Measurement of the air boundary layer on the periphery of a rotating grinding wheel using LDA

H Wu\textsuperscript{1,a}, B Lin\textsuperscript{2,b}, R Cai\textsuperscript{1,c} and M N Morgan\textsuperscript{1,d}

\textsuperscript{1}AMTReL, GERI, Liverpool John Moores University, Liverpool, UK
\textsuperscript{2}School of Mechanical Engineering, Tianjin University, Tianjin, China

E-mail: \textsuperscript{a}h.wu@2005.ljmu.ac.uk, \textsuperscript{b}linbinph@tju.edu.cn, \textsuperscript{c}r.cai@ljmu.ac.uk, \textsuperscript{d}m.n.morgan@ljmu.ac.uk

Abstract. In this paper, the velocity profile of the air boundary layer around a rotating grinding wheel was measured using the Laser Doppler Anemometry technique. Experimental results show that the tangential velocity of the air decreases greatly with increasing distance from the wheel surface. The distribution of the tangential velocity is also found to be almost uniform near to the centre of the wheel width, and decreases greatly as the wheel edge is approached. Generally, the radial velocity of air in the area close to the wheel surface is small, and then increases with the increasing distance from wheel surface.

1. Introduction
Grinding fluid plays a crucial role in grinding, but the grinding wheel is essentially a high-speed rotating disk and as a result a boundary layer of air develops around the periphery of the wheel surface. The air boundary layer has a sufficient energy in high speed grinding to impede the penetration of fluid to the grinding zone.

The problem of grinding fluid application has aroused some interest which has led to studies of air flow around grinding wheels. Lots of work has been carried out using Pitot tubes, manometer and the hot-wire anemometer to investigate the air velocity distribution around the grinding wheel. The Pitot tube method and the manometer measure pressure, and this can then be converted into mean velocity. Usually, profiles for various wheel shapes are given and the results of previous authors show that the greatest air currents are the peripheral, not the flank currents. The distribution of air velocity in the radial direction changes exponentially decreasing with the distance from the wheel periphery [1].

The velocity profile showing peaks at the edges of a rotating grinding wheel is sometimes reproduced in the literature review. These results are very similar to Trmal’s [2], where the air velocity also changes along the wheel width reaching the minimum value in the middle section. J. Shibata et al’s [3] experimental results show that the distribution of the air velocity is non-uniform over the wheel width, and there are two peaks of air velocity around both sides of the wheel, and these two peaks tend to shift toward the center of the wheel width with the distance radially outwards from the wheel surface. But Radhakrishnan [4] and Sven [5] presented an air boundary layer profile with a central maximum.

The conflict in experimental results was possibly caused by the use of different experimental parameters and experimental measurement methods. Most of the research was carried out with Pitot tube, and due to the principle of this method, only one component velocity can be measured at one
point. Furthermore, the Pitot tube is an intrusive measurement and not sensitive enough to measure the low velocity air flow, accordingly, most researchers only measured the tangential component velocity of the air boundary layer around grinding wheel.

This paper will describe the Laser Doppler Anemometry (LDA) experimental technique used to observe and improve understanding of the air boundary layer flow motion around the rotating grinding wheel. The results will help to understand the existing air boundary layer knowledge and validate the previous experimental results. The measurements described by the present authors are unique and may be helpful to other researchers. In earlier AMTRel studies [6], LDA was used to investigate the effects of the air boundary layer on grinding fluid application. However, the previous velocity measurements were not developed in full-scale. This paper presents the air velocity profile results across a wide range of regions.

2. LDA system
Currently, the Laser Doppler Anemometry (LDA) is the state-of-the-art implement for measuring the velocity of fluid flow (liquid and gas). This is a well-established and efficient method of obtaining non-intrusive flow measurements, because of its optical principle and technique [7]. Moreover, the LDA measurement has a very high spatial resolution due to small measurement volume, so it can be used to provide accurate data on the complicated varying flow conditions.

In this paper, a high-accuracy Argon ion Laser Doppler Anemometry system based on burst spectrum analysis was employed to investigate of air boundary layer flow around the grinding wheel. It is based on a two-component dual-beam LDA system in back-scatter mode, and the blue/green laser combinations make it suitable for measuring the orthogonal velocity components of air flows simultaneously.

Despite the obvious advantages of the LDA technique, there is a slight disadvantage when the LDA is applied to the current study. The diameters of the laser beam are 1.35mm, so the measurement point is approximately 0.7mm from the wheel surface when the laser beams are aligned parallel to the wheel surface. As a result, the velocity data immediately beneath the wheel will not be captured. Unfortunately, no other practicable measurement instrument can get closer to the measurement point than LDA. When two-component measurements are attempted close to the wheel, one component of the laser beams will be blocked and reflected by the wheel. In that area, which is very close to the wheel, only one velocity component can be obtained.

3. Experimental arrangement and method
A surface grinder arrangement, illustrated in Figure 1, was prepared for this research. The diameter of the wheel was 182.5mm after dressing; the rotational speed of the wheel was 2088rpm, i.e., the wheel tangential speed was approximately 20m/s; the wheel width was 25mm.

Figure 1. Experimental arrangement

Figure 2. Schema of the configuration
The LDA laser probe was placed parallel to the wheel spindle (the schema of the arrangement is shown in Figure 2). The probe was mounted on a traverse, and with the help of this traverse, three-dimensional movement of laser probe was facilitated with a distance resolution of 0.02mm. A smoke generator was employed to apply the seeding particle for the LDA measurement.

![Figure 3. Measurement principle](image)

The air boundary layer was measured in the area beneath the grinding wheel as this was the area most readily accessed. As shown in Figure 2 and Figure 3a, a total of six data groups were obtained along six vertical lines, in the wheel radial direction. The six lines were distributed evenly along the wheel axial direction from the wheel edge to the wheel middle section, and due to the symmetry of the wheel, measurements were undertaken on one side only. The gaps between every two proximate lines were 2.5mm. Along each line, the measurement was developed from the wheel cylindrical surface to a distance 40mm radial outward with a step gap of 0.5mm. In each measurement point, two velocity components were measured, i.e., the tangential velocity and the radial velocity (Figure 3b.).

4. Results and discussion
The measured tangential velocity profile of the boundary layer around the rotating grinding wheel is shown in Figure 4.

![Figure 4. Measured tangential velocity profile of air boundary layer](image)
Along each line outward from the wheel, the air velocity is observed to decrease with distance from the wheel surface. This trend was stronger in the first 20mm from the wheel surface. The velocity decreases greatly from 20m/s to approximately 4m/s (if the maximum air velocity is equal to the wheel tangential speed) in this region (Figure 4). The air velocity close to the middle section of the wheel (Lines: 0, 1, 2 and 3) is clearly much higher than that close to the wheel edge (Lines: 4 and 5). The maximum velocity measured was approximately 14m/s, this occurred very close to the wheel surface and to the wheel centre.

At the second half distance (20mm – 40mm from wheel surface), the air velocity exhibited no great change. At a distance of 40mm the air velocity in each measurement line decreased to the similar value of approximately 2mm/s.

As shown in Figure 4, these air velocity profiles in the wheel radial direction agree with results reported by other research. However, in the wheel axial direction, the results are different. Clearly, the maximum velocity is not at the edge of the wheel. Moreover, there is no obvious central maximum peak or those two peaks of air velocity along the wheel axial direction.

The air velocity distribution along the wheel axial direction is demonstrated more clearly in Figure 5. This picture is a scatter with data points connected by continuous lines. The velocity values are still the tangential velocity, and the data source is the same as in Figure 4. Due to the symmetry of surfaces about the wheel middle section, the data at the right-hand side in the picture are simply mirrored from the data of the left hand side.

![Air boundary layer velocity distribution](image)

**Figure 5.** Measured tangential velocity distribution of air boundary layer

During the measurements along the wheel radial direction, the point of origin was defined as the position where the part of blue laser beams skimmed over the wheel cylindrical surface (the blue laser beams were used to measure the air tangential velocity). Each curve in the picture is the measured data at the points with the same coordinate in the wheel axial direction (shown in the legend). The top line is the highest tangential velocity curve, and its position is most close to the wheel cylindrical surface. From the top to the bottom, the distance increases from the wheel surface and the air velocity decreases rapidly. However, this graphical figure shows clearly the tangential velocity distribution along the wheel width. At a distance of 5mm to 0mm to the wheel edge, the velocity decreases quickly, but from 5mm to the center surface of the wheel (12.5mm), the velocity has no big change, especially in the area close to the wheel and the area far from the wheel. Although in most data curves
the maximum velocity values are not in the middle section of the wheel, the air velocities change smoothly in the area from 7.5mm to 17.5mm in the wheel axial direction.

Figure 5 shows again that, there is not the central velocity peak along the wheel width, and the ‘two-peak’ velocity distributions shown by other researchers are not as obvious.

The reasons for the difference in the results published by the different researchers, are perhaps due variation in wheel size and surface topography and also to the different experimental conditions. It is proposed that the factors most strongly influencing the velocity distribution in the wheel axial direction are wheel width and wheel roughness. Further work is required to confirm this.

\[ \text{Figure 6. Measured radial velocity distribution of air boundary layer} \]

An advantage of the Laser Doppler Anemometry technique is that it allows the radial component velocity to be measured at the same time as the tangential velocity. The air radial velocity profile is shown in Figure 6. Because the magnitude of this velocity component is much smaller than the tangential velocity (the maximum value is about 3m/s), the greater turbulence in the radial direction can be identified. The trend of the velocity does not vary greatly, though the general trend can be seen. Generally, the radial velocity of air in the area close to the wheel surface is small, and then increases with the distance from the surface. Close to the wheel edge (Line 0), the velocity decreases and then increases again at a distance of 10mm. All the radial velocities do not change any significant amount when the distance from wheel surface is greater than 20mm.

The radial velocity of the air boundary layer is small in the area approaching the wheel surface, compared to the tangential velocity, so the profile of the resultant velocity of these two components is similar to that shown in Figure 4.

5. Conclusions

The two components of velocity of the air boundary layer around the periphery of a rotating grinding wheel was measured using LDA (Laser Doppler Anemometry) for the surface grinding situation. The results show that the profile of the air tangential velocity in the wheel radial direction is similar to results published by other researcher, i.e. decreasing greatly with the distance increasing from wheel surface. However, the velocity profile in the wheel axial direction is different, in that there is no central velocity peak nor two velocity peaks either side of the wheel middle section. The distribution

5
of the tangential velocity is almost uniform near the wheel middle section and decreases greatly approaching the wheel edge in the wheel axial direction.

The radial velocity value is smaller than the tangential velocity of the air and it shows the great turbulence in the radial direction. Generally, the radial velocity of air in the area close to the wheel surface is small, and then increases with the increasing distance from the wheel surface.

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