EFFECT OF TOP COVER SHAPE ON ENERGY DEMANDS AND WORKSPACE PRESSURE OF MULCHER

JAKUB CEDIK[1], JAN CHYBA[2], MARTIN PEXA[1]
STANISLAV PETRASEK[2]
[1]Czech University of Life Sciences Prague
Faculty of Engineering, Department for Quality and Dependability of Machines, Prague, Czech Republic
[2]Czech University of Life Sciences Prague
Faculty of Engineering, Department of Agricultural Machines, Prague, Czech Republic

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e-mail: cedikj@tf.czu.cz

Mulchers with vertical axis of rotation are highly energy demanding machines and it is expedient to increase their effectiveness. The paper deals with evaluation of the effect of the shape of mulcher's workspace cover on energy demands and pressure conditions of the workspace of mulcher with vertical axis of rotation. The pressure conditions inside the workspace are connected with the airflow which is vital for the correct function of the machine. The laboratory model of one mulcher's rotor was used for the measurement. Three workspace cover shapes were used for the measurement, including shapes called "drop", "toroid" and flat cover which was used as a reference. The measurement was carried out at cutting speeds of 21, 42, 63, 84 and 105 ms^{-1}. The proposed shapes of mulcher's workspace cover showed higher energy demands, while the cover in shape "toroid" significantly affected the pressure profile in the mulcher workspace.

KEYWORDS
mulcher, energy demands, pressure conditions workspace cover, energy losses

1 INTRODUCTION

Mulching is a technological process which is used for cutting and crushing green plant residues, old grass on permanent grasslands, treatment of fallow lands and crushing crop residues on the arable land. During mulching the crushed plant residues are left on the soil surface for its easy decomposition. [Mayer 2007, Syrovy 2013].

Mulcher with vertical axis of rotation belongs between rotary mowers. Rotary mowers have a high energy demands, mainly because of a high cutting speed and also high air and material resistance. Results of authors regarding energy demand of various rotary mowers differ substantially. The sources reported required power input in range of 3.5–23 kWm^{-1} (where m^{-1} is the working width of the machine) [McRandal 1978, Tuck 1991, Srivastava 2006,Syrovy 2008, ASABE 2011,Cedik2015; Kumhala 2016].

Pressure conditions and associated air flow inside the workspace of mulcher (i.e. ventilation effect) is very important parameter for the energy demands and quality of work of mulcher [Chon 1999a,b]. Speed and direction of air flow affects the relative speed of air and tool and thereby influences aerodynamic resistance and also repeated contact of plant matter with tool, which is vital for perfect crushing of cut plant matter and its easy decomposition. The uniform dispersion of crushed plant matter in the whole working width of machine, which is also very important parameter in terms of quality of work, is also highly affected by pressure conditions and airflow inside the workspace [Cedik 2016a,b,c]

Cutting speed is one of the parameters that influences the speed and direction of the airflow in the mulcher's workspace. The cutting speed of rotary mowers is usually within range of 71–84 ms^{-1} [O'Dogherty 1982, Jun 2006]. [Srivastava 2006] reported that for reliable function the cutting speed should be within the range of 50–75 ms^{-1} in dependence on the sharpness of cutting tool. The optimization of the cutting speed and the cutting tool shape can significantly reduce the power consumption [Hosseini 2012, Kakahy2014].

The workspace cover has also very strong effect on the energy demands and work quality and its modification can improve the air flow performance [Chon 2005]. [Hagen 2002] reported that the configuration of the workspace cover has equal significance as configuration of the blade in terms of airflow in the workspace. The mulcher's workspace cover design must allow maximum airflow and re-circulation of the grass clippings for better work quality [Chon 2004]. The height of the machine also influences the air flow profile of the mulcher's workspace [Jun 2008].

The aim of the paper was to evaluate two proposed workspace cover shapes for mulcher with vertical axis of rotation from viewpoint of power input and pressure conditions inside its workspace, while flat cover was used as a reference.

2 MATERIALS AND METHODS

Measurement was carried out under laboratory conditions at Faculty of Engineering of Czech University of Life Sciences Prague. For the measurement a laboratory model of a single mulcher rotor was used (fig. 1). The model was based on the mulcher MZ 6000 with three rotors and working width of 6 m, produced by the BEDNAR FMT, Ltd company, from which the drive mechanism and the blade section was used. The working speed of the mulcher MZ 6000 is 1000 rpm. To drive the rotor with a diameter of 2 m an asynchronous electromotor with power of 22 kW was used. The speed of the electromotor was controlled by means of frequency converter.

The mulcher MZ 6000 as well as the model has a flat cover of the workspace, as can be seen in the fig. 1. For the measurement two additional shapes of the workspace cover were proposed and manufactured. The first in the shape, called "toroid" and the second in the shape, called "drop". The flat cover of workspace was used as a reference. The profiles of the proposed workspace covers can be seen in the fig. 2 and 3. The target was to smoothly redirect the upward velocity at the tip of the blades in order to ensure better recirculation of cut plant material in the workspace and avoid the peak shape at the centre of the rotor which is not efficient according to [Chon 2003].

In order to determine the influence of the workspace cover shape on the power input of the mulcher the torque sensor Manner Mfi 2500Nm_2000U/min (accuracy 0.25%) was mounted between the gearbox and the drive shaft. The data from torque sensor were stored at personal computer's hard drive with frequency of 5 Hz.

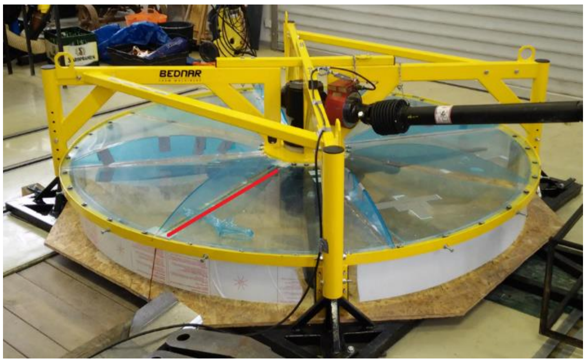

Figure 1. Laboratory model of mulcher rotor with flat cover (red line indicates the position of pressure sensors)

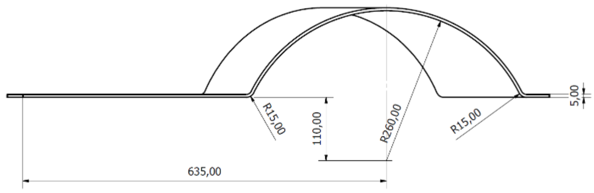

Figure 2. The profile of the workspace cover shape "toroid"

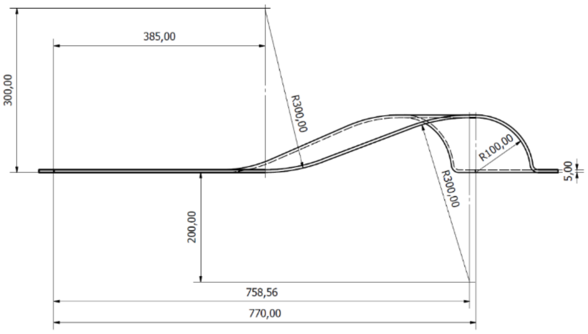

Figure 3. The profile of the workspace cover shape "drop"

Figure 4. Used pressure sensors, placed on the flat workspace cover

For determination of the workspace cover shape effect on the pressure conditions inside the workspace of the mulcher, the strain gauges pressure sensors, made by Association for Research and Education, Ltd, were used (fig. 4). The sensors are in the form of strips with 24 individual sensors on each strip. Sensors are placed on the strip with 1 cm gap. Three strips placed in series were used for the measurement. The sensors were placed on the bottom side of the top cover of the workspace radially to the axis of rotor and its position is highlighted by a red line in the fig. 1. The zeroing of the sensors between measurements was done by means of external pressure sensor, provided by manufacturer. The parameters of the sensors are listed in table 1. The data from the pressure sensors were stored on the personal computer's hard drive with frequency of 2.5 Hz.

The measurement was carried out at rotation speeds of 200, 400, 600, 800 and 1000 rpm, which corresponds to cutting speeds of 21, 42, 63, 84 and 105 ms^{-1}. With proposed shapes of workspace cover it was not possible to reach 1000 rpm, because of high accelerometric vibrations of the central part of the frame. The highest measured vibrations reached almost 12 g. The values for 1000 rpm were calculated based on the trend from lower rotation speeds. For the calculation of the torque the 2nd degree polynomial functions were used, because in this case the main part of the energy losses is consumed by air resistance.

Parameter	Value
Pressure range	93–107 kPa
Temperature range	15–40°C
Sampling frequency	10 Hz
Accuracy	<10 Pa
Nonlinearity and hysteresis	<8 Pa
Noise	± 5 Pa

Table 1. Parameters of the pressure sensors

3 RESULTS AND DISCUSSION

The figure 5 showsthe laboratory model of the mulcher with workspace cover in the shape of "toroid".

Figure 5. The workspace cover in the shape of "toroid" mounted on the laboratory model

3.1 Determination of the effect of mulcher's workspace cover shape on energy demands

In the figure 6 and 7 the course of the torque and power input of the laboratory model for all three variants of the workspace cover shapes can be seen.

From figures 6 and 7 it can be seen that the proposed shapes of the workspace cover had negative effect on the power input. This is most probably caused by the fact, that blades are spining bigger volume of air, which results in higher energy demands.

This also confirms the fact, that the workspace cover in the shape of "toroid", which has the biggest volume of workspace, showed the biggest power input (by 20.8% higher in comparison with the flat cover). The workspace cover in the shape of "drop" showed higher power input by 5.5% in comparison with flat cover.

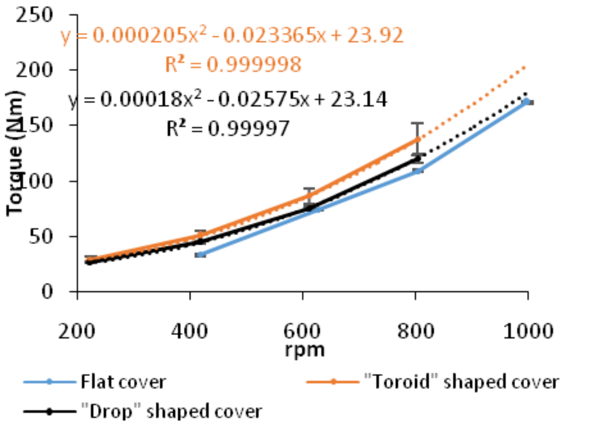

Figure 6. Course of torque for all three cover shapes in dependence on rotor speed

The analysis of variance, complemented with Tukey's HSD post hoc test (tab. 2), showed statistically significant difference in torque between all shapes of workspace cover at significance level α = 0.05.

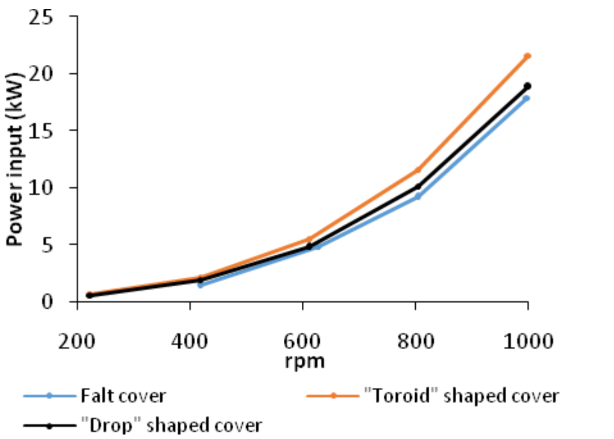

Figure 7. Course of power input for all three cover shapes in dependence on rotor speed

ANOVA				
α = 0.05	**Sum of squares**	**Degrees of freedom**	**Variance**	**F**
Between groups	170384.6	2	85192.3	1323.5
Within groups	74409.6	1156	64.4	
Total	244794.2	1158		
Tukey's HSD Post-hoc Test				
Flat vs "Toroid"	Diff=28.4930, 95%CI=27.1918 to 29.7943, p=0.0000			
Flat vs "Drop"	Diff=11.2925, 95%CI=9.8189 to 12.7661, p=0.0000			
"Toroid" vs "Drop"	Diff=-17.2005, 95%CI=-18.8520 to -15.5490, p=0.0000			

Table 2. Analysis of variance of measured torque values for all three shapes of workspace cover at 800 rpm.

3.2 Determination of the effect of mulcher's workspace cover shape on pressure conditions

The results of the pressure conditions measurement inside the workspace for all three variants of the workspace cover shapes can be seen in the figures 8, 9 and 10. From figures it can be clearly seen that in the workspace of the mulcher the vacuum was created as a result of rotational movement of working tools.

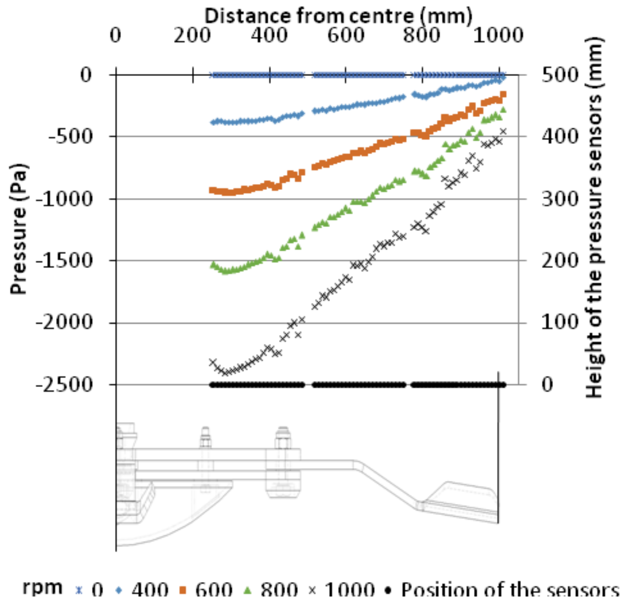

Figure 8. Course of pressure at different rotation speedswith flat cover

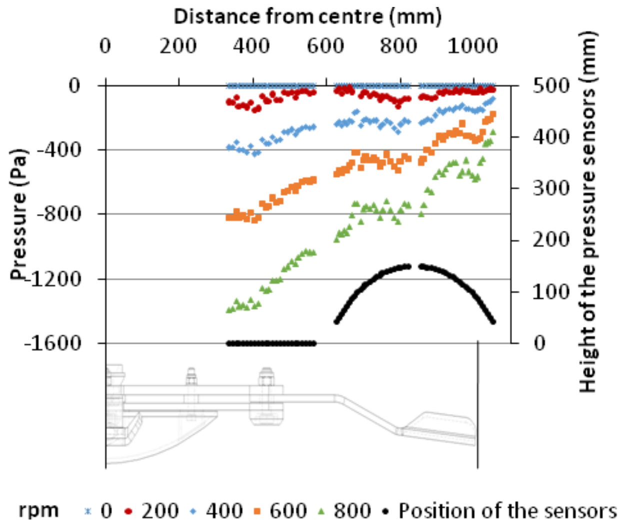

Figure 9. Course of pressure at different rotation speeds with cover in the shape of "toroid"

It is evident that for flat and „drop" shaped covers the pressure is decreasing from rotor periphery towards to the centre almost linearly (deviations from linearity are probably caused by the shape elements on working mechanism i.e. retaining screw, nuts, and other shaped projections of the working tool). This phenomena is caused mainly by the centrifugal forces of the rotating air in the workspace and it is in good agreement with results of other authors obtained by using mathematical model for municipal mower [Chon 2003, Chon 2004].From the figures it is obvious that the cover in the shape of „toroid" showed substantial effect on the course of the pressure as its deviations from linearity are higher in comparison with other cover shapes. This is most probably caused by more frequent occurance of turbuences in the workspace. This is also in good agreement with higher standard deviation of measured torque as can be seen in the figure 6. The measured course of the pressure may be also to a certain extent affected by the position of the sensors.

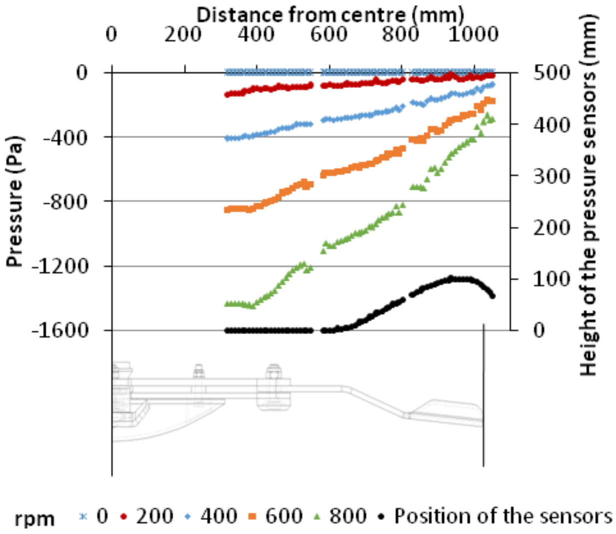

Figure 10. Course of pressure at different rotation speeds with cover in the shape of "drop"

The maximum reached vacuum was 2.41 kPa and it was achieved with flat cover of the workspace. The figure 11 shows the comparison of maximum reached vacuum in the workspace for different rotation speeds of the rotor and different cover shapes. It is evident that the proposed shapes of the workspace cover decreases the maximum reached vacuum. At working speed 1000 rpm the decrease is approx 13.9% for cover shape called „toroid" and 8.8% for cover shape called „drop".

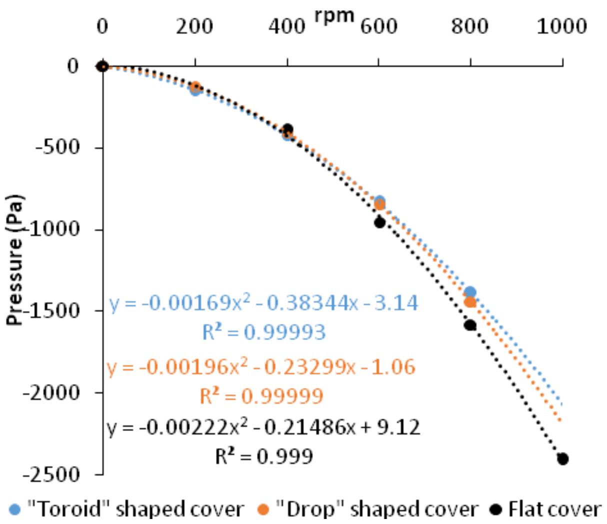

Figure 11. Comparison of maximum reached vacuum in the workspace for all three cover shapes at different rotation speeds

In the table 3 the analysis of variance, complemented with Tukey's HSD post hoc test is shown. There was found a statistically significant difference in maximum reached vacuum between all tested shapes of the mulcher's workspace cover at 800 rpm.

The figure 12 shows the pressure difference between maximum and minimum reached vacuum for different rotation speeds of the rotor and different cover shapes. The pressure difference is important for quality of work. According to other sources [Chon 2004], the low pressure at the centre is increasing the upward velocity in the area around the tip of the blades and thus increasing the mulching effect.

ANOVA				
α = 0.05	Sum of squares	Degrees of freedom	Variance	F
Between groups	2465612	2	1232806	11138.3
Within groups	39734.6	359	110.7	
Total	2505346.6	361		
Tukey's HSD Post-hoc Test				
Flat vs "Toroid"	Diff=193.9396, 95%CI=190.8729 to 197.0062, p=0.0000			
Flat vs "Drop"	Diff=142.1937, 95%CI=138.4125 to 145.9749, p=0.0000			
"Toroid" vs "Drop"	Diff=-17.2005, 95%CI=-18.8520 to -15.5490, p=0.0000			

Table 3. Analysis of variance of measured values of maximum vacuum in the workspace for all three shapes of workspace cover at 800 rpm.

The maximum pressure difference was reached with flat cover and its value reached 1.95 kPa at 1000 rpm (105 ms^{-1}). [Chon 2005] using a mathematical model estimated the pressure difference for double rotor municipal mower with rotor diameter of 0.6 m to 3 kPa at 2700 rpm (82 ms^{-1}).

From the figure it can be seen that the cover shape called "toroid" decreased the pressure difference by approx. 15.2% and cover shape called "drop" by approx. 9.7%. at 800 rpm. At 1000 rpm the cover shape "toroid" decreased the pressure difference by approx. 17.2% and cover shape called "drop" by approx 8.5%.

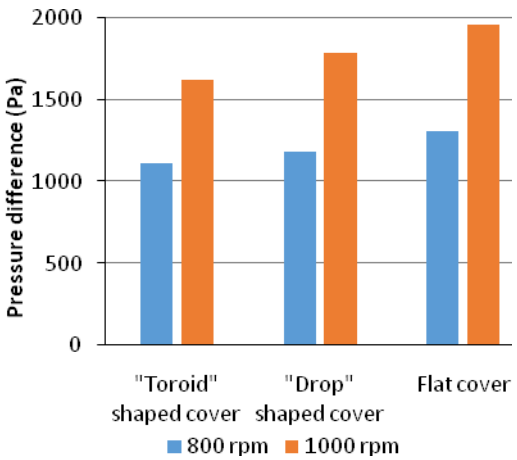

Figure 12. Comparison of pressure differences reached in the workspace for all variants of cover shapes

4 CONCLUSIONS

During the measurement of the pressure conditions inside the mulcher's workspace the following conclusions were made:

- The proposed shapes of workspace cover showed statistically significant increase of power input, probably because of bigger volume of the workspace.
- The workspace cover shape called "drop" as well as the reference flat cover showed linear decrease of the pressure from circumference of the rotor towards to its centre. The workspace cover shape called "toroid" showed significant deviations from linearity in course of the pressure.

- Maximum reached vacuum in the workspace was measured 2.41 kPa. Proposed shapes of workspace cover showed statistically significant decrease of maximum the maximum reached vacuum in the workspace.
- Proposed shapes of mulcher workspace cover also showed decrease in pressure difference in the workspace.

From the obtained results it can be stated, that from the point of view of power input the flat cover is optimal. From the point of view of pressure conditions, according to [Chon 2003, Chon 2004, Chon 2005], the maximum reached vacuum and the pressure difference are important factors that are affecting the work quality. From measured results of the pressure conditions also the flat cover seems to be optimal. However, the cover in the shape of "toroid" may cause more frequent occurance of turbuences in the workspace which may result in the more contacts of the cut plant matter with the blades and thus better work quality.

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CONTACT:

Ing. Jakub Cedik, Ph.D.
Czech University of Life Sciences Prague, Faculty of Engineering, Department for Quality and Dependability of Machines
Kamycka 129, Prague 6, 16521, Czech Republic
+420 22438 3321, cedikj@tf.czu.cz