Investigation of the Influence of the Airflow Around a Grinding Wheel on the Coolant Supply

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Abstract. The fast rotation of the grinding wheel creates an airflow near its surface, which causes a deflection of the coolant jet. To obtain an efficient and reliable grinding process, it is necessary to consider the airflow when dimensioning the coolant supply. For this purpose, the airflow around rotating grinding wheels was analyzed and characterized. In this research the airflow velocities around the grinding wheel were measured using a Prandtl tube, high-speed records were used to analyze the interactions between coolant supply and the airflow and positions for an effective air deflection were examined. It is found that the influence of the airflow especially depends on the cutting speed and the porosity of the grinding wheel, the airflow is not constant along the width of the grinding wheel and without air deflection the coolant jet requires an exit velocity of at least 50% of the grinding wheel peripheral speed.

1. Introduction
The material removal with a large variety of cutting edges and high cutting speeds is characteristic for grinding. As a result, it is possible to achieve tight tolerances for form and dimension as well as high rates in material removal because of the development of synthetic, extremely hard cutting materials. Compared to machining with geometrically defined cutting edges higher specific energies are needed. An adequate lubrication and cooling are especially necessary when grinding with high material removal rates to avoid undesired structural properties. The precise use of cooling lubricant could impact positively on the tolerances for form and dimension, the surface quality and the boundary zone. The fast rotation of the grinding wheel creates an airflow near the surface, which causes a deflection of the coolant jet. In the context of high-speed grinding, consideration of airflow effects around the grinding wheel become more important. In addition, the increasing demand for sustainability in manufacturing technology is shifting the focus to the efficient use of cooling lubricants in line with economic and ecological requirements. [1; 2]

The airflow around the grinding wheel is a layer of air created directly on the wheel surface by boundary layer friction and adhesion when the wheel rotates. [2] The creation of the airflow is essentially influenced by three factors: the cutting speed, the surface topography (grit size and dressing conditions) and the porosity of the grinding wheel. The air is absorbed through the pores in the grinding wheel and is circulated by rotation. The friction between the air layer and the grinding wheel surface builds up airflow and the centrifugal force accelerates the air continuously outward from the grinding wheel. This creates an airflow which, due to its radial alignment to the grinding wheel axis, counteracts the cooling lubricant supplied.
There are different studies conducted on the airflow around the grinding wheel. For example, Alenius and Johansson performed measurements to determine air movements and the transport of grinding particles [3]. Okubo et al. developed a technology to reduce the required amount of coolant supply whereby air supplied above the grinding point from the side of the wheel effectively intercepts the airflow around the grinding wheel [4]. Klocke, Beck and Tawakoli prove the existence of the airflow, analyzed the profile image and provide statements on the jet pressure required to pass the airflow [5–7].

In this paper, the airflow around rotating grinding wheels is analyzed and characterized. For this purpose, different methods for analyzing the airflow were tested. The main objective is to give the user an understanding of the influence of airflow on the grinding process and coolant supply as well as to provide information on how to reduce the impact of the airflow. For this research, the flow velocities of air movement around the grinding wheel were measured using a Prandtl tube, high-speed records were used to analyze the interactions between coolant supply and the airflow and positions for an effective air shielding were examined.

2. Experiment Methods
The experiments were conducted on a surface and profile grinding machine ABA ECOLINE 1006 CNC with improved spindle for cutting speeds up to 80 m/s. For the research of the influence of airflow on the coolant supply different types of grinding wheels were used. One open-pored aluminum oxide grinding wheel (400 x 30 x 127 mm) which is vitrified bonded and has a grit size of 60. The second grinding wheel is also vitrified bonded but sintered aluminum oxide (400 x 30 x 127 mm) with a grit size of 90. These two wheels are reinforced for the use up to 80 m/s. A synthetic resin bonded diamond grinding wheel (400 x 20 x 127 mm) with a grit size of 126 was also examined. A needle nozzle with a total cross-section of 15.7 mm² was used for the coolant supply with emulsion (5%).

For measuring the velocity of the airflow a Prandtl tube was used. This tube has two ports, one for measuring the dynamic and one for the static pressure. The relationship between the measured dynamic pressure and flow velocity can be described by Bernoulli’s principle (1).

\[ p_{\text{dyn}} = \frac{1}{2} \rho v^2 \]  

A stainless steel tube with an elliptical head was used. The inner diameter of the tube is 0.3 mm throughout. The outer diameter is 2.3 mm at the tip and 4 mm at the shaft. In combination with a pressure gauge, the differential pressure can be measured. When measuring the flow velocity with a Prandtl tube, it should be noted that it only measures the airflow in one direction. For video recording a high-speed-camera Keyence VW-9000 was used.

3. Results and discussions
The research carried out on the airflow can be divided into three parts. First of all the airflow around the grinding wheel is characterized by measuring the airflow velocity in radial and axial direction of the grinding wheel using a Prandtl tube. Afterwards, the functional relationships of the coolant supply and the airflow are analysed using a high-speed camera. Furthermore, investigations regarding airflow deflection are presented.

3.1. Characterization of the airflow around the grinding wheel
The first investigations were aimed at characterizing the airflow around the grinding wheel and visualizing its profile. For this purpose, the flow velocities in the radial and axial direction of the grinding wheel were measured using a Prandtl tube. First, the flow velocity of the airflow was investigated as a function of the radial distance to the grinding wheel. Here, the measuring point of the Prandtl tube was positioned exactly in line with the rotational axis below the grinding wheel and the
flow velocities were measured tangentially at different distances (Figure 1). The Prandtl tube could be positioned close to the wheel surface due to its small diameter of 1 mm. The peripheral speed of the grinding wheel \( v_s \) was varied between 20 and 60 m/s. These speeds are above the common machining speeds for the present conventional grinding wheel.

![Figure 1](image1.png)

**Figure 1.** Ratio of the airflow velocity \( v_L \) to the peripheral speed \( v_S \) of the grinding wheel with different radial distances to the surface.

The velocity of the airflow shows an exponential decrease of the flow velocity with increasing radial distance to the surface of the grinding wheel. It should be noted that the airflow measured 1 mm from the grinding wheel surface only applies about half the speed of the peripheral speed. This can be observed at all grinding wheel peripheral speeds between 20 and 60 m/s.

The same test setup was additionally carried out with different types of grinding wheels. In addition to the aluminum oxide, a finer sintered aluminum oxide and a diamond grinding wheel were used, as well as a plane steel wheel. The results with a peripheral speed \( v_s \) of 35 m/s are shown in Figure 2.

![Figure 2](image2.png)

**Figure 2.** Ratio of the airflow velocity \( v_L \) to the peripheral speed \( v_S \) of different types of grinding wheels with different radial distances to the surface.
The exponentially decreasing course of the airflow velocity with increasing radial distance is found in similar form in all types of grinding wheels. It is noticeable that the influence of the airflow decreases with a finer grit size or a smoother wheel surface. A rough and open-pored grinding wheel can carry more air with it and accelerate it more. A diamond grinding wheel with a closed resin bonding has no porosity and can be compared to a plane steel wheel in terms of airflow. Almost no difference can be observed here, although the surface roughness differs significantly. The porosity has therefore a bigger influence on the airflow than the topography of the grinding wheel surface.

The plot of the flow velocity of different grinding wheels close to the grinding wheel surface with variation of the wheel peripheral speed shows an almost linear course (Figure 3). Depending on the topography of the grinding wheel, however, the linear curves have different gradients ($\mu_L$).

![Graph of the airflow velocity at different peripheral speeds](image)

**Figure 3.** Influence of grinding wheel topography on the formation of the airflow at different peripheral speeds

The graph of the open-pore and rougher aluminum oxide grinding wheel (grit size 60) has a steeper gradient than the graph of the more dense and finer sintered aluminum oxide grinding wheel (grit size 90). Compared to this, the graph of the closed diamond grinding wheel with a very fine surface topography has a much flatter slope. By defining a gradient $\mu_L$ for various types of grinding wheels, it is possible to describe the formation of the air cushion at different wheel peripheral speeds.

In addition to characterizing the airflow in the radial direction, the behavior of the airflow in the axial direction, i.e. across the wheel width, was also investigated. The result of the research of the open-pored aluminum oxide grinding wheel is shown below as an example (Figure 4).
The width of the grinding wheel used is 30 mm, so that the measuring points +15 and -15 mm represent the edges of the wheel. Starting from the center axis of the grinding wheel, the airflow has a symmetrical image. The maxima are not, as possibly expected, exactly in the center of the wheel, but at a distance of approx. 10 to 13 mm from the center axis. The greater the peripheral speed of the grinding wheel, the further the highest flow velocity of the air cushion "moves" to the center axis. The air on the sides of the grinding wheel is accelerated centrifugally due to the rotation. In addition, there is the airflow at the periphery of the grinding wheel. These combine in the boundary area to form this characteristic velocity profile.

As an interim conclusion on the characterization of the airflow, it can be noted that different grinding wheels have a similar profile of the airflow. However, there are strong differences in the characteristics of the airflow depending on the structure of the wheel surface and the porosity. It should also be noted that the airflow varies along the width of the wheel. Furthermore, the shape of the airflow strongly depends on the peripheral speed of the grinding wheel.

### 3.2. Analysis of the functional relationships between the coolant supply and the airflow

To analyze the functional relationships between the coolant supply and the airflow around the grinding wheel, test series were carried out with a high-speed camera. Here, for example, it was observed how the coolant jet, which hits the grinding wheel tangentially, behaves when there is an increase of the peripheral speed of the grinding wheel or the exit speed of the coolant jet.

There are image sections from the recorded videos in Figure 5. In the tests on image sections 1-3, the peripheral speed of the grinding wheel was increased from 25 to 35 m/s, and the coolant jet exit speed was kept constant at 15 m/s. It can be seen that at 35 m/s the coolant jet is deflected by the airflow so strong that it no longer hits the wheel surface tangentially and thus the coolant cannot be carried into the contact zone. At low speeds of the grinding wheel, the coolant jet is less affected and can hit the wheel tangentially. In image sections 4 and 5, at a peripheral speed of 35 m/s, the coolant jet exit speed is increased to 30 m/s and it can be clearly seen that the jet is no longer significantly influenced by the airflow, hits the wheel tangentially and is carried along by it. Such a high exit velocity is useful for breaking through the airflow. However, if this also increases the flow rate too much, the grinding process is no longer efficient and the contact zone can be heavily flooded. Aquaplaning effects are possible in this case. The adhesion of the cooling lubricant to the grinding wheel surface also decreases if the coolant jet velocities are too high.

![Image of airflow measurement](image_url)
3.3. Investigations regarding the position for airflow deflection

The purpose of this study is to determine the position at which the airflow should be deflected and how quickly the airflow rebuilds after deflection.

First, the airflow velocity was measured in the 6 o’clock position at different positions of the air deflector plate (air shield), so that the effectiveness of the air shield position could be determined. The effectiveness of the airflow deflection describes how many percent of the airflow velocity is deflected in contrast to a setup without air shield. The air shield was placed at five different positions around the grinding wheel as close as possible to the wheel surface (Figure 6 right). With the grinding wheel rotating at peripheral speeds of 25 - 35 m/s, the effectiveness of the airflow deflection was measured and displayed without the influence of a workpiece (Figure 6 left).

As a result, it can be noted that the closer the deflector plate is to the measuring point or the contact zone, the more effective the air deflection. However, a useful airflow deflection can already take place at a more distant point (angular position 280°) to the contact zone at the presented velocities. If the air shield is located at this point, the airflow can already be reduced by approx. 40%. Of course, this
depends on the grinding wheel topography. It is also noticeable that the peripheral speed of the grinding wheel does not have a great influence on the effectiveness of the airflow deflection.

By using the high-speed camera, it was additionally possible to investigate the effect of the airflow deflection with coolant supply (Figure 7).

Figure 7. High-speed records for the investigation of the coolant jet influence with airflow deflection

In the left image section 1, the coolant jet is shown without the air shield at a peripheral speed of 35 m/s. The jet is deflected by airflow so much that it cannot hit the grinding wheel tangentially and misses it. In the image section 2, an air shield was placed in angular position 2 (Figure 6). The jet is deflected less and hits the grinding wheel but can’t adhere to the wheel effectively. The air shield in image section 3 was attached in angular position 3 (Figure 6). Here, the jet can hit the wheel tangentially and is pulled along by the wheel. The airflow is deflected very effectively and the coolant jet is no longer strongly influenced.

In addition to the position of the shield on the grinding wheel, the position of the air shield radially to the wheel surface was investigated. This is very important for the user, as it represents the extent to which it is necessary to readjust the air shield in the event of wheel wear. The air shield was placed in angular position 4 (Figure 6) and moved away from the grinding wheel surface at different wheel peripheral speeds (Figure 8).

Figure 8. Effect of different radial distances of the air shield for airflow deflection
When looking at the measurement results, it is noticeable that a deflector plate causes a significant airflow deflection at a radial distance of up to 1 mm from the grinding wheel surface. Here, the airflow can be deflected by more than 50%. For a more effective deflection, the air shield must be positioned closer to the contact zone. At a distance of 3 mm and more, only a slight effect due to the air shield can be seen. The different influences of the air shield on the airflow at the various wheel peripheral speeds are almost the same in the present investigations.

4. Conclusions
The production process of grinding is particularly characterized by its high geometrical accuracy as well as high surface qualities when machining hard materials. High cutting speeds are often used for this purpose, which lead to the formation of an airflow around the grinding wheel. This airflow prevents the cooling lubricant from reaching the contact zone, therefore there is a risk of thermal damage in the boundary zone. If the airflow is not considered when dimensioning the coolant supply, process quality and reliability will be significantly affected.

The results of the research shown here allow a characterization of the airflow. It should be noted that the characteristics of the airflow depend both on the surface roughness of the grinding wheel, but especially on the cutting speed and the porosity. In addition, the flow velocity of the airflow is not constant over the width of the grinding wheel. This must be considered when dimensioning the coolant supply, because cooling lubricant should be supplied at least at the speed of the airflow. With the presented measurement setup the flow velocities of the airflow around the grinding wheel can be measured precisely. Near the surface, the airflow velocities are only approx. 50% of the peripheral speed of the grinding wheel. Closed and fine grinding wheels even have significant lower airflow velocities. Although the airflow should always be deflected as close as possible to the contact zone, larger distances can also be sufficient for the process. If an air shield is used to deflect the airflow, a readjustment in the event of grinding wheel wear is necessary after a distance of approx. 1 mm from the grinding wheel surface.

In the future, further investigations will be carried out to determine the influence of the grinding wheel topography and the grinding wheel type on the characteristics of the airflow. The aim is to provide a model for different types of grinding wheels that describes the characteristics of the airflow, so that the coolant supply can be optimized and efficiently dimensioned. The maximum capacity of the grinding wheel to absorb cooling lubricant also has an influence on this. In addition, the airflow is to be simulated with flow simulations and thus allow the dimension of the coolant supply without experimental investigations. Alternative “air shields” will also be developed and investigated, which don’t require readjustment in the event of wheel wear.

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