Validation of cutting force characteristic for complex toolpath

Henrik Sykora, Attila Kovács and Dániel Bachrathy

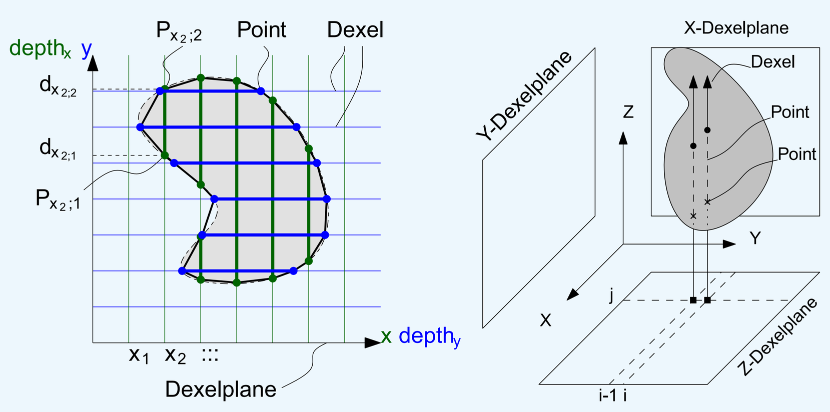
Budapest University of Technology and Economics
Department of Mechanical Engineering
Faculty of Applied Mechanics

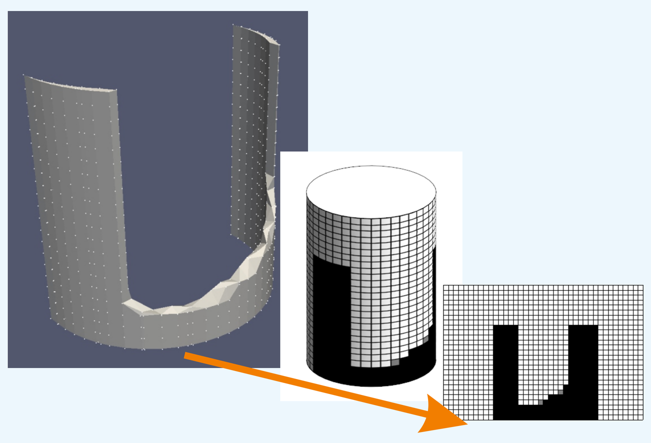
Abstract

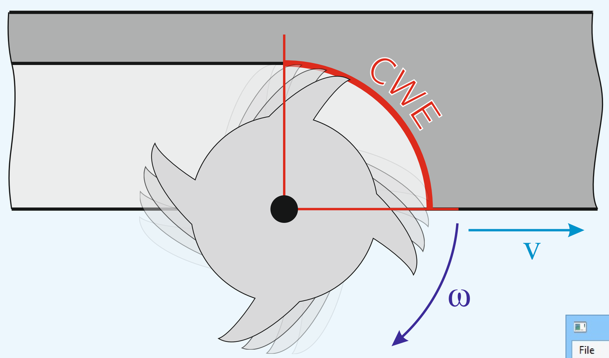
In the design of the milling process of a product, CAM (Computer-Aided Manufacturing) software can be used to generate a tool path which is appropriate for the geometric requirements, however these algorithms do not take the dynamic effects into account. In order to make optimal usage of the machines, it is indispensable to know the connection between the milling tool and workpiece (CWE - Cutter Workpiece Engagement) accurately, however the commercially available CAM programs usually do not provide a possibility to obtain this kind of data. Even if the CWE is known, it is essential to use an appropriate cutting force function to predict the resultant cutting forces and moments, the resultant vibrations, the surface quality and stability properties [1, 2].
The main goal of our work is to develop a program capable of generic 3 axis milling simulation with a cylindrical milling tool, along with the computation of forces and the moments and the experimental validation of the theoretical model.

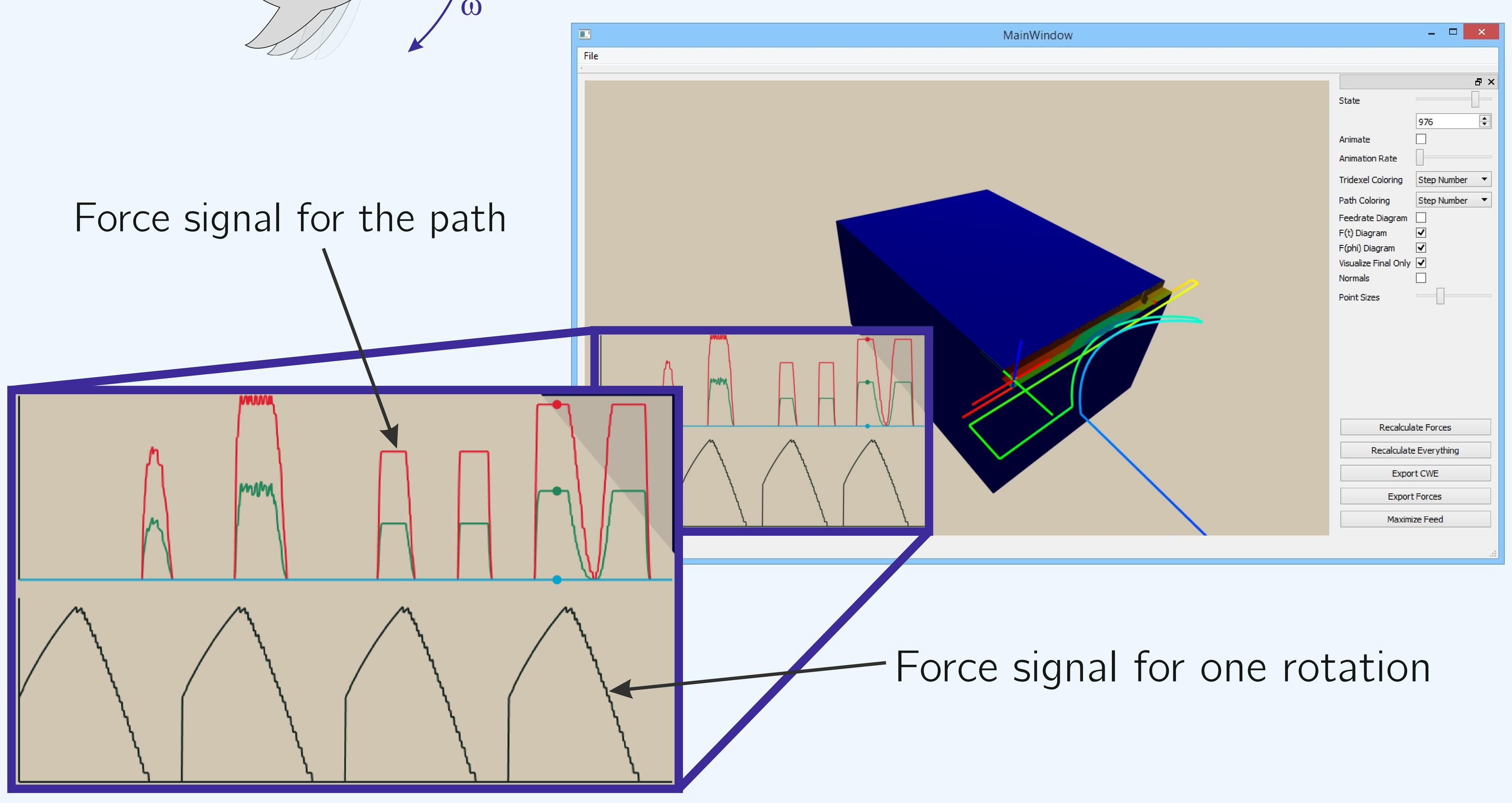
Software

The software utilises the multi-dexel solid modelling technique, because this method allows us to calculate the CWE for irregular toolpaths easily and accurately. It can calculate the time-force functions along the toolpath, and can optimise the feed rate. It was implemented in C++ programming language that allows developing a modular and fast code.



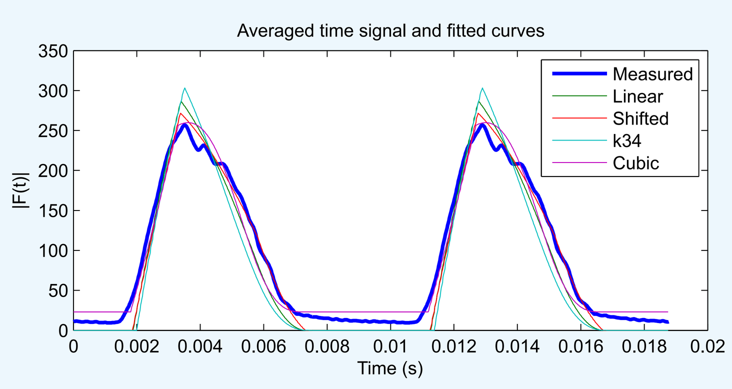






Force models

In the calculation of the cutting force components, it is essential to determine the relationship between the local chip thickness and the specic force. In principle this relationship is based mainly on the material properties. In practice, the resultant cutting force is measured and then different force models are fitted, from the simplest linear (1), the shifted-linear (2), the three quarter (3), to the third order polynomial (4) force model. The resultant coefficients are in close correlation with the material properties.



$$F_{\text{linear}} = k\,w\,h \quad (1)$$

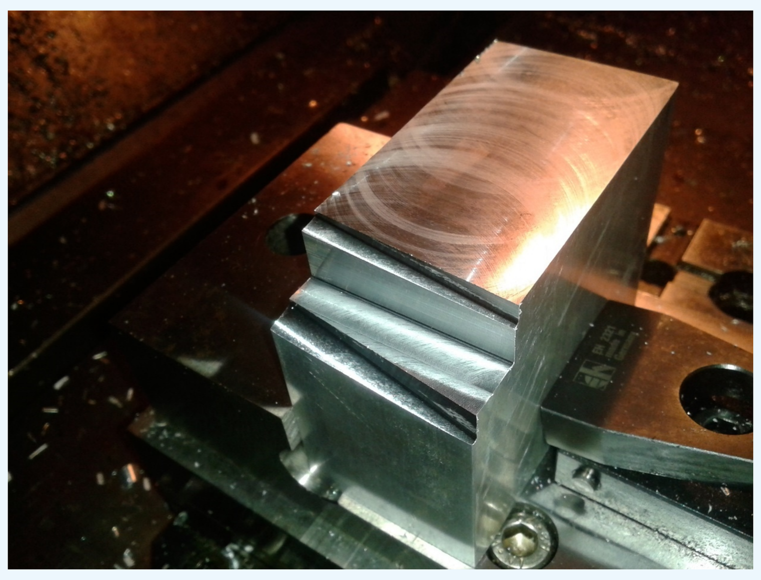
$$F_{\text{shifted}} = k_{\text{shift}}\,w\,(h+h_{\text{shift}}) \quad (2)$$

$$F_{\text{three-quarter}} = k_{3/4}\,w\,h^{3/4} \quad (3)$$

$$F_{\text{polynomial}} = w\,(Q_0 + Q_1 h + Q_2 h^2) \quad (4)$$

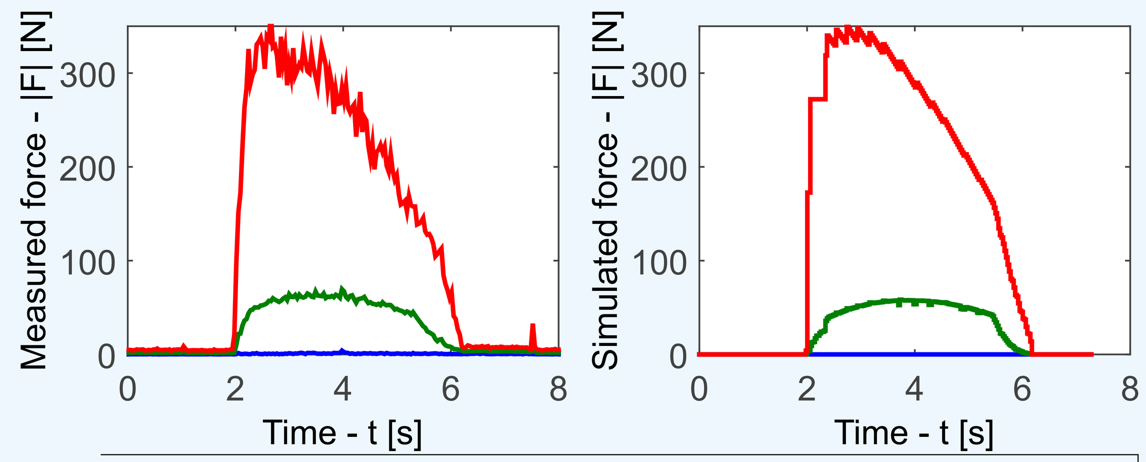
Measurement

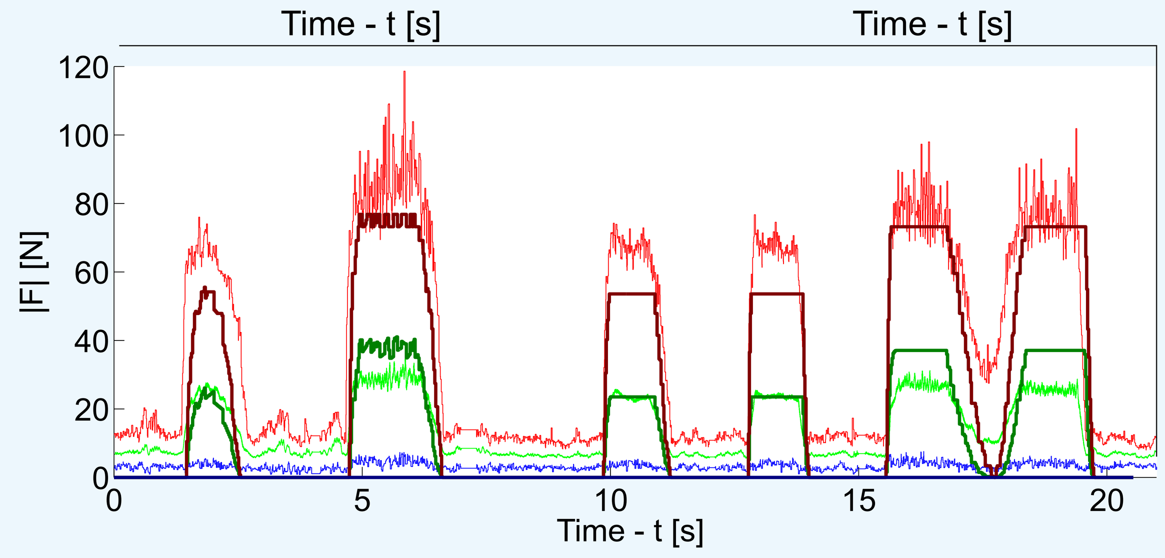
Several cutting force measurements were carried out with constant radial and axial depth of cut with the measurement setup presented in [3]. Different force models were fitted for each measurement, based on the time function of the cutting force (Figure at „Force models" section). It is found, that cutting force models with multiple parameters can lead to smaller errors, however, the linear and three-quarter rule have smaller deviations between different measurement conditions, hence these two are good candidates for force computations at complex CWE-s.
Secondly, we used a toolpath for which the axial and the radial immersions were changing continuously (Figure below). The CWE was computed based on the multi-dexel solid modelling and the resultant cutting force is computed for the linear force model. The figures in the results section present the measured and the calculated forces.
Finally, we conducted an experiment with a more complex toolpath, where a circular arc was investigated, on which we tested the force signal by up- and downmilling procedures. It turned out, that the software does not handle up/down milling well, its cause is under investigation.
In the future, we plan to perform tests with more complex toolpaths and workpiece



Results

Based on the very good agreement shown in the figures below, we can state, that the simplest force functions (linear, three-quarter) can be used to compute the resultant cutting force precisely in milling if the CWE is determined with high accuracy.
On the Figure below small jumps can be seen in the time signal of the measured data, this is due to the fact that the simulation has constant feed motion, however in reality this is not true for the milling machine due to the finite accelerations at the corners. For better comparison of the forces, we had to compensate this effect by including small time-shift in the signal.
The software can be extended with many more features, for example stability calculations to avoid chatter, simulation of more complex tool geometries, 5 axis milling, STL import for initial workpieces.





Acknowledgement

This poster was supported by the Hungarian Scientic Research Fund - OTKA PD-112983 and the Janos Bolyai Research Scholarship of the Hungarian Academy of Sciences.

References

[1] Y. Altintas, P. Kersting, D. Biermann, E. Budak, B. Denkena, I. Lazoglu: Virtual Process systems for part machining. CIRP Annals - Manufacturing Technology, Vol. 63 (2014) pp. 585-605.
[2] D. Bachrathy: Cutting dynamics and surface quality. PhD dissertation, Budapest University of Technology, Department of Applied Mechanics, (2006)
[3] I. Biro, M. Czampa, T. Szalay: Experimental Model for the Main Cutting Force in Face Milling of a High Strength Structural Steel, Periodica Polytechnica Mechanical Engineering, 59(1) (2015) pp. 16-22