PRESSURE CONDITIONS INSIDE THE WORKSPACE OF MULCHER WITH VERTICAL AXIS OF ROTATION

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Abstract

Maintenance and treatment of permanent grassland areas, areas left fallow and mulching in combination with other workflows (mowing, grazing) represent advantageous procedures. Conventional impact grass cutting and chopping is energy demanding. The energy demands and the quality of work is affected by air flow and pressure conditions inside the mulcher workspace. In this paper the pressure inside the workspace of the mulcher with vertical axis of rotation is measured and analyzed. The dependencies of pressure inside the workspace of mulcher on rotation speed and distance from the axis of rotation were examined. The torque and power input of the mulcher are also presented. It was found that inside the workspace the negative pressure is created due to centrifugal force and the pressure decreases with the square of rotation speed.

Key words: mulcher, pressure, torque, power.

INTRODUCTION

Currently, increasing importance on reducing the energy demands of agricultural operations is being put. This may be achieved in various ways, for example by reducing wear of the tools or by material or structural modifications. (MÜLLER ET AL., 2014; MULLER ET AL., 2013).

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 treatment of fallow lands. Mulching can also be used for crushing crop residues on the arable land (SYROVÝ ET AL., 2013; MAYER & VLÁŠKOVÁ, 2007; ANDREJS, 2006).

Mulcher with vertical axis of rotation is very similar to rotation mowers. Many authors tried to measure the energy demands of rotation mowers but their results differ significantly (Table 1).

Tab. 1. – Results of energy demands 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 (1978)	5	Mower
	3.5–6.5	Mower with conditioner

The typical cutting speed of the disc and rotary mowers ranges between 71–84 m s^{-1} (O'DOGHERTY, 1982). Optimization of the cutting speed, the knife shape, the blade oblique angle and the blade rake angle can significantly reduce the energy consumption

(KAKAHY ET AL., 2014; HOSSEINI & SHAMSI, 2012; JOHNSON ET AL., 2012).

Ventilation effect formed by working tools and air pressure in the workspace influence significantly the energy demands and work quality of mulcher with vertical axis of rotation. Direction and speed of air flow have an influence on relative speed of air and tool and thus influence aerodynamic resistance and also repeated contact of plant matter with tool, which lead to the perfect crushing of plant matter. Last but not least, air flow and pressure conditions in workspace of mulcher influence uniform dispersion of crushed plant matter in the whole working width of machine (JUN ET AL., 2008; CHON & AMANO, 2004; CHON & AMANO, 2003; CHON ET AL., 1999A,B).

Air flow, aerodynamic resistance and pressure conditions in workspace of mower are mainly influenced by the design of knife, cover of workspace and cutting speed (ČEDÍK ET AL., 2016; ZU ET AL., 2011; JUN ET AL., 2008; CHON & AMANO, 2004; CHON & AMANO, 2003; HAGEN ET AL., 2002). CHON & AMANO (2003) found out, that speed of air flow increases in direction from the centre of rotor towards its periphery and also, that the speed of air flow in areas of interaction of two rotors can be unstable.

The aim of the study was to determine the pressure conditions inside of workspace of the mulcher with vertical axis of rotation in radial direction to axis of rotation and create the dependencies of pressure in mulcher workspace on the cutting speed and distance from the rotor center.

MATERIALS AND METHODS

In order to determinate the pressure conditions in workspace of mulcher with vertical axis of rotation there was used a model of one rotor of mulcher. It was designed at Department of Agricultural Machines at Faculty of Engineering, Czech University of Life Sciences Prague. The basis of this model was formed by working mechanism of three-rotors mulcher MZ 6000 produced by the BEDNAR FMT company. The rotor diameter is 2 m and driving gear is ensured by electric motor MEZ with performance of 22 kW and equipped by frequency converter Siemens, 30 kW. This model is shown in the Fig. 1.

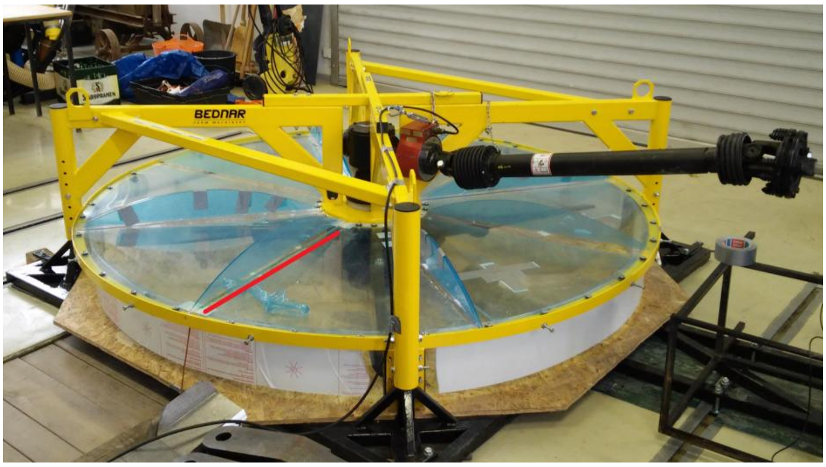

Fig. 1. – Used model of one mulcher rotor with highlighted location of the pressure sensors

Pressure scanning was carried out by means of pressure sensors in the form of pressure tapes produced by the Association for Research and Education, Ltd. (Fig. 2). These pressure tapes were placed inside the top cover of workspace, radially to the axis of rotation of the working tools (Fig. 1). Three pressure tapes were used for scanning. Data from pressure tapes were stored on the PC hard disc with a scanning frequency of 2.5 Hz. All the data were processed by means of MS Excel programme. Parameters of pressure sensors are given in Table 2.

Furthermore, there were scanned the torque and performance by means of torque sensor MANNER Mfi 2500 Nm_2000 U/min (accuracy 0.25 %). The revolutions were scanned by optical sensor Sick WL4-3N1330 with one pulse per revolution. These data were stored on hard disc of measuring computer HP mini 5103 with use of A/D converter LabJack U6 with 18 bit resolution and module for pulse sensors Papouch Quido 10/1. Frequency of data scanning was 5 Hz.

Measurements have been always carried out in a steady state at different revolutions. Working revolutions of mulcher are 1000 rpm. There were chosen the following measuring revolutions: 400, 600, 800 and 1000 rpm, which corresponds to the cutting speed about 42, 63, 84 and 105 m s^{-1}.

Fig. 2. – Pressure sensors

Tab. 1. – Parameters of the pressure sensors

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

RESULTS AND DISCUSSION

In the Fig. 3 there is shown the course of torque and power in dependence on revolutions. It is obvious, that the torque rises with square power of speed of rotation, which is caused by resistance of air, which creates main part of produced energy. It means that power increases with cube power of revolutions, as it is obvious on the Fig. 3.

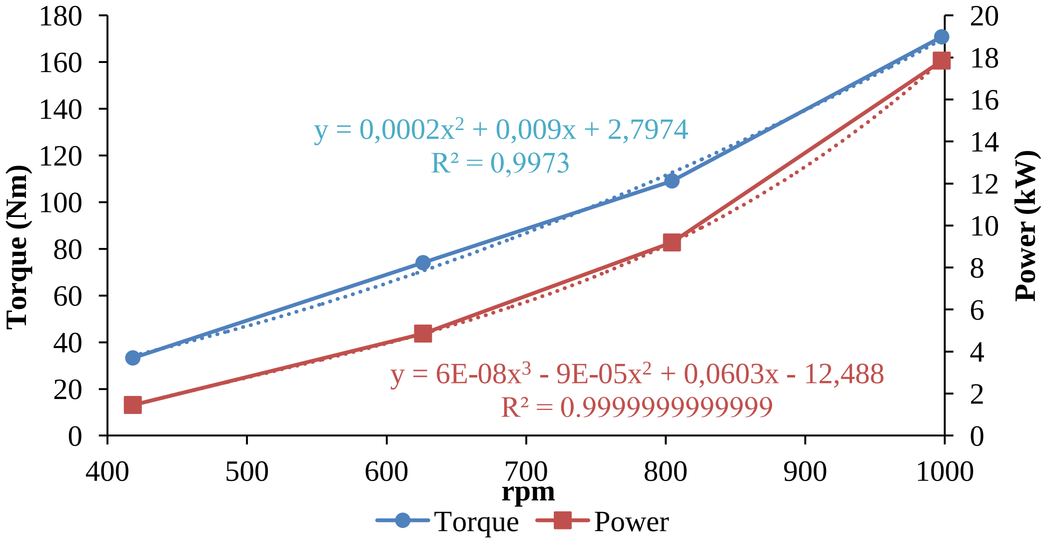

Fig. 3. – Torque and power of the mulcher model in dependence on rotation speed

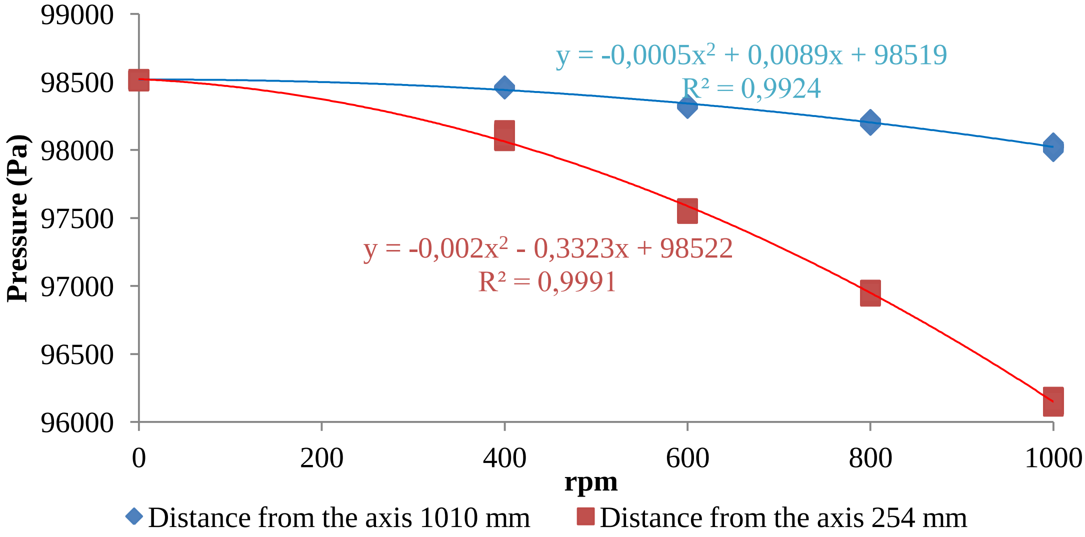

Fig. 4. – Pressure in workspace of the mulcher model in dependence on rotation speed

In the Fig. 4 there are shown dependences of pressure in workspace of mulcher model on revolutions in two distances from the axis of rotor. It is obvious, that in workspace of mulcher there is created negative pressure by movement of working tools and this negative pressure increases with square power of rotor revolutions. Under working revolutions (1000 rpm) there is created negative pressure on periphery of rotor around 0.49 kPa and in the distance of 254 mm from axis of rotor 2.36 kPa. The pressure difference makes about 1.87 kPa.

In the Fig. 5 there is shown the course of pressure from individual pressure sensors. We can see, that the pressure, depending on revolutions, decreases from periphery towards the centre of rotor almost linearly. During the comparison of pressure courses with drawing of working tool placed under graph, it is possible to see the effect of individual elements on working tool on course of pressure, for example tool cranking, cloth, fixing screw etc.

During the measurements there was determined the lowest pressure near to the centre of rotor. CHON & AMANO (2004) have also measured near to the centre of rotor of municipal mower the lowest pressure caused by centrifugal forces. This result is also in good accordance with the results of CHON & AMANO (2003), who state an increase of flow velocity from the centre of rotor towards its periphery.

The mulcher BEDNAR MZ 6000 equipped with three rotors, which driving mechanism was used as a basis of model, draws during the idle operation approx. 30 kW (ČEDÍK ET AL., 2016). In comparison with results achieved with the laboratory model, where the power of 17,8 kW is necessary for one rotor, it is obvious, that in the real mulcher there is an interaction between the individual rotors, which causes lower losses caused by the air resistance. This fact is in good agreement with findings determined by (CHON & AMANO, 2003), who stated unstable flow velocity in area of interaction of two rotors.

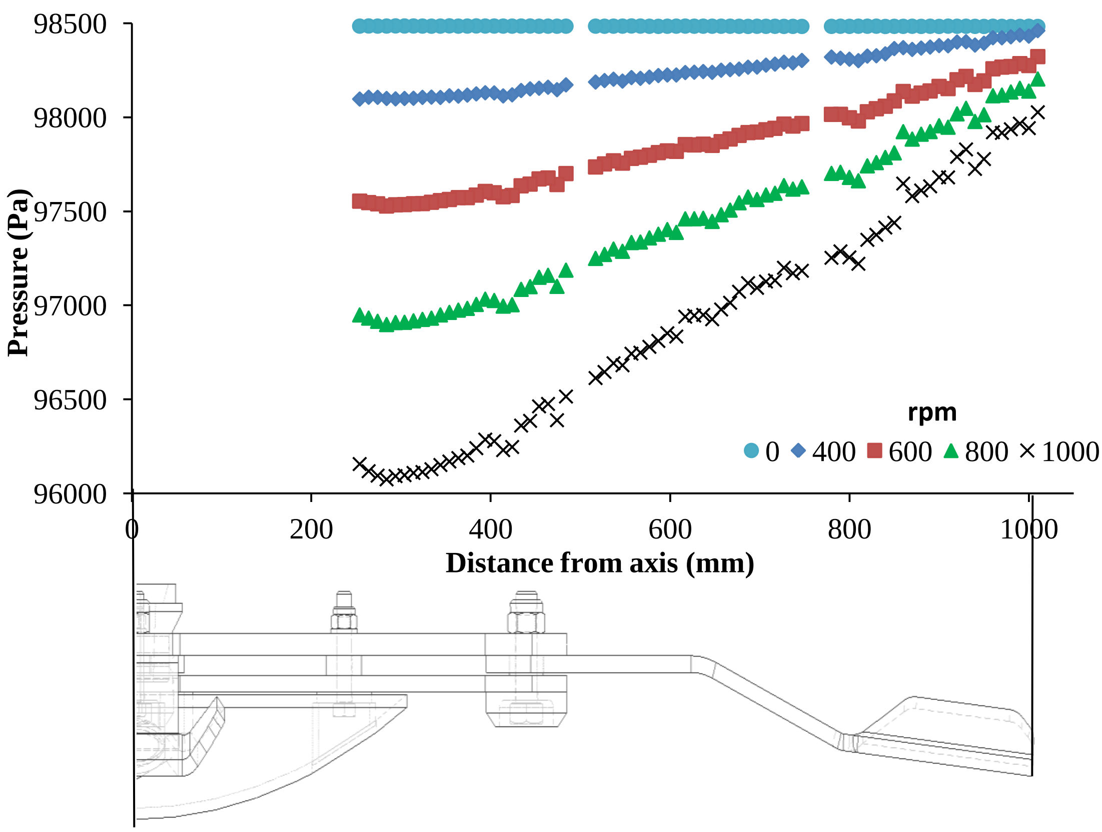

Fig. 5. – Course of the pressure in workspace of the mulcher model at different rotation speeds

CONCLUSIONS

It was determined, that negative pressure was created in mulcher workspace by the movement of working tools. This negative pressure is increasing from the periphery of rotor towards its centre. This negative pressure rising with square power of engine revolutions and the highest measured negative pressure was approx. 2.36 kPa. The decrease of pressure was almost linear across mulcher workspace section. The deviations are probably caused by the design of the working tool. This phenomenon is probably a consequence of centrifugal force.

Negative pressure in the centre of rotor can cause a suction of higher quantity of grass matter under the rotor and thus it can reduce the work quality. In order to increase the work quality there is desirable to carry out the measurements leading to an increase of negative pressure on the periphery of rotor, with the aim to prevent the grass matter or its part to penetrate into the space under centre of rotor.

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