Comparison of compensation strategies of structural effects

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Abstract

High dynamics of machine tool centers lead to high acceleration forces and, thus, may deform the machine structure and result in force coupling effects. In order to achieve high productivity combined with high path accuracy, a numerical compensation of these dynamic effects is desirable. In model based evaluation, the chosen compensation strategy has turned out to be crucial for effectiveness of dynamic compensation. Offline compensation offers a possibility to compensate dynamic effects without deeper knowledge of accessing numerical control (NC) parameters. As drawback offline compensation needs in advance execution or modeling of the desired trajectory to gather occurring deviation values.

Online compensation opens a broader range of possibilities for access points and compensation models. Best results on a model based evaluation of compensation strategies has been reached with superposed compensation on the torque feed forward input of the drives evaluated from set acceleration and jerk.

1 Introduction

Especially in precision and ultra precision manufacturing, high path accuracy and, thus, stiff machine structures are required. Due to material restrictions and high manufacturing cost, the possibilities to improve through structural modification are limited.

Dynamic effects are usually not principal objects of compensation. Especially in finishing processes high machine dynamics and excellent surfaces are requested whereby a high contour accuracy at high acceleration and jerk levels is needed. For an effective compensation, a detailed comprehension of sources for the dynamic effects for a particular machine structure and thus the occurring deviations is crucial.

1.1 Measuring Deviations

R-Test [1] and double ball bar offer a wide range of possibilities for data acquisition for linear and rotary axes. These two measurement devices where used to gather reference data. During the evaluation of the force coupling effects (section 2. “Force Coupling Effects”) the double ball bar has been used to detect one dimensional deviations of the tool centre point (TCP) position.

Alternatively, dynamic effects can be captured by gathering position data directly from the measurement system of the machine itself. Most NC-Systems offer interfaces for direct data logging whereat the TCP position is not ascertainable.

2 Force Coupling Effects

A five-axis blade milling machine, showing significant force coupling effects has been used for the verification of the model and as base of the investigation. The most prominent effects appear between the rotational B-Axis which is located on a linear Z-Axis (see Fig 1).

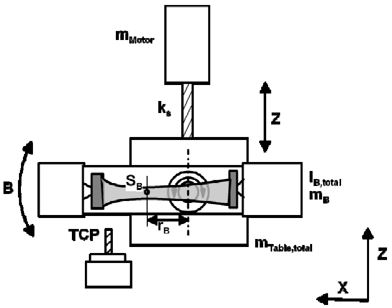

Fig 1 Axis configuration

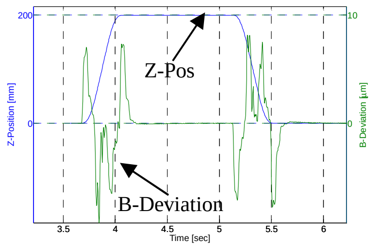

Fig 2 Z-Positioning

The eccentric mass distribution of the B-Axis (due to A-Axis mounting and drive) causes interactions between B-acceleration and Z-position and between Z-acceleration and B-angle position. The values of internal measurement systems of the machine demonstrate that the resulting deviations are measured and influenced by numeric control. A Z-trajectory of 200mm and back to the initial point at high dynamic settings show strongly systematic deviations on the B-Axis measurement system (Fig 2). Extended measurements with probes exposed further deviations of the entire machine structure which are not visible for the measurement systems of the machine.

3 Modeling

The state-space struction model consists of 3 bodies with 2 input signals (force on Z-Axis and Torque on B-Axis), 10 output signals (Z-displacement, A-rotation and B-rotation of upper and lower body, measurement system displacement of Z- and B-Axis, TCP z-displacement and displacement of force transmission point of the Z-slide) and 26 states. The force coupling effect is modelled as force on axis y due to acceleration of axis x (Fig 3).

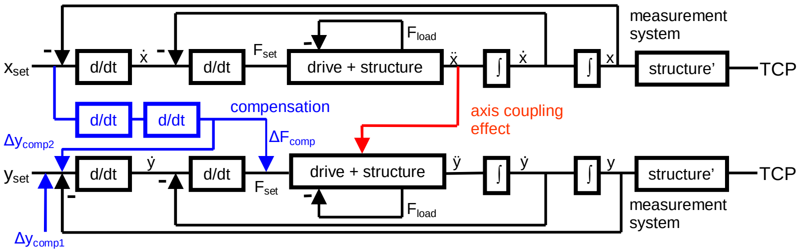

Fig 3 Compensation model

4 Compensation strategies

Either an offline or an online compensation can be performed. Offline means that the compensation will be based on previously measured or simulated values of the desired trajectory [2]. This may be suitable for high-volume production, but not for flexible manufacturing.

An online compensation strategy will get its parameter directly from the actual internal values of the numerical control, which need to be accessible on the fly. Further there are several interfaces where compensation can be inserted. The most apparent way is to get the accruing deviations for a certain trajectory either by measurement or simulation and superpositioning of the inverted deviation directly on the set position (Δy_{comp1} Fig 3). A simulation of this compensation strategy shows that a reduction of the initial deviation of about 30% can be reached. But following the model, a broader frequency band will be excited.

The input values of the model have been obtained directly from the NC set point generation during the measurement. Since the deviations show strong dependence on the acceleration it appears to be reasonable to use actual acceleration values in order to derive the compensation values. The acceleration values will be multiplied with an optimized gain and superposed directly on the position set point value (Δy_{comp2} Fig 3).

The resulting simulation of the TCP position shows deviations at the same order of the amplitude to the offline compensation but with much less excitation.

Since all measured dynamic deviations are due to occurring acceleration forces, the variation of the acceleration and jerk value will also have significant influence on the machine behavior. The derivation of the set acceleration values will allow using jerk level as further input for the evaluation of the compensation value, which will still be superposed on the Z-position set point. The evaluation of the model shows resulting deviations at the same order than the acceleration based compensation.

The set point value is exposed to severe influence of the Numeric Control such as interpolation, filtering and limitations. Thus it would be most effective to apply any online compensation at the latest accusable point of data processing, which would be the torque feed forward input of the drives (ΔF_{comp} Fig 3). Compensation based on acceleration and jerk will lead to a modeled reduction of the TCP deviations in Z-direction of about 60%.

5 Summary

For effectiveness of dynamic compensation, the compensation strategy is crucial. Offline compensation needs in advance execution or modeling of the desired trajectory to gather occurring deviation values.

Online compensation opens a broad range of possibilities for access points and compensation models. Best result on a model based evaluation of compensation strategies has been reached with compensation superposed directly on the torque feed forward input of the drives evaluated from set acceleration and jerk (as deviation of acceleration

References

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