Agronomy Research **14**(2), 337–344, 2016

Influence of blade shape on mulcher blade air resistance

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Abstract. Mulching is an energy-intensive agricultural operation. The efforts to reduce the energy intensity makes the designers explore new solutions which would reduce the energy intensity. One of the possibilities to reduce the energy intensity of mulching is to use a work tool of different shape. The paper introduces comparison of several shapes of blades intended for the mulcher with vertical axis of rotation, where especially the rake and cloth angle is changed. The measurement was performed by means of a laboratory model of a one mulcher rotor and in the field conditions where the mulcher Bednar MZ 6000 with a range of 6 m and three rotors had been used. The measurement was performed particularly from the point of view of the energy loss caused by drag of knives. The measurement done by means of the model of the mulcher has confirmed the hypothesis that larger cloth causes increased resistance of the mulcher and higher rake angle results in decreased mulcher resistance. However, larger cloth may contribute to better work quality in the field conditions.

Key words: Mulcher blades, mulching, energy loss, rake angle, cloth angle, air resistance.

INTRODUCTION

Mulching is a technological process during which crushed plant residues are left on the surface. It is primarily used for cutting and crushing green plant residues, old grass on permanent grasslands and for treating fallow lands. Mulching can also be used for crushing crop residues on the arable land (Andrejs, 2006; Mayer & Vlášková, 2007; Syrový et al., 2013).

Mulcher with vertical axis of rotation (Fig. 1) is a rotation mower. Many authors tried to measure its energy intensity but their results differ significantly (Table 1).

The energy intensity of mulching or shredding of plant material is dependent on the type of processed crop, parameters of the cut (mass performance, cutting speed etc.) and shape and condition of the cutting tool (Syrový et al., 2008; Hosseini & Shamsi, 2012; Kronbergs et al., 2013; Pecenka & Hoffmann, 2015). Shape of the cutting tool, especially the rake angle and the angle of the tool cloth (Fig. 2), may significantly affect the energy intensity of work. Concerning mulchers with vertical axis of rotation, the rake angle is mostly 0° which is a perpendicular cut. In the literature the rake angle have been studied in the range 0–50°. The most effective cut was found within the range 15°–30° (O'Dogherty & Gale, 1986; O'Dogherty & Gale, 1991; Kakahy et al., 2012; Kakahy et al., 2013) depending on other parameters of the cut such as cutting speed. Chattopadhyay and Pandey (2001) observed the lowest required energy at the rake angle of 40°.

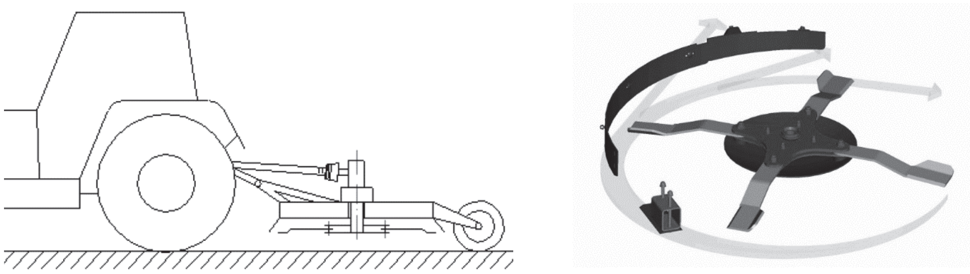

Figure 1. Principial figure of mulcher with vertical axis of rotation (Bednar FMT, 2013; Andrejs, 2004).

Table 1. Results of energy intensity of rotation mowers, measured at different conditions

Source	Performance requirement (kW m^{-1})	Conditions
Čedík et al. (2015)	10–23	Mulcher working with mass performance of 10–35 t h^{-1}
ASABE D497.7 (2011)	5	Mower
	8	Mower with conditioner
Syrový et al. (2008)	6.67	Mower with the average mass performance 120 t h^{-1} and blunt blades.
	5.67	Mower with the average mass performance 120 t h^{-1} and sharp blades.
Srivastava et al. (2006)	11–16	Mower at a speed of 15 km h^{-1}
Tuck et al. (1991)	8–10	Mower with sharp blade
	10–12	Mower with worn blade
McRandal & McNulty (1978b)	5	Mower
	3.5–6.5	Mower with conditioner

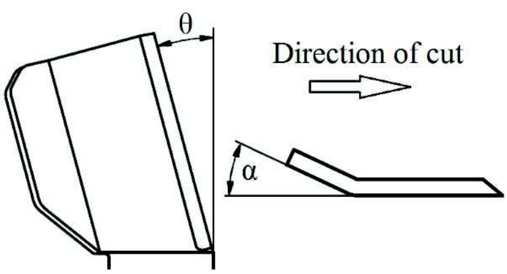

Figure 2. Angles on the cutting tool (θ – rake angle, α – cloth angle).

Another parameter affecting energy intensity of the mulcher with vertical axis of rotation is the energy loss. Identified energy losses of rotary mowers are the following: acceleration of the material to the output speed, overcoming friction forces between the material and the cover of the mower mechanism while the material is still pressed by the cutting device, overcoming friction forces between the blade and the stubble/soil, continuous movement of the air in the cut area (so called ventilation effect), overcoming mechanical friction forces of the drive mechanism and other parasitic losses. Total losses may be greater than the real cutting performance (Persson, 1987; O'Dogherty & Gale, 1991).

The experiments with mowing machines with vertical axis of rotation proved that 50% of the input energy is used for 'transport' of the plants while only 3% of the input energy is used for cutting the plant stems (McRandal & McNulty, 1978a).

The aim of the paper is to verify the impact of changing the cloth angle and the rake angle on the energy loss during mulching because energy losses are important part of the total energy intensity of the mulcher with vertical axis of rotation.

MATERIALS AND METHODS

Shapes of working tools were modified as follows: modification of the rake angle, modification of the cloth angle and extension of the blade. As for the original working tool the rake angle is 0° (perpendicular cut), the cloth angle is 45° and the blade length is 205 mm. As for the designed working tools (Fig. 3) the rake angle is 0°, 15° and 25°, the cloth angle 35° and 25° and the blade length 312 mm for tools with the rake angle 0°, 319.5 mm for tools with the rake angle 15° and 333.9 mm for tools with rake angle 25°. The tools are marked as follows: rake angle X cloth angle (e.g. 0X35 means the rake angle is 0° and the cloth angle is 35°).

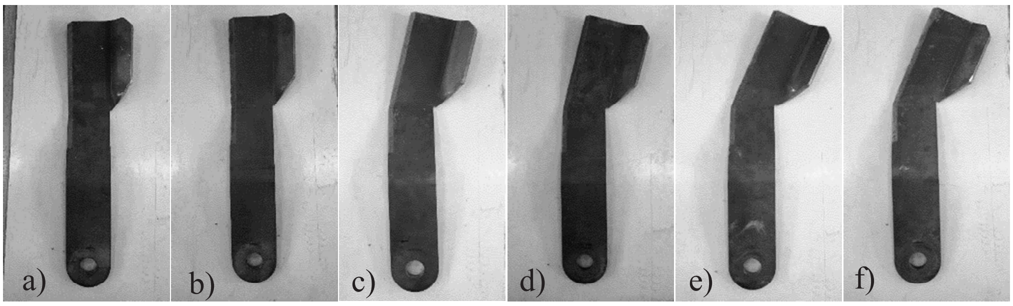

Figure 3. Proposed working tools (a – 0X35, b – 0X25, c – 15X35, d – 15X25, e – 25X35, f – 25X25).

In order to determine the impact of designed working tools on energy losses a measurement was carried out using a laboratory model of a one mulcher rotor (Fig. 4) in laboratory conditions. The model is driven by an asynchronous electric motor with the power of 22 kW and a frequency inverter Siemens with maximum power 30 kW. The torque, input power and rotor speed were measured by means of the torque sensor MANNNER Mfi 2500Nm_2000U/min (accuracy 0.25%). The data were saved to a hard drive of the measuring computer HP mini 5103 by means of the A/D converter LabJack

U6 with resolution 18bit and the module for pulse sensors Papouch Quido 10/1. The frequency of capturing the data was 5 Hz.

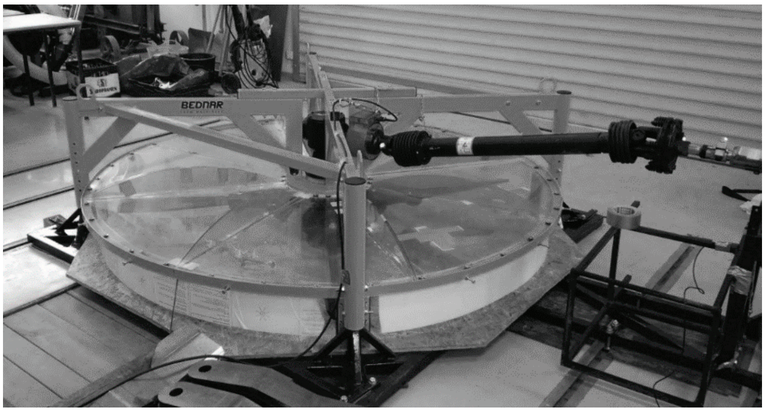

Figure 4. Laboratory model of one mulcher rotor.

Moreover, a measurement was carried out in field conditions with real mulcher where the torque and the input power, transmitted through the PTO shaft of the tractor to the mulcher machine running idle in a working height (approximately 50 mm) above the grassy stubble field, were measured. The Mulcher MZ 6000 with a vertical axis of rotation made by the company Bednar FMT s.r.o. was used during the field measurement as well as the tractor FENDT 818 (Fig. 5). The above mentioned mulcher has a working range 6 m, three rotors and working rotor speed 1,000 rpm. The above mentioned torque sensor Manner was used for measuring the torque and the input power. The frequency of capturing the data was 5 Hz. The moisture of the grass mater was high with an average value 67% and a standard deviation 7.3%.

Figure 5. Working set – tractor Fendt 818 and Mulcher MZ 6000.

RESULTS AND DISCUSSION

The torque increased with the second power of the rotational speed which is caused by the air resistance. During the measurement most of the measured variants did not reach 1,000 rpm due to safety since the acceleration of the model frame vibrations reached up to 12 g at the peak values. The values for 1,000 rpm were calculated by means of the 2nd degree polynomial with the coefficient of determination higher than $R^2 = 0.999$. Fig. 6 depicts progress of the input power depending on the rotor speed of the model for the individual shapes of working tools. It is evident that the input power increases with the third power of the speed. When comparing the individual variants it is evident that low cloth angle means low losses due to air resistance. This is caused by the fact that smaller cloth means smaller front area which has major influence on air resistance. In the case of increasing rake angle the front area reduces as well as the air resistance coefficient C_X, but decline of the input power is not so distinctive (significant).

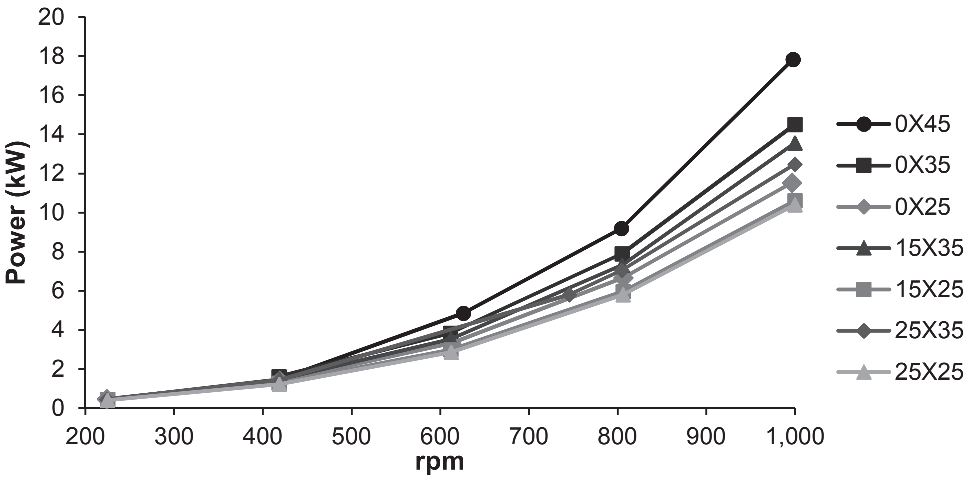

Figure 6. Dependence of power on rotation speed of rotor for all shapes of working tools.

Fig. 7 presents the comparison of tools with a zero rake angle measured in the field conditions with the mulcher MZ6000 at 50 mm high above the grass stubble. It is evident that a low cloth angle means low energy losses during any rotor speed. The reason is the same as for the laboratory model, i.e. small front area of the tool thus lower air resistance. Fig. 8 presents the comparison of the influence of increasing rake angle for tools with the cloth angle 25°. There are deviations from the results of measurement on the laboratory model which are probably caused by random errors made during the measurement in field conditions. It is obvious that the rake angle does not have such a significant effect on the dissipation of power in the given conditions, as the cloth angle.

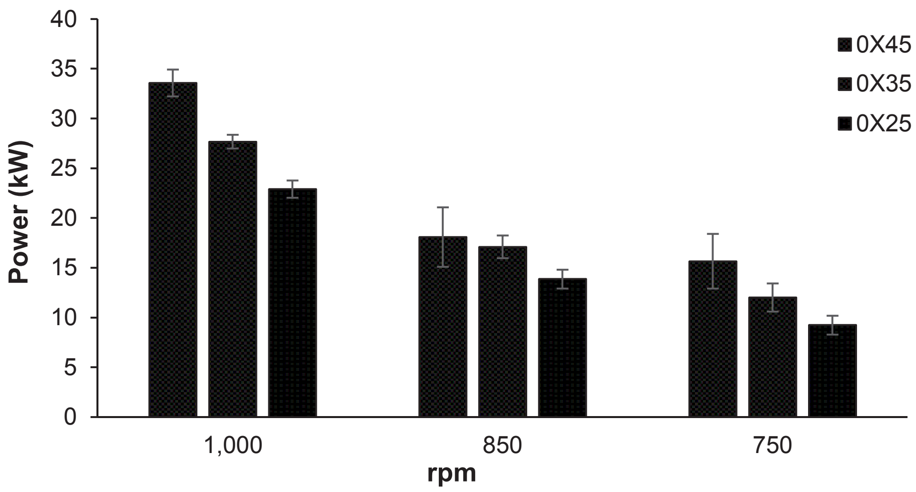

Figure 7. Comparison of mulcher input power for tools with different cloth angle.

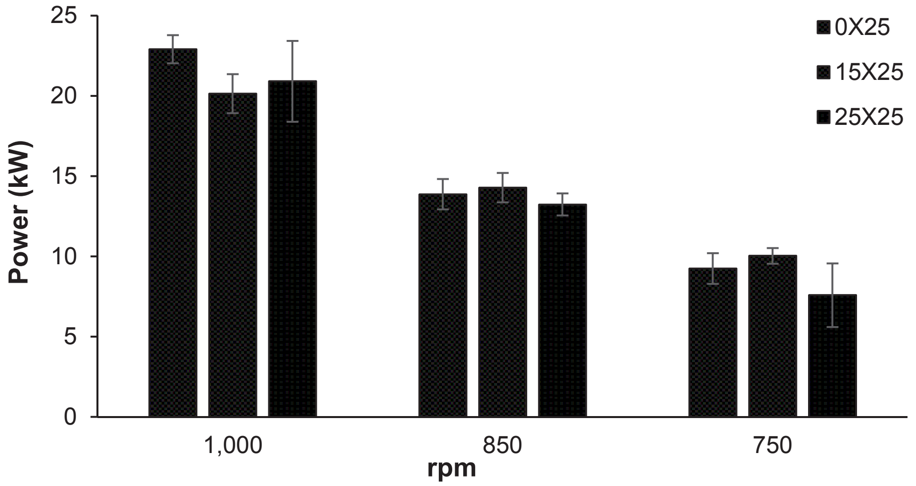

Figure 8. Comparison of mulcher input power for tools with different rake angle.

CONCLUSIONS

The measurement performed by means of the laboratory model proves that reducing the cloth angle means lower losses due to air resistance because lower cloth angle causes reducing the front area of the tool. Increasing tool rake angle also causes reduction of aerodynamic losses since the front area is reduced and the air resistance coefficient is affected. Optimizing the shape of the blade from the point of view of aerodynamics helps to save the energy which is also confirmed by Zu et al. (2011). It was also found out that the rotors in the mulcher influence each other since the input power of the laboratory model of the mulcher rotor was significantly higher than 1/3 of the input power of the whole mulcher when running idle.

Losses measured in the field conditions helped to verify the hypothesis derived from the laboratory model. The dissipation of power is affected mainly by the speed and the cloth angle, the rake angle does not have such a significant effect on reducing the energy losses during idle running. However, it can be assumed that the rake angle has a particular influence on the cutting energy. Use of low cloth angles may cause decrease of work quality because lower cloth angles reduce ventilation effect which provides repeated contact of the blade with the material and thus helps to perfect crushing of the above ground parts of plants.

ACKNOWLEDGEMENTS. Paper was created with the grant support of Technological Agency of Czech Republic (TAČR) – TA03010138 – Application of elektromotors in agriculture machinery.

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