Special Interest Group Meeting on Thermal Issues
Laboratory for Machine Tools and Production Engineering (WZL) of
RWTH Aachen, Germany, February 2020
www.euspen.eu

Spline approximation approach for elastic machine tool structure modelling

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Abstract

Uncontrolled environmental conditions often impact manufacturing processes and lead to product quality fluctuations. For machine tools, thermal influences are a major limitation to the volumetric performance. Climate controls for the shop floor, machines or thermally stable structural designs are often economically not feasible, promoting control-based compensation as a possible solution. Since the relationship between disturbing quantities and effects are complex and specific to each machine, appropriate modelling is a critical requirement.

The rigid body model, prevailing in various mathematical formulations [1], is currently a frequently used kinematic model for controller-based compensation of geometric errors and is computationally evaluable on the controller itself. One drawback of this model is that typically the compensation is based on static error tables and the variability of geometric errors is not taken into account. It is therefore the subject of many research activities to consider the variability of geometric errors within extended model approaches or alternatively to record them process parallel [2–4]. In general, the statement can be made that the more information is available on the geometric state of the machine, the less complex models are required. The same applies vice versa. In the context of digitalization, the availability of process-parallel data increases, but still the direct process-parallel recording of the volumetric error is technically unsolved. By recording and knowing the temperature and force distribution on the machine structure, it is possible, for example, to predict the deformation using FEM models, and hence predict the resulting volumetric error. However, this also requires precise information on the geometric structure of the machine and its material composition. The problem that arises is on the one hand the high computational effort that results from the division into finite elements and on the other hand the high initial effort required for the geometry and material modelling. The effort for creating the model is not scalable to different machine types and must be done individually.

Instead of classic FEM the authors pursue a new modeling concept for the elastic structure deformations, which is based on the approximation of typical deformation modes based on Bézier curves. Spline-based deformation modelling is described in various literature as particularly computationally efficient, with only small approximation errors compared to FEM [5–7].
Since this method is not based on basic physical assumptions, it is necessary to specify sensible preforming modes for machine tool structure components based on expert or experimental knowledge. The authors use additional machine tool integrated inclination and interferometric sensors to define actual deformation constraints. Preliminary tests are performed to compile a catalog of deformation modes, of which the best fitting ones are selected.
The spline information is stored in a JSON (JavaScript Object Notation) file, which also contains the machine tool structural loop as well as rough structure component dimensions an positions. The authors call this abstracted physical body model. The foundation on JSON allows for arbitrary enrichment of the dataset with additional keys and objects, so that also static deformation data (geometric errors according to ISO 230-1:2012) can be stored. The authors developed the software VoluSoft which can read and write these files as well as calculate and visualize the machine deformation and the resulting volumetric error at arbitrary machine positions [8]. With this concept the authors try to overcome the drawbacks of FEM-based machine tool structure modelling and develop a solution, which is highly adaptable to different machine tool types even if no detail Information about machine geometry and material is available.

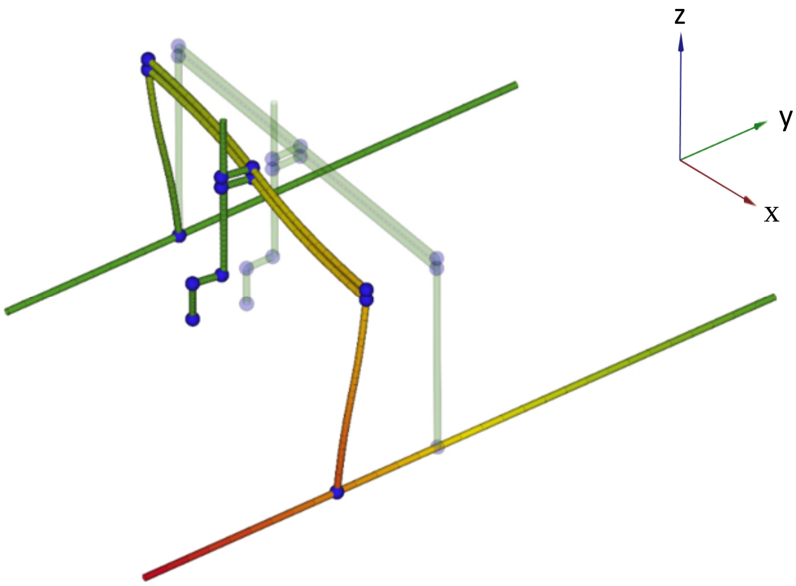

Figure 1 Visualization of a spline-based abstracted physical body model of a FYXZ serial machine tool kinematic. The shown deformation can occur by unsymmetrical deformation of the gantry-axis (Y).

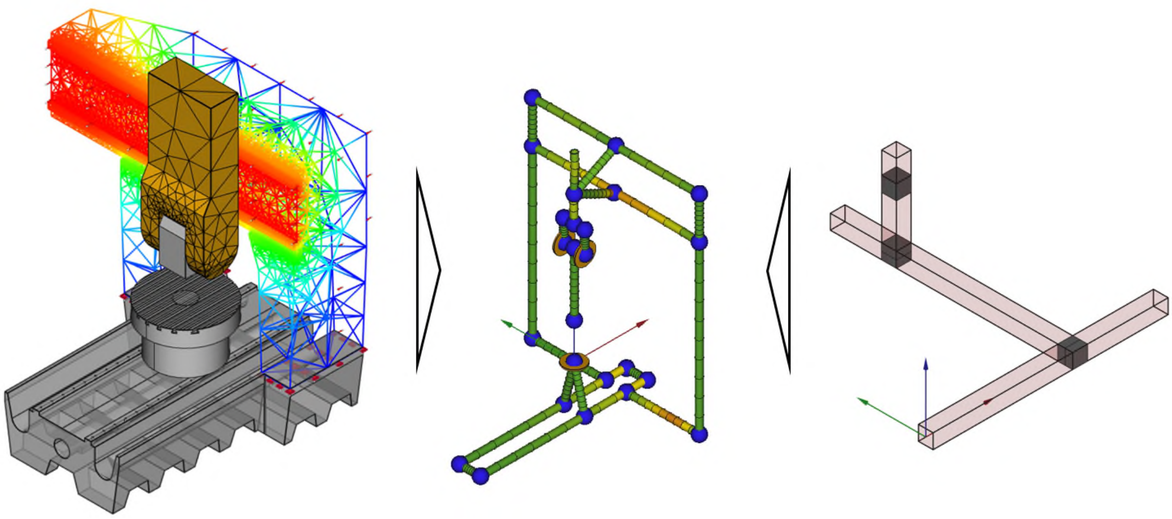

Figure 2 Comparison of FEM-based model (left), rigid-body model for linear axes (right) and spline-based abstracted physical body model (middle) of the exact same machine

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