Analysis of the Flow Field of Rotating Milling Cutters in Idle Mode

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Introduction

Rotating tools are generally assumed to be one of the major sources of noise in machines. Vortices shedding from the rotating tool may cause turbulent flow fields.

The relevant mechanisms for the reduction of noise emission of rotating systems are rather found in aviation than in the field of machine tools. The combination of noise emission and flow field has been described in numerous papers. Hübner et al. [1] describe the measurement conditions of rotors with radial cylinders and their influence on the defined noise emission. Advice on how to reduce the noise emission is not mentioned, however. Detailed investigations into impulse noise caused by wing-turbulence interaction are discussed in [2]. In [3] and [4] detailed possibilities are presented for the reduction of noise emission in rotating systems. In [3] obvious reductions of noise emission, caused by compressed air in the trailing edges of turbines, are analysed. [4] describes a three-dimensional measurement of the flow field of a counter flow engine. The measurements were carried out by a hot-wire anemometer. The noise emission could be properly predicted by the three-dimensional measurement of the flow field of the counter current engine.

Experimental Approach

According to the approach suggested in the papers, the flow field of the rotating tool is examined first. In a later step noise reduction possibilities will be considered.

This paper focuses on the flow field of a milling cutter in idle mode. First, measurements obtained by a scanning laser Doppler vibrometer are analysed. The test object is a milling cutter for T-slots. The test reading shows turbulences caused by vortices only in the chip space of the milling cutter and the near field of the cog. Subsequently, the flow field of the same milling cutter is simulated by ANSYS CFX. The simulation confirms the test reading obtained by the scanning laser Doppler vibrometer. Additionally, a different type of milling cutter is tested in water. The turbulence caused by this milling cutter occurs again only in the chip space. Therefore, different geometries are simulated to detect relevant parameters that cause turbulences.

Experimental Analysis with a scanning laser Doppler vibrometer

The measuring principle of the scanning laser Doppler vibrometer is based on the Doppler shift. Originally, the Doppler effect is the change in wavelength and frequency of a wave for an observer, which moves relative to the source of the waves.

Figure 1: Measurement setup for the scanning laser Doppler vibrometer

In general, the scanning laser Doppler vibrometer is used to analyse vibrating surfaces. This principle can also be applied to the analysis of flow fields. In this case the laser beam ejected by the vibrometer is reflected by a non-vibrating surface. Here, the turbulences of the air in-between the vibrometer and the surface cause the change in frequency and wavelength of the transmitted beam. The turbulences are caused by the rotating cutter. High accuracy is required to avoid undesired vibrations of the surface, by which the measuring beam is reflected. A solid steel plate was used for the measurements described.

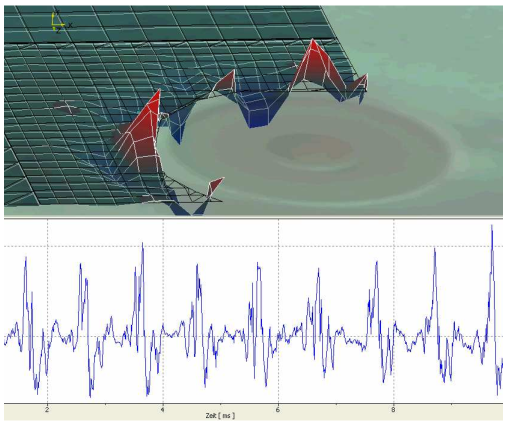

Figure 1: Result of the measurements with the scanning laser Doppler vibrometer

Figure 2 shows the results of the analysis with the scanning laser Doppler vibrometer. The measurement conditions are presented in Table 1.

The upper picture in Figure 2 shows that the disturbances of the flow field, which can be attributed to turbulence, occur mainly within the height of the cog. The lower picture shows the disturbance of the flow field over time. The data was measured in the area of the chip space.

Parameter	Unit	Value
Number of samples	-	1024
Sampling rate	kHz	102.4
Measurement period	ms	10
Resolution	µs	9.765625

Table 1: Measurement conditions

The major disturbance at every 1 ms can be attributed to the passing cog. The disturbances in-between the cog-related disturbances can be attributed to turbulence in the chip space. To verify the results gained by the scanning laser Doppler vibrometer, simulations were carried out in ANSYS CFX.

Simulation in ANSYS CFX

A CAD model of the T-slot milling cutter was created in SolidWorks. In order to minimise the computing time, symmetries were used and only one subdomain of 72° of the milling cutter was modelled. The created CAD model was imported into the grid generator ICEM CFD and a tetrahedral grid was generated. Initial conditions were specified in ANSYS CFX Pre, according to Table 2.

Parameter	Unit	Value
Rotational speed	min^{-1}	6000
Air pressure	bar	1.03
Air temperature	°C	25

Table 2: Initial conditions

The boundary conditions are

- Stationary wall, flow involving friction,
- Rotation conditions inter subdomains (72°).

$$D_{sim} = D_{tool} + 20 \cdot h_{cog} \quad \text{[mm]} \qquad (1)$$

The diameter of the simulation area is fixed according to equation (1). It is the sum of the diameter of the milling cutter and the twentyfold height of the cog.

Description	Parameter		
	b [mm]	h [mm]	n [min^{-1}]
Standard	4	2	6000
Variation b	20	2	6000
Variation h	4	20	6000
Variation n	4	2	30000

Table 3: Overview of parameter variation for simulation

Table 3 gives an overview of the parameter variation for the CFD simulation. The parameters are the width of the milling cutter *b*, the height of the cog *h* and the rotational speed *n*.

The results of the simulative parameter variation are listed in Table 4. The simulation shows that a fivefold increase of the width of the milling cutter seems to cause a total pressure increase. Since the increase is fivefold the standard pressure, it can be neglected. The tenfold increase of the height of the cog also has only minor influence. The rotational speed was increased fivefold. The major increase shows the total pressure *p*. Even if the fivefold increase of the rotational speed is excluded, the pressure still rises 5.74 times.

Variation	v	$E_{kin,turb}$	p
	[m/s]	[m²/s²]	[Pa]
Standard	15.74	0.84	5.45
b	15.71	0.80	28.27
h	62.96	4.00	61.35
n	78.49	7.28	156.40

Table 4: Results of simulative parameter variation

Conclusions

The measurements carried out by the scanning laser Doppler vibrometer showed turbulences in the area of the cogs of the milling cutter. As vortices shedding from the rotating tool were expected but could not be measured, several CFD simulations with changing rotational speed, height of cog and width of cog were run. The measurements were confirmed by the results. They showed the turbulences again in the chip space.

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