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# Modelling the dynamic contact forces during orthogonal turn-milling

**Katharina Knape**[1,*], **Steffen Nitzschke**[1,**], and **Elmar Woschke**[1,***]

[1] Institute of Mechanics, Otto-von-Guericke-Universität, Universitätsplatz 2, 39104 Magdeburg, Germany

The aim of this work is to numerically calculate the effective cutting forces during orthogonal turn-milling using the well-known analytical approach introduced by Victor/Kienzle in connection with a multi-body system. Starting with a routine that numerically computes the mill's infeed with the implemented dexel model, it is possible to reconstruct and follow the tool's outline and track caused by its rotation. Hence, the acting cutting forces can be determined.

## 1 Introduction

The method of turn-milling, a promising cutting process combining the two conventional machining operations turning and milling, is already successfully used in order to create microstructures on tribologically stressed surfaces [2]. It not only offers a more sustainable and environmentally friendly way to mill, it is also a technique with lower cutting temperatures which helps to increase the tool's life [3]. Due to nonlinear effects, like vibration excitations caused by interrupted cutting and their repercussions on the system, this manufacturing method needs to be further investigated to ensure a stable process and a reproducible surface quality. This simulation contains the dexel model to discretize the work piece's surficial area. Once the intersection between the tool and the work piece is found, the cutting depth and therefore the acting cutting force can be calculated.

## 2 Kinematics of the system

In order to describe the kinematics of the system, a multi-body-system is used. For the sake of simplicity and to reduce the numerical computation time, only the tool's teeth are modelled according to the sizes of the real mill with the help of a stereolithography file as shown in figure 1. The work piece, in this case a shaft, is described through the dexel model which uses lines with their direction depending on the cross-section of the work piece to represent it as a flat projection [6].
Figure 2 illustrates the application of the dexel model for a cylindric shaft.

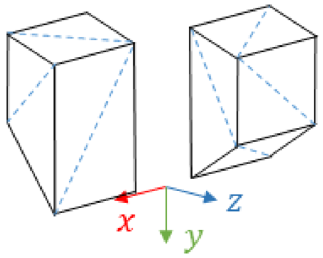

**Fig. 1:** tool model: the mill's surface described by triangles

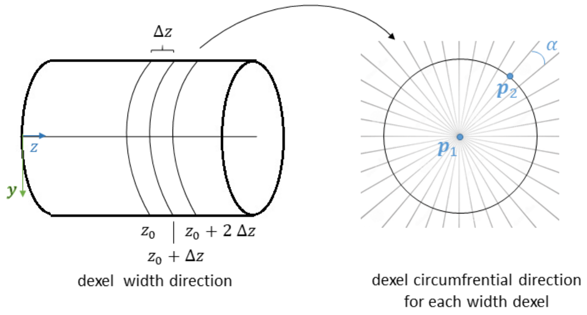

**Fig. 2:** work piece model: discretization of the surface by a certain number of width and circumfrential dexel

The main advantage in using the dexel model is determined by the possibility of a one-dimensional calculation of the intersection between the mill described through the Hesse normal form of a plane and the shaft by using a linear equation for each dexel. As can be seen in figure 2, the point $\boldsymbol{p}_2$ is calculated depending on the angle $\alpha$ which itself is a fuction of the chosen number of dexel for the circumference.

$$\boldsymbol{n} \cdot \boldsymbol{x} = \boldsymbol{n} \cdot \left( \boldsymbol{p}_1 + \tau \, \frac{\boldsymbol{p}_2 - \boldsymbol{p}_1}{|\boldsymbol{p}_2 - \boldsymbol{p}_1|} \right) = d \qquad (1)$$

The cutting process can only be considered successful, if the point lies within a triangle of the tool's surface and if the shaft's new radius $\tau$, the distance between the point of intersection and the center of the cross section, is shorter than the preceding value.

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[*] E-mail: katharina.knape@ovgu.de

[**] E-mail: steffen.nitzschke@ovgu.de

[***] E-mail: elmar.woschke@ovgu.de

## 3 Calculation of cutting forces

In order to calculate the cutting forces, the widely used formula introduced by Victor and Kienzle is applied which usually serves as a rough calculation of the acting cutting forces during milling and turning in the field of production engineering [4].

$$F = K \cdot b \cdot h^{(1-m_c)} \cdot k_{c1.1} \tag{2}$$

The approach contains the correction factor $K$ which includes the influences of the cutting velocity, the tool's material and wear. The variables $b$ and $h$ describe the chip's geometry depending on the cutting depth. The exponent $m_c$ as well as the specific cutting force $k_{c1.1}$ can be found in tables according to the material of the work piece [4]. Table 1 summarizes the simulation parameters adapted to the ones used during the tests conducted in the corresponding literature [1].

**Table 1:** Cutting conditions for the simulation

| parameter | value | parameter | value |
|---|---|---|---|
| tool's radius | 16 mm | work piece's radius | 52 mm |
| number of teeth | 2 | work piece material | Al6061-T6 |
| tool's rotational speed | $10000\,\frac{\text{rad}}{\text{s}}$ | work piece's rotational speed | $40\,\frac{\text{rad}}{\text{s}}$ |
| tool's infeed | 1 mm | axial infeed | $4\,\frac{\text{mm}}{\text{min}}$ |

## 4 Results

Implementing the data given in table 1, one full tool rotation was examined which yields the red curve shown in figure 3. The model tends to slightly overestimate the acting cutting forces due to this being defined as a rough calculation and the choice of the correction factors from tables.

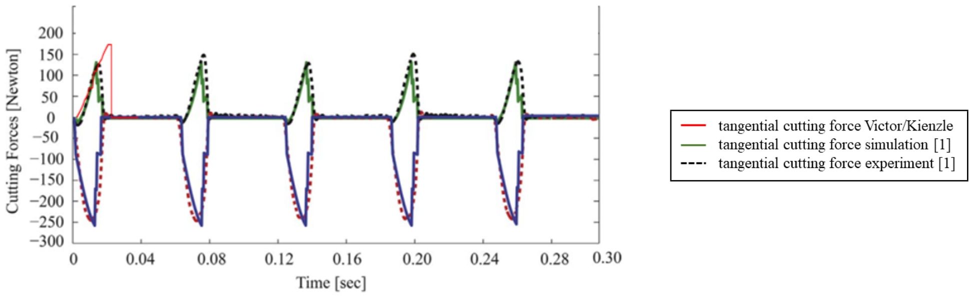

**Fig. 3:** Simulation results compared with data from literature [1]

## 5 Conclusion

A model to numerically calculate the cutting forces acting during the orthogonal turn-milling process using the analytical approach introduced by Victor/Kienzle is presented. Considering the fact that the chosen formula is about a rough calculation, the occuring slight differences are resonable so that it can be said that the simulation results came to good agreement with the data found in literature.

In future work, the periodic elastic deformations, for example through a finite element analysis, should be taken into accout since they influence the cutting depth, the chip's geometry and therefore the cutting forces as well.

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## References

[1] A. Comak, Y. Altintas, Mechanics of turn-milling operations, Int. J. Mach. Tools Manuf. **121**, 2-9 (2017).
[2] U. Karaguzel, M. Bakkal, and E. Budak, Process Modeling of Turn-Milling Using Analytical Approach, CIRP. **4**, 131-139 (2012).
[3] M. Kara, E. Budak, Optimization of Turn-milling Processes, CIRP. **33**, 476-483 (2015).

[4] W. König, F. Klocke, Fertigungsverfahren 1: Drehen, Fräsen, Bohren (Düsseldorf: VDI-Verl., Düsseldorf, 2008), p. 43 ff.

[5] U. Karaguzel, E. Uysal, E. Budak, and M. Bakkal, Analytical modeling of turn-milling process geometry, kinematics and mechanics, Int. J. Mach. Tools Manuf. **121**, 2-9 (2017).

[6] Z. Hou, Beitrag zur voxelbasierten Simulation des fünfachsigen NC-Fräsens, PhD-Thesis, Technische Universität Berlin, Fakultät V - Verkehrs- und Maschinensysteme, 2003, p. 16 ff.