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Air flow conditions in workspace of mulcher

J. Čedík[1,*], J. Chyba[2], M. Pexa[1], S. Petrásek[2], J. Jedelský[3] and M. Malý[3]

[1]Czech University of Life Sciences, Faculty of Engineering, Department for Quality and Dependability of Machines, Kamýcká 129, CZ16521 Prague 6, Czech Republic
[2]Czech University of Life Sciences, Faculty of Engineering, Department of Agricultural Machines, Kamýcká 129, CZ16521 Prague 6, Czech Republic
[3]Brno University of Technology, Faculty of Mechanical Engineering Department of Thermodynamics and Environmental Engineering, Technická 2896/2, CZ616 69 Brno, Czech Republic
[*]Correspondence: cedikj@tf.czu.cz

Abstract. Currently, there has been a great effort on increasing the efficiency of agricultural machinery. The energy demands of mulching with the vertical axis of rotation depends on the amount of processed material per unit of time, its properties and efficiency of material processing. Another important factor that is affecting the overall energy demands is the energy losses, which can be even higher than energy, required for the processing of material. The efficiency of the material processing and the energy losses are influenced to a large extent by the air flow inside the mulcher workspace, which is created by the movement of working tools. The air flow ensures the repeated contact of the processed material with the working tools, affects the energy losses and the quality of work. The contribution deals with the air flow conditions inside the workspace of mulcher with the vertical axis of rotation. The velocity of the air flow was measured my means of LDA (Laser Doppler Anemometry) method in three planes above the surface (180, 100 and 20 mm) and in two directions (peripheral and radial). The laboratory model of one mulcher rotor from mulcher MZ 6000 made by BEDNAR Ltd. company was used for the measurement. From the results it is evident that the maximum values of peripheral velocity of the air flow reach approx. 50% of the velocity of the tools. In the radial plane an air vortex is created between 20 and 100 mm planes above the surface around the tip of the blade.

Key words: mulcher, airflow velocity, cutting tool, mower.

INTRODUCTION

In present time there is a great pressure on manufacturers of agriculture machinery in terms of decreasing the energy demands and increasing the work efficiency. Mulching is energy demanding operation which has many utilizations. Mulchers can be used for treatment of permanent grasslands, fallow lands or crop residues on arable land. During mulching the plants are crushed and left on the soil surface. The principle of mulching is to enable easy and quick decomposition of plants or plant residues (Mayer & Vlášková, 2007; Syrový et al., 2013)

Mulchers with vertical or horizontal axis of rotation are in principle rotational mowers. Other authors found that common rotational mowers have the energy demands between 3.5–16 kW m^{-1} (kW per meter of working width of the machine) (McRandal & McNulty, 1978; Tuck et al., 1991; Srivastava et al., 2006; Syrový et al., 2008; ASABE D497.7, 2011). Mulchers with horizontal or vertical axis of rotation have typically higher energy demands than common rotational mowers since the mulchers are used to crush and disperse the plants on the surface. In previous studies, it was found that the energy demands of the mulcher with vertical axis of rotation highly depend on the amount of processed material (mass performance) and may have value up to 22.6 kW m^{-1} (Čedík et al., 2015; Kumhála et al., 2016; Čedík et al., 2017c).

The mulchers have higher energy losses than common rotational mowers, which mainly causes the higher energy demands. In the workspace of the mulcher with the vertical axis of rotation the so-called ventilation effect is created as a result of movement of cutting tools. The ventilation effect is vital for proper function of mulcher with vertical axis of rotation. Total energy losses may be greater than the energy used for cutting plant material (O'Dogherty & Gale, 1991; Čedík et al., 2016b; Kumhála et al., 2016).

The other authors (Persson, 1987; O'Dogherty & Gale, 1991) identified the following energy losses of the mower machine:

- Acceleration of the material to the output speed
- Friction forces between the material and the cover of the mower mechanism
- Friction forces between the blade and the stubble/soil
- Air movement in the cut area
- Mechanical friction forces of the drive mechanism.

The energy demands and quality of work of mulcher highly depends on the air movement inside the workspace of mulcher (ventilation effect) (Chon et al., 1999a; 1999 b). The energy demands are influenced by aerodynamic resistance of the working tools, which depends on relative speed and direction of the air flow and working tools inside the workspace. From the viewpoint of work quality, the air movement inside the workspace is essential for repeated contact of the cut plant matter with blades of cutting tools and ensures the uniform dispersion of chopped plant matter on the surface. (Čedík et al., 2016a; 2016b).

Direction and speed of the air flow are influenced by the cutting speed, the shape of working tools and the shape of workspace cover (Hagen et al., 2002; Zu et al., 2011; Hosseini & Shamsi, 2012; Kakahy et al., 2014; Čedík et al., 2017a; Čedík et al., 2017b). Hagen et al. (2002) reported that the shape of workspace cover has equal significance as the shape of cutting tool as regards to air flow.

The rotational mower has the cutting speed commonly in the range of 71–84 m s^{-1} (O'Dogherty, 1982; Jun et al., 2006). According to Srivastava et al. (2006), the cutting speed of rotational mower should be in the range of 50–75 m s^{-1} in dependence on the sharpness of the cutting tool.

Other authors (Chon & Amano, 2003; Chon & Amano, 2004; Chon & Amano, 2005) measured the air flow velocity inside the workspace of municipal mowers in tangential and axial direction. They found that in the tangential direction the air flow velocity increases with the distance from rotor centre. Near the side cover the tangential velocity slightly decreases due to wall friction. In axial direction the air flow velocity peaks at the tip of the blade near the circumference of the rotor.

This paper aims to experimentally determine the velocity of air flow inside the workspace of the mulcher with the vertical axis of rotation at different rotation speeds.

MATERIALS AND METHODS

The measurement took place at the Department of Agricultural Machines at Czech University of Life Sciences Prague. In order to determine the velocity of the airflow inside the workspace of the mulcher, a laboratory model of a single mulcher rotor was used. The working mechanism of three-rotor mulcher MZ 6000 produced by the BEDNAR FMT, Ltd. company was used as a base for the laboratory model. The Mulcher MZ 6000 has a working width of 6 m and rotor speed of 1,000 rpm. The diameter of the rotor of the laboratory model is 2 m and an 22 kW asynchronous electromotor MEZ was used to drive the model. The speed of the electromotor was controlled by a frequency converter. The laboratory model of the mulcher rotor is shown in Fig. 1.

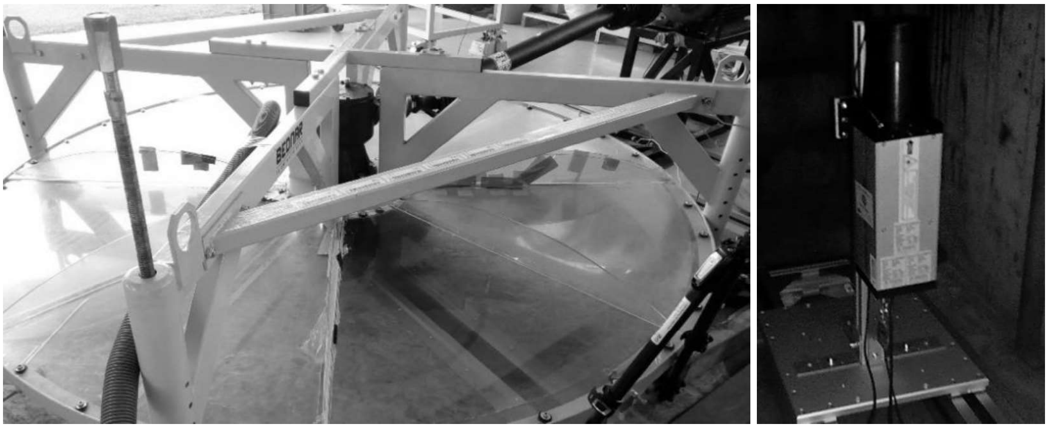

Figure 1. Laboratory model of one mulcher rotor (left) and the FlowExplorer Mini LDA measuring device in the assembly pit (right).

The working tools with the rake angle of 0° and the trailing edge angle of 35° was used for the measurement. The angles on the working tool are schematically illustrated in Fig. 2. The cutting tool and influence of its shape on energy demands during operation are described in (Čedík et al., 2017c), the influence of cutting tool shape on air resistance is described in (Čedík et al., 2016b).

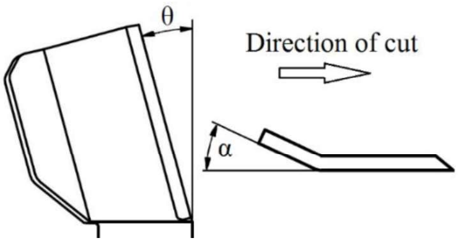

Figure 2. Schematically illustrated angles on the cutting tool (θ – rake angle; α – trailing edge angle).

During the measurement the velocity of the air flow inside the workspace of mulcher, the rotation speed of the rotor and ambient conditions, such as air pressure and temperature were measured.

The velocity of air flow inside the workspace was measured by means of LDA (Laser Doppler Anemometry) method. The FlowExplorer Mini LDA (Fig. 1) made by Dantec Dynamics A/S was used for the measurement (calibration coefficient uncertainty lower than 0.1%). The LDA was configured in the backscatter mode. A built-in, diode-pumped solid-state laser generated beams with 660 and 785 nm wavelength. The beams were split into two pairs of parallel beams with the power of 30 mW each. One beam in each pair was shifted by 80 MHz. A converging transmitting/receiving lens with 300 mm focal length was used to form an ellipsoidal measurement volume with the size of app. 0.1 × 0.1 × 1 mm. Dantec BSA P80 signal processor was used to process the measured signal. BSA flow software v5.20 was used to control the data acquisition and the following setting was used: Photomultiplier sensitivity 1,050 V, signal gain 20 dB. The measurement was limited to 20,000 samples acquired or a 10-second acquisition duration at each measured point. The LDA device measures the velocity of particles traversing the measured volume, but not the air molecules, so seeding the flow field must be performed, for that purpose the oil fog generator was used.

The measuring LDA device was placed under the laboratory model in the assembly pit. Two directions of the air flow were measured, peripheral and radial. The measurement was performed in three heights above the surface, 20 mm (under the working tool), 100 mm (approx. at the level of the working tool) and 180 mm (above the working tool). Because of the limitations of the measurement device the air flow velocity was measured between 440 mm and 980 mm from the centre of the rotor. The step between individual measurement points in the radial direction was 20 mm.

The measurement was performed at rotation speeds of 400, 500 and 600 rpm, which corresponds to cutting speeds of approx. 41.9, 52.4 and 62.8 ms^{-1}. Higher rotation speeds were problematic in terms of data validation. The speed of the rotor of the model of mulcher was measured by means of optical sensor with one pulse per revolution since the measurement was carried out in stable rotation speeds. The data from the optical sensor was stored at the hard drive of measuring computer via a module for impulse sensors Papouch Quido 10/1.

RESULTS AND DISCUSSION

Peripheral air flow velocity

In Fig. 3 the peripheral air flow velocity in the height of 20 mm above the surface in dependence on the distance from the centre of the rotor is shown. It can be seen that under the working tools the peripheral velocity increases almost linearly with the distance from the centre. At all measured rotation speeds the maximum values of peripheral air flow velocity are reached at the 980 mm from the centre of the rotor at the tip of the blade. This result is in good agreement with results of Chon & Amano (2003) who also found the maximum values of tangential air flow velocity near the circumference of the rotor. Compared with the velocity of the tip of the working tool (cutting speed) (41.89 ms^{-1}), at 400 rpm, the maximum value of the peripheral air flow velocity reaches approx. 49.75%. At 500 rpm the maximum value of the peripheral air flow velocity reaches approx. 49.96% of the velocity of the working tool (52.36 ms^{-1}) and at 600 rpm the maximum value of the peripheral air flow velocity reaches approx. 49.96% of the velocity of the working tool (62.83 ms^{-1}). Compared with peripheral air flow velocity at 400 rpm the maximum peripheral air flow velocity at 500 rpm is by approx. 25.5% higher, at 600 rpm the maximum peripheral air flow velocity is by approx. 45.7% higher in comparison with air flow velocity at 400 rpm.

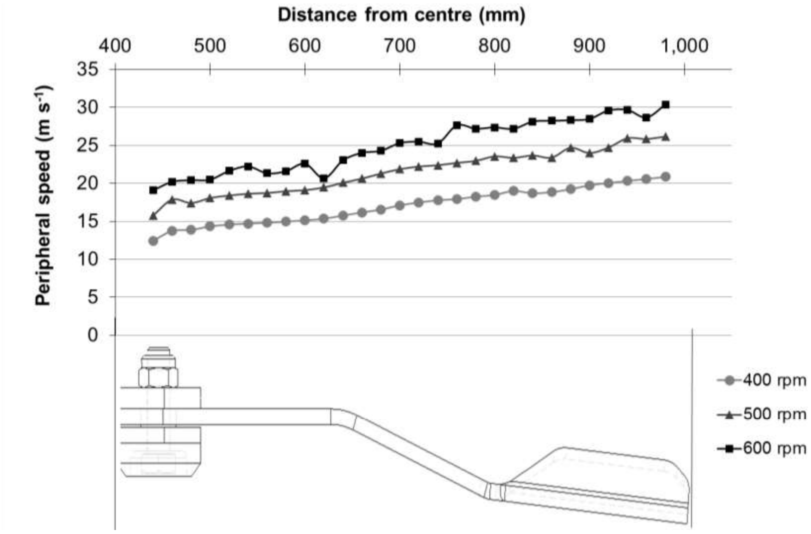

Figure 3. The peripheral air flow velocity profile at the height of 20 mm above the surface at different rotation speeds.

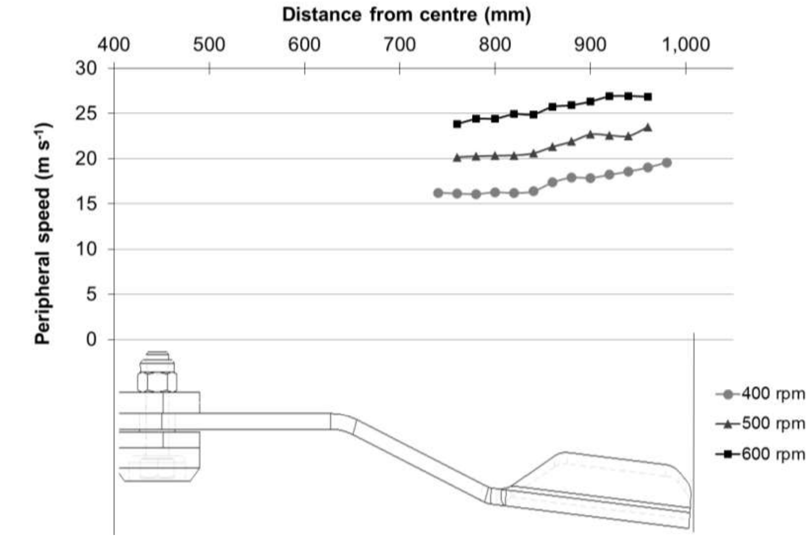

Figure 4. The peripheral air flow velocity profile at the height of 100 mm above the surface at different rotation speeds.

In Fig. 4 the peripheral air flow velocity in the height of 100 mm above the surface in dependence on the distance from the centre of the rotor is shown. At this height it was not possible to measure all determined points because the LDA device was capturing reflections from the cutting tool and data were not valid. The data were valid only between approx. 740–960 mm from the centre of the rotor. From the figure it is evident that the peripheral velocity of the air flow increases almost linearly with distance from the centre of the rotor but it reaches slightly lower values compared with the height of 20 mm. The maximum measured values of the peripheral air flow velocity are reached in the range of 940–980 mm from the rotor centre.

In Fig. 5 the peripheral air flow velocity profile at the height of 180 mm above the surface in dependence on the distance from the centre of the rotor can be seen. From the figure it is evident that up to approx. 740 mm from the rotor centre the peripheral velocity of the air flow increases almost linearly. Between 740–980 mm from the rotor centre the air flow velocity is almost constant at 400 rpm. At 500 and 600 rpm the rapid increase of peripheral velocity between 740–780 mm from the rotor centre can be seen. Between 780–980 mm from the rotor centre the velocity of the air flow remains nearly constant at 500 and 600 rpm. This phenomenon is probably caused by the shape of the trailing edge of the working tool and its angle. It can be assumed that with increasing rotation speed this phenomenon will have a stronger effect. Near the rotor periphery the slight decrease of air flow velocity can be seen, this decrease is caused by the wall friction between the air and side cover of the workspace. Similar phenomena was reported also by Chon & Amano (2004) and Chon & Amano (2005). The maximum values of air flow velocity at height of 180 mm is reached between approx. 780–920 mm from the rotor centre. Compared with the cutting speed of the tip of the blade the maximum measured values of peripheral air flow velocity at 400, 500 and 600 rpm reaches 42.2%, 42.9% and 42% respectively. Compared with the air flow velocity in the height of 20 mm and 100 mm the lower values were reached in the height of 180 mm.

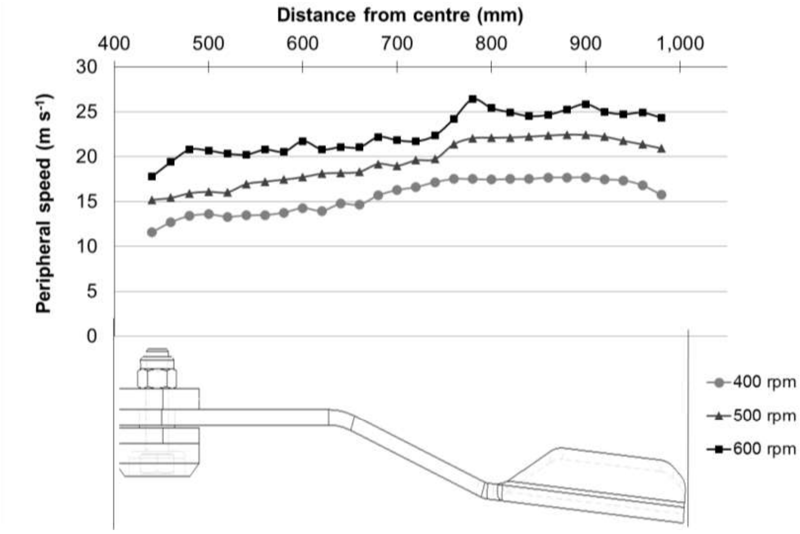

Figure 5. The peripheral air flow velocity profile at the height of 180 mm above the surface at different rotation speeds.

Also, the results can be compared with measured pressure profile inside the workspace, presented in (Čedík et al., 2016a; Čedík et al., 2017a). It was found that inside the workspace the vacuum is created and it is increasing almost linearly from periphery towards to the rotor centre. This result is in good agreement with results obtained from air flow velocity measurement, since it was confirmed that the higher pressure at the rotor periphery is caused by centrifugal forces of rotating air inside the workspace because the peripheral direction of velocity is predominant.

Radial air flow velocity

The radial air flow velocity is important in terms of quality of work, because it ensures repeated contact of the cut material with the blades of the working tools. In Fig. 6 the radial air flow velocity profile at the height of 20 mm above the surface is shown. It can be seen that under the working tools the air flow reaches positive values, it means that the cut material is pushed away from the centre of the rotation towards to the rotor periphery. Further, it can be seen that for all measured rotation speeds the maximum measured values are reached at 980 mm from the rotor centre, this is probably caused by the centrifugal forces of the rotating volume of air inside the workspace. Also, it may be noted that in the height of 20 mm above the surface the significant radial air flow appears only in the range of approx. 800–980 mm from the centre of the rotor, in the range of 440–800 ms^{-1} the radial air flow velocity is lower than 1 ms^{-1}.

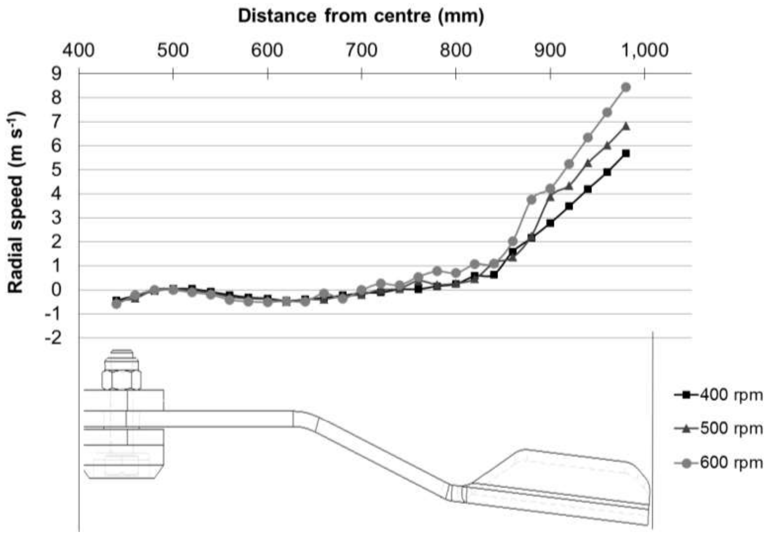

Figure 6. The radial air flow velocity profile at the height of 20 mm above the surface at different rotation speeds.

In Fig. 7 the radial air flow velocity profile at the height of 100 mm above the surface is shown. From the figure it is evident that at 100 mm above the surface the radial air flow velocity reaches negative values which means that the cut plant material is pushed back towards the rotor centre. Also, it can be seen that the higher values of the radial air flow velocity are reached between approx. 800–980 mm from the rotor centre. In the range of approx. 800–900 mm from the rotor centre the rapid increase of radial air flow velocity can be seen, then it remains nearly constant up to 980 mm from the rotor centre. A peak of radial air flow velocity, located at the distance of 680 mm from the rotor centre, is probably caused by the cranked part of the working tool, the value of air flow velocity at this peak was nearly the same for all measured rotation speeds.

A combination of radial air flow velocity at the height of 20 mm and 100 mm creates the air vortex, which ensures the circulation of the material trough the blades of the working tools. This air vortex appears in a range of approx. 800–980 mm from the rotor centre where the blades of the working tools are located, however, the air flow velocity at the height of 20 mm is decreasing more rapidly with decreasing distance from the rotor centre in comparison with the air flow velocity at the height of 100 mm. Results of other authors (Chon & Amano, 2003; Chon & Amano, 2004), who found the peak of axial upward air flow velocity near the rotor periphery, confirms the air vortex around the tip of the blade.

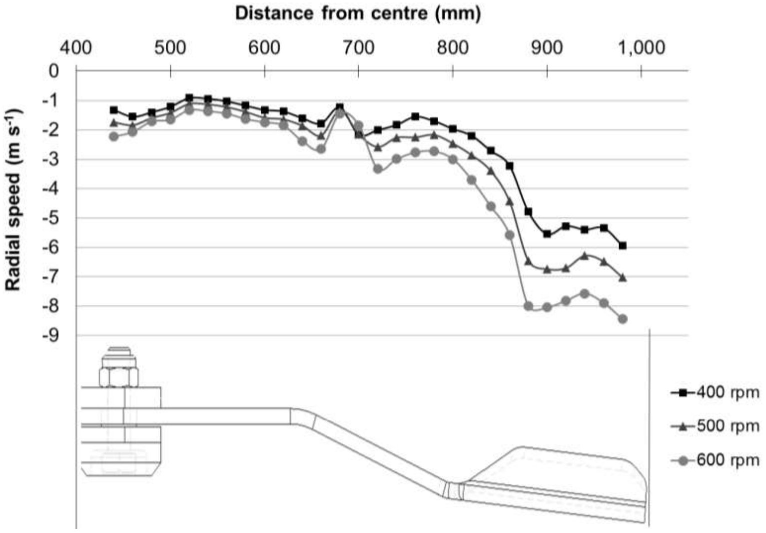

Figure 7. The radial air flow velocity profile at the height of 100 mm above the surface at different rotation speeds.

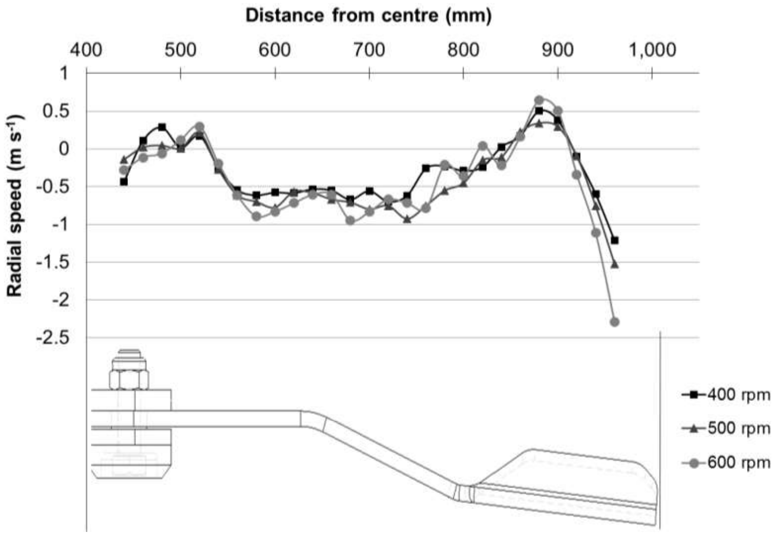

Figure 8. The radial air flow velocity profile at the height of 180 mm above the surface at different rotation speeds.

In Fig. 8 the radial speed in the height of 180 mm above the surface is shown. From the figure it can be seen that the radial air flow velocity in the range between 440–900 mm from the rotor centre is close to zero, changes direction and does not exceed the range from -1 to –0.5 ms^{-1}. For all measured rotation speeds, the peak values are negative and are reached at the distance of 980 mm from the rotor centre.

CONCLUSIONS

From the results of the measurement following conclusions were made:

- The peripheral air flow velocity increases with the distance from the rotor centre.
- The peak values of peripheral air flow velocity reach approx. 50% of the velocity of the tools. Near the side cover of the workspace the peripheral air flow velocity may decrease due to wall friction.
- In the radial plane the air vortex is created. This air vortex appears between the heights of 20 mm and 100 mm above the surface around the tip of the blade.

The contribution is focused on the experimental description of the air flow conditions inside the workspace of mulcher with the vertical axis of rotation. The air flow conditions affect the quality of work and energy demands of the mulcher. From the viewpoint of quality of work the higher radial and axial velocity could improve the work quality. That may be achieved by modification of working tool or workspace cover in order to redirect the radial and upward velocity at the tip of the blades and ensure better recirculation of cut plant material around the blades of the working tools (Čedik et al., 2017a; Čedik et al., 2017b). Also, the shape of workspace cover could be optimized according to course of the radial air flow velocity so that the volume with low values of radial velocity would be minimized.

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