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Procedia CIRP 58 (2017) 517 – 522

www.elsevier.com/locate/procedia

16th CIRP Conference on Modelling of Machining Operations

# A study of the interaction between coolant jet nozzle flow and the airflow around a grinding wheel in cylindrical grinding

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**Abstract**

A grinding wheel rotating at high circumferential speed induces a boundary-layer airflow which possibly can detain the coolant from submerging into the grinding zone, in order to prevent thermal damage. To study the profile of the airflow, general laws of fluid dynamics are applied and the analytical results compared with results from CFD simulations. These are used to investigate the interaction of the coolant with the grinding wheel under the influence of the airflow with different coolant nozzle types and parameters. For validation high speed imaging is employed. The conclusions may help for a general understanding of the interaction between wheel-airflow-coolant.


Peer-review under responsibility of the scientific committee of The 16th CIRP Conference on Modelling of Machining Operations

*Keywords:* Grinding; Simulation; Cooling Fluid; Airflow

## 1. Introduction

A suitable coolant delivery remains crucial in conventional and energy intense grinding processes. Malkin and Anderson described the high thermal flux into the workpiece by plowing and sliding of the grinding grains and possible thermal damage due to high surface temperatures [1,2]. However an inefficient usage of coolant can contribute largely to the total energy balance of the machine and thus the production costs to a remarkable share [3]. The flood cooling method, which is still widely used in industry, generally delivers huge amounts of coolant at low pressures and undefined direction onto the grinding wheel and grinding zone, where typically a large amount of the fluid is neither used for cooling nor lubrication in the grinding zone. An experimental investigation counted only 4-30% of the coolant flow passing through the grinding zone [4]. The velocity ratio between coolant and tangential speed of the grinding wheel, the alignment of the coolant nozzles as well as their shape have been identified as the most significant factors for an efficient coolant delivery [5,6]. Much research has been done on jet nozzles to reduce the amount of fluid required and thus significantly lower the energy consumption by evaluating different nozzle designs in flat [7] as well as cylindrical grinding [8,9], where round nozzles allowed substantial lower coolant volume flows. Research and experience in industry clearly show that the coolant can be inhibited from entering into the grinding zone by the air boundary layer around the rotating grinding wheel. This phenomenon is also known as the air barrier [9]. Thus for the optimal design of fluid supply intense knowledge about the airflow is essential.

In literature many investigations about the boundary layer flow of grinding wheels can be found, most of them dealing with face grinding. Starting with schlieren imaging of the airflow [10], measurements with intrusive methods like hot-wire-anemometers [11] and the non-intrusive laser Doppler anemometry [12] have been used to investigate the flow conditions for cylindrical grinding wheels in radial and axial dimensions. Different velocity


Peer-review under responsibility of the scientific committee of The 16th CIRP Conference on Modelling of Machining Operations
doi:10.1016/j.procir.2017.03.261

distributions in outer and central regions of the grinding wheel surface have been detected. In recent years computational fluid dynamics (CFD) became a powerful and feasible tool for investigating various parameters including the influence of the surface roughness, porosity of the grinding wheel and the effect of air scrapers on the wheel boundary flow [13,14].

This work aims to contribute for the understanding of the interaction of the coolant jet of different nozzle types with the grinding wheel considering the airflow. As stated in [15] the Rouse shape nozzle is considered in literature as being optimal concerning jet flow quality in terms of coherence and disturbances. But the distribution of the coolant across the width of the grinding wheel (axial direction) for wider wheels as well as the interaction with the airflow is often neglected. First the general velocity distribution for a cylindrical shaped grinding wheel is shown. In a second part the interaction between coolant jets and the airflow field is investigated whereas the effect on the grinding process of the nozzles is known [8,9]. Full 3D-CFD simulations were performed and compared to high-speed images of an experimental set-up.

## 2. Analytical Equations

A complete analytical solution of the airflow around a rotating grinding wheel does not exist, but general remarks can be given. The grinding wheel is modeled by a rotating disk with basically two outer flow regions, the flow over the faces and the lateral flow respectively. When considering the porosity of a grinding wheel an inner flow through the tool can influence both regions.

Air as a viscous medium sticks on the walls of the rotating disk and is accelerated up to the surface velocity at the wall. The radial velocity profile away from the wall is defined by the inner friction. For several boundary layer flows exist empirical values related by the Reynolds number of the flow. For example the flow profile on the side faces can be modeled as a rotating disk, where an analytical solution is given by Schlichting [16]. Driven by velocity gradients the air is flowing to the lateral area of the wheel. To solve the Navier-Stokes equations analytically for the circumferential area of a disk, a general solution cannot be presented. Simplifying these equations leads to a velocity profile, which does not match with measurements or simulations as a result of the side and radial flow from the inner wheel. Analyzing various velocity profiles from simulations and measurements a function (1) is found describing the velocity profile in peripheral direction in the middle of the disc, where the peripheral velocity *u(r)* reaches its maximum, by construction of the known dependencies:

$$u(r) = \frac{c_1}{\left(\left(r + \frac{c_4}{1000}\right) c_2\right)^{c_3}} \qquad (1)$$

with *r* as the radius, greater as the wheel Radius *R*. The constants $c_1$ *to* $c_4$ are depending on the viscosity, wall velocity, surface topology and geometrical parameters. Figure 1 shows a fit of the trial function with a measured velocity profile from [12] and with a simulation of the airflow of a rotating grinding wheel in the center of the peripheral areas (boundary conditions explained in the next chapter, no workpiece).

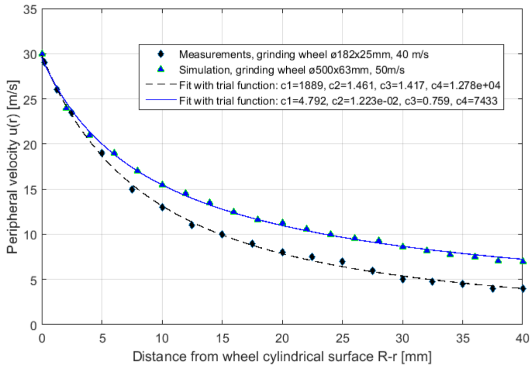


Fig. 1. Measured airflow velocities for two different grinding wheels for measurement and simulation each compared with the trial function.

Setting the assumptions static, rotational symmetric, uncompressible, no volume forces, very long cylinder and the boundary condition no airflow through the wall of the disc, the continuity results in $u_r=0$. The simplified Navier-Stokes equations in *r*-direction are

$$-\frac{u_\phi^2}{r}\rho = -\frac{\partial p}{\partial r} \qquad (2)$$

as considering $u_\varphi(r=R)=\omega R$ and $u_\varphi(r=\infty)=0$, leads to the simplified Navier-Stokes equations in *φ*-direction:

$$u_\phi(r) = \frac{\omega R^2}{r} \qquad (3)$$

Combining equation 2 and 3 and assume $p(r=\infty)=p_\infty$, the resulting pressure profile *p(r)* in radial direction in cylinder coordinates is

$$p(r) = p_\infty - \frac{1}{2}\frac{v_c^2 \cdot R^2}{r^2} \cdot \rho \qquad (4)$$