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

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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, Syrový 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⁻³ (where m³ is the working width of the machine) [McRandall 1978, Tuck 1991, Srivastava 2006, Syrový 2008, ASABE 2011, Cedík2015; Kumhala 2016].

Pressure conditions and associated airflow 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 [Cedík 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.
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.

![Figure 1](image1.jpg)

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

![Figure 2](image2.jpg)

**Figure 2.** The profile of the workspace cover shape “toroid”

![Figure 3](image3.jpg)

**Figure 3.** The profile of the workspace cover shape “drop”

![Figure 4](image4.jpg)

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

| 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 shows the laboratory model of the mulcher with workspace cover in the shape of “toroid”.

![Figure 5](image5.jpg)

**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 spinning 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.
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 $\alpha = 0.05$.

|             | ANOVA                  |
|-------------|------------------------|
| $\alpha = 0.05$ | 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 |

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.
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“.

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%.

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 “toroid” as well as the reference flat cover showed linear decrease of the pressure from circumference of the rotor towards 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 occurrence of turbluences 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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REFERENCES

[ASABE 2011] American Society of Agricultural and Biological Engineers. ASABE D497.7 – Agricultural Machinery Management Data. St. Joseph: The American Society of Agricultural and Biological Engineers. 2011

[Cedik 2015] Cedik, J. et al. Mulcher energy intensity measurement in dependence on performance. Agronomy Research, 2015, Vol.13, No.1, pp. 46-52. ISSN 1406894X

[Cedik 2016a] Cedik, J. et al. Pressure conditions inside the workspace of mulcher with vertical axis of rotation. In: D. Herak, ed. Proceeding of 6th International Conference on Trends in Agricultural Engineering 2016 – Part I, Prague, 7-9 September, 2016, Prague: Czech University of Life Sciences Prague, pp. 129-134. ISBN 978-80-213-2683-5

[Cedik 2016b] Cedik, J. et al. Influence of blade shape on mulcher blade air resistance. Agronomy Research, 2016, Vol.14, No.2, pp. 337-344. ISSN 1406894X

[Cedik 2016c] Cedik, J. Research of influence of operational and constructional parameters on energy demands and quality of work of mulcher. Dissertation thesis, Prague: Czech University of Life Sciences Prague, 2016 (in Czech)

[Chon 1999a] Chon, W. et al. Investigation of flows around a rotating blade in a lawn mower deck. In:Proceedings of the 1999 3rd ASME/JSME Joint Fluids Engineering Conference, FEDSM ‘99 (CD-ROM), San Francisco, 18-23 July 1999, New York: American Society of Mechanical Engineers, ISBN 0791819612

[Chon 1999b] Chon, W. et al. Experimental study of aerodynamics around co-rotating blades in a lawn mower deck. American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED, 1999, Vol.250, pp 57-64, ISSN 08881116

[Chon 2003] Chon, W. and Amano, R. S. Experimental and computational studies on flow behavior around counter rotating blades in a double-spindle deck. KSME International Journal, 2004, Vol.18, No.8, pp 1401-1417, ISSN 1738-494X

[Chon 2004] Chon, W. and Amano, R. S. Experimental and Computational Investigation of Triple-rotating Blades in a Mower Deck. JSME International Journal Series B: Fluids and Thermal Engineering Journal, 2003, Vol.46, No.2, pp 229-243, ISSN 1340-8054

[Chon 2005] Chon, W. and Amano, R. S. Investigation of Flow Behavior around Corotating Blades in a Double-Spindle Lawn Mower Deck. International Journal of Rotating Machinery, 2005, Vol.1, pp 77-89, ISSN 1542-3034

[Hagen 2002] Hagen, P.A. et al. Experimental Study of Aerodynamics Around Rotating Blades in a Lawnmower Deck. In: ASME 2002 Joint U.S.-European Fluids Engineering Division Conference, Montreal, 14-18 July 2002, New York: American Society of Mechanical Engineers, pp. 67-76. ISBN 0-7918-3615-0

[Hosseini 2012] Hosseini, S. S. and Shamsi, M. Performance optimization of a rotary mower using Taguchi method. Agronomy Research, 2012, Vol.10, No SPEC. ISS. 1, pp. 49-54, ISSN 1406894X

[Jun 2006] Jun, H. J. et al. Development of a side-discharge mid-mower attached to a tractor. In: Proc. 3rd international symposium on Machinery Mechatronics for agricultural and Biosystems Engineering, Seoul, 23-25 November, 2006, pp. 484-490

[Jun 2008] Jun, H. et al. Development of Side-discharge Type Mid-mower Attached to a Tractor. Engineering in Agriculture, Environment and Food, 2008, Vol.1, No.1, pp. 39-44. ISSN 1881-8366

[Kakahy 2014] Kakahy, A. N. et al. Effects of knife shapes and cutting speeds of a mower on the power consumption for pulverizing sweet potato vine. Key Engineering Materials, 2014, Vol.594, pp. 1126-1130. ISSN 1662-9795

[Kumhala 2016] Kumhala, F. et al. Measurement of mulcher power input in relation to yield. Agronomy Research, 2016, Vol.14, No.4, pp. 1380-1385. ISSN 1406894X

[Mayer 2007] Mayer, V. and Vlaskova, M. Set-aside land cultivation by mulching. Agritech Science [online], 2007. Vol.1, No.2, pp. 1-5, [15 June 2017], Available from <http://www.agritech.cz/clanky/2007-2-1.pdf>, ISSN 1802-8942, (in Czech)

[McRandal 1978] McRandal, D. M. and McNulty, P. B. Impact cutting behaviour of forage crops I. Mathematical models and laboratory tests. Journal of Agricultural Engineering Research, 1978, Vol.23, No.3, pp. 313-328, ISSN 1095-9246

[McKendry 1982] O’Dogherty, M. J. A review of research on forage chopping. Journal of Agricultural Engineering Research. 1982, Vol.27, No.4, pp. 267-289, ISSN 1095-9246

[Srivastava 2006] Srivastava A. K. et al. Engineering principles of agricultural machines. St Joseph: American Society of Agricultural Engineers, 2006, ISBN 978-1892769503

[Syrovy 2008] Syrovy, O. et al. Energy savings in crop production technologies. Prague: Research Institute of Agricultural Engineering, p.r.i., 2008, ISBN 978-80-86884-44-8 (in Czech)

[Syrovy 2013] Syrovy, O. et al. Mobile energy devices and the approximate values of unit fuel and energy consumption. Prague: Research Institute of Agricultural Engineering, p.r.i., 2013, ISBN 978-80-86884-79-0 (in Czech)

[Tuck 1991] Tuck, C. R. et al. Field Experiments to Study the Performance of Toothed Disk Mowing Mechanisms. Journal of Agricultural Engineering Research, 1991, Vol.50, pp. 93-106, ISSN 1095-9246

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