in the existing models.

The objective of this thesis was to develop a software which can simulate a 3-axis milling process by performing the following tasks: parameterization of the tool path geometry and determination of cutting engagement angles, generation of jerk-limited feed profiles on tool path segments, calculation of cutting, inertial and frictional forces and torques, calculation of power and energy consumed in the machining process and visualization of effects of kinematic parameters on it. This software should serve as a part of an overall solution for the problem of MT rigid body dynamics modeling.

1. Engagement angle
The pixel-based parameterization of the tool path and the determination of cutting engagement angles has been done by use of an external software programmed by Mr. Nicolas Planquet in his MSc thesis. All necessary modifications of this program have been made to incorporate it as a module in our program. This module provides the values of cutting engagement angles during the whole machining process and parameterized tool path coordinates as well.

2. Cutting forces
The feed axis model, used in this Master Thesis for the dynamic calculation, explores the rigid body dynamics of axes driven by rotational motors. The most common types of modern feed axes designs include preloaded ball screw drive with a gearbox or a ball transmission and a table with roller guideways.

3. Jerk-limited velocity profile
The jerk-limited velocity profile is based on the jerk-limited velocity profile algorithm introduced by Yusuf Altintaş. For each segment of the tool path, with the desired values of feed rate, acceleration, deceleration and jerk, the program generates the corresponding velocity and acceleration profiles.

4. Rigid body dynamics
The aim of this section is to calculate the total torque which the motor must supply during the machining process. The inputs for this part of the program are the generated feed rates and acceleration during the machining process, the user input values and the cutting forces.

The total motor torque $T_{M}$ is a sum of following torques:

$$T_{M} = T_{c} + T_{f} + T_{in} + T_{fr} + T_{GW}$$

where:
- $T_{c}$ – Torque to overcome the gravity force
- $T_{fr}$ – Frictional torque in guideway system
- $T_{in}$ – Frictional torque in bearings
- $T_{fr}$ – Torque to overcome inertial forces

Conclusion
This software utility represents a module in an overall simulation environment for MT dynamics. This environment, which is currently under development in the LICP, will include tool path generation, control modeling, tool path engagement determination, stability modeling and machining process optimization.

Comparison of the results with other theoretical models has been successful and the software is now ready for an experimental validation. Future work needed to improve the developed software: (i) Expand the application to analyze nonlinear segments, (ii) Generation of feed rate profiles for the segments which are not parallel with machine tool axes, (iii) Provide a sampling time which would correspond exactly to the step length obtained by the pixel based method, (iv) Develop an improved methodology for tool path parameterization and cutting engagement determination to obtain more accurate results.

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