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# MECHANICS OF THE MILLING OF LOGGING RESIDUES WITH A MERI CRUSHER MJS-2.5 DT MACHINE

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**Abstract.** The object of the analysis was a Meri Crusher MJS-2.5 DT crushing machine powered by a Valtra T-190 tractor. The crusher was 2500 mm wide and the power of the tractor was 190 HP. During the analysis the quantity of the biomass to be milled and the productivity of the milling operation itself were determined. Based on given technical parameters of the crusher (the rpm of the PTO, number of cutters, diameter of the drum and the driving speed of the tractor), the rpm of working drum, the linear velocity of the cutters, the power and torque of the working drum and the milling productivity were determined. Based on the analysis of working movements of the machine, the forces which occur on the cutters were calculated. It was found that the average force on one cutter was 190 N.

**Key words:** logging residues, crusher, labour consumption

## INTRODUCTION

The process of milling is mainly based on empirical knowledge. The theoretical processes of milling are very difficult to describe, and even an approximate description is not easy, which is a major hindrance in the development of scientific disciplines studying those processes. This is the reason why the knowledge about milling has empirical character [Zawada 1998]. Industrial milling is a typical branch of technology, to the development of which practical experience has greatly contributed, and not scientific analysis itself. The theory of the process is difficult to describe because of the structure of the material milled which consists of soil, often with stones, covered with a layer of thick and thin branches (logging residues) forming irregular patterns. Apart from branches, the area left after clear cutting is rich in tree stumps, which with their roots sit in the soil.

The process of designing crushing machines has an interdisciplinary character [Różański and Jabłoński 2002 a]. Apart from the technical knowledge, closely connected with machine construction, the process of designing requires the knowledge of other, sometimes remote scientific disciplines, like the soil science, road construction,

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silviculture and soil mechanics with its principles which form the theoretical base of milling forest logging residues and ways to calculate the milling forces [Różański and Jabłoński 2002 b, 2005 b].

The crushing machines that are used today consist of three main components: a working drum, a rear drum and a felling frame with fittings. The working drum is the most important part of a crusher, on which the cutters for milling soil, stones and wood are fitted. The rear drum helps in milling, depending on the type of the crusher used, while the felling frame presents a special outfit of crushers used in their work in young tree-stands. The fittings are a collection of different machine parts which are used in work. They form mechanisms which allow to move the drums and the frame. They also comprise the cutters (of different kinds in different machine types) fitted to the working drum.

## METHODS

The processes and phenomena present during the operation of milling were analysed. As the object of the analysis of the theory of milling, a MJS-2.5 DT crushing machine was selected, because its kinematics is interesting, according to the authors of the article. The crushing machine consists of three main parts: a milling drum with cutters (with an insert made of sintered carbides) fitted to it, a rear drum and a felling frame. The milling drum is powered from the PTO of the tractor, through a T--transmission and two chain transmissions (DT) which are assembled on both ends of the milling drum (Fig. 1).

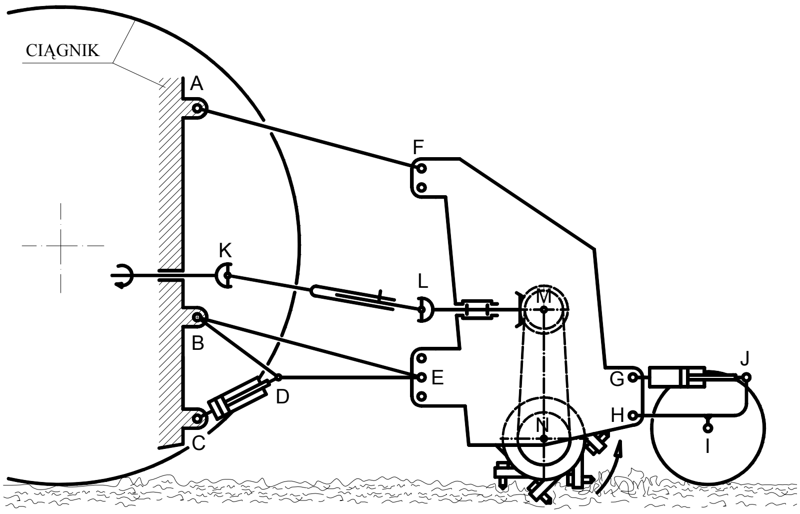


Fig. 1. The drawing of the crushing machine MJS-2.5 DT at work: A, B, C, D, E, F – mechanism for lifting the milling drum, G, H, I, J – mechanism for lifting the rear drum, K, L, M, N – mechanism for driving the milling drum
Rys. 1. Schemat rozdrabniarki MJS-2,5 DT w czasie pracy: A, B, C, D, E, F – mechanizm podnoszenia walca roboczego, G, H, I, J – mechanizm podnoszenia walca ugniatającego, K, L, M, N – mechanizm napędu walca roboczego

The machine body with transmissions, the milling drum, the rear drum can be lifted and lowered by means of two hydraulic cylinders fastened with articulated joints to the rocking levers (BDE) of the four-bar linkage. The driving shaft with two Cardan joints (K, L) and telescopic couplings enables to transfer the torque regardless of the machine position above the ground. The rear drum is connected to the milling drum frame with a pair of rocking mechanisms (HJ), controlled with two hydraulic cylinders (GJ). The rear drum that can rotate freely is fastened to the rockers (HJ). This mechanism enables to position the axis of the rear drum regardless of the position of the milling drum, which can be used while the machine is transported to its work site.

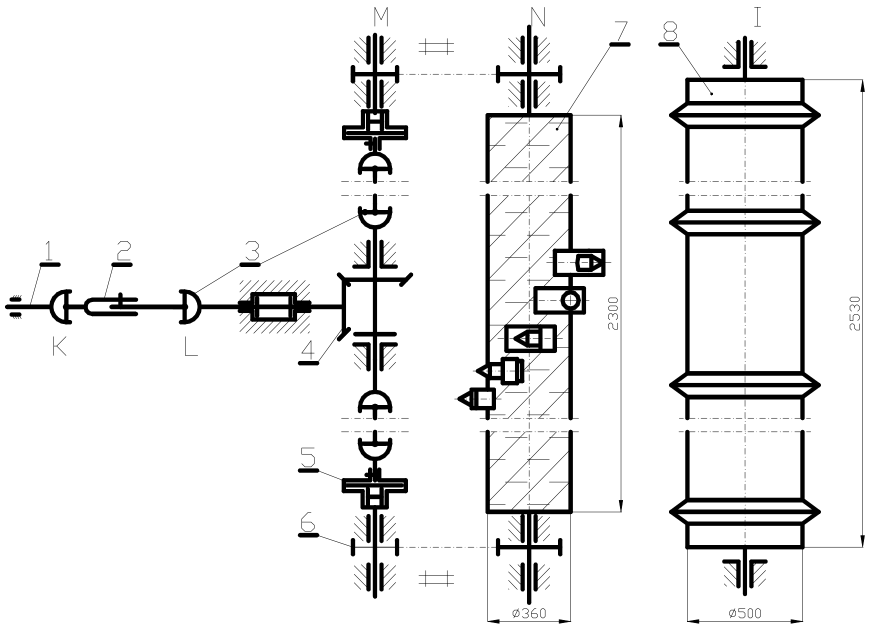


Fig. 2. The kinematic diagram of the crushing machine MJS-2.5 DT: 1 – PTO, 2 – Cardan shaft, 3 – universal couplings, 4 – T-transmission, 5 – hydraulic clutch, 6 – chain transmission, 7 – milling drum, 8 – rear drum
Rys. 2. Schemat kinematyczny rozdrabniarki MJS-2,5 DT: 1 – WOM, 2 – wał Cardana, 3 – sprzęgła przegubowe, 4 – przekładnia kątowa, 5 – sprzęgło hydrauliczne, 6 – przekładnia łańcuchowa, 7 – bęben roboczy, 8 – bęben ugniatający

The rotational direction of the milling drum is in agreement with the direction of free rolling of the rear drum that follows the milling drum (when the tractor moves forward). In case of backward driving, the milling is down-cut operating mode.

The steel frame of the milling drum with a fixed blade prevents the crushed logging residues, soil and stones from being hurled upwards by fast moving cutters on the milling drum. The cutters that are fitted to the drum, form long screw lines (2) in such a way that each cutter moves in a different plane that is perpendicular to the drum axis. The angle between the cutter holder axis and the tangent to the drum is 3-7 degrees and the cutters can turn round and shift. This guarantees better milling efficiency and longer life of cutters. The fixed blade, which also helps crush the material milled, is placed behind the milling drum.

Based on the technical parameters of the tractor and crusher (PTO rotational velocity, number of cutters, milling drum diameter, driving speed, rear drum diameter; Table 1) the rotational velocity of the milling rum, the linear velocity of the cutters, the power and torque of the milling drum and the milling efficiency of the machine were calculated. The analysis of the movements of the cutters enabled to determine the sum of circumferencial forces on cutter tips and the average force exerted by one cutter.

Table 1. Technical characteristics of the crusher MJS-2.5 DT and tractor Valtra T-190
Tabela 1. Dane techniczne rozdrabniarki MJS-2,5 DT i ciągnika Valtra T-190

| Parameter<br>Parametr | Symbol | Unit<br>Jednostka | Value<br>Wartość |
|---|---|---|---|
| Maximum tractor engine power<br>Maksymalna moc na wale silnika ciągnika | $P_1$ | kW | 139.65 |
| Power used for driving<br>Moc zużyta na opory jazdy | $P_j$ | kW | 30 |
| Tractor engine rotational speed<br>Prędkość obrotowa wału silnika | $n_1$ | 1/min | 1 000 |
| T-transmission ratio<br>Przełożenie przekładni kątowej | $i_1$ | | 17/23 |
| Chain transmission ratio<br>Przełożenie przekładni łańcuchowej | $i_2$ | | 17/23 |
| Diameter of working drum<br>Średnica walca roboczego | $D_r$ | mm | 360 |
| Length of working drum<br>Długość walca roboczego | $L_r$ | mm | 2 500 |
| Number of cutters<br>Liczba zębów roboczych | $z$ | pcs<br>szt | 93 |
| Radius of the circle drawn by cutter tips<br>Promień okręgu wierzchołków zębów | $R_r$ | mm | 260 |
| Diameter of rear drum<br>Średnica walca ugniatającego | $D_u$ | mm | 500 |
| Length of rear drum<br>Długość walca ugniatającego | $L_u$ | mm | 2 730 |
| Number of collars on rear drum<br>Liczba kołnierzy na walcu ugniatającym | $k$ | psc<br>szt | 6 |

The theoretical productivity was calculated according to the following formula:

$$W = V_j \cdot L_r \cdot k_1 \cdot k_2 \ [\mathrm{m^2/h}] \tag{1}$$

where:

$V_j$ – tractor driving speed, m/h,
$L_r$ – length of the working drum, m,
$k_1$ – coefficient for idle and auxiliary time (assumed $k_1 = 0.7$),
$k_2$ – coefficient for overlapping field stripes (assumed $k_2 = 0.9$).

The rotational speed of the working drum was calculated according to the following formula:

$$n_r = n_1 \cdot i_1 \cdot i_2 \quad [1/min] \tag{2}$$

Linear speed of cutter tips was calculated as follows:

$$v_r = \frac{\pi \cdot R_r \cdot n_r}{30} \quad [m/s] \tag{3}$$

Power on the working drum ($P_r$) was calculated as follows:

$$P_r = (P_1 - P_j) \cdot \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 \quad [kW] \tag{4}$$

where:

$\eta_1$ – efficiency of the two Cardan couplings and the telescopic coupling,
$\eta_2$ – T-transmission effciency,
$\eta_3$ – efficiency of two Cardan couplings,
$\eta_4$ – chain transmission effciency.

The following coeffcient values were adopted: $\eta_1$ = 0.96, $\eta_2$ = 0.95, $\eta_3$ = 0.98 and $\eta_4$ = 0.92.

The torque on the working drum was calculated as follows:

$$M_r = \frac{P_r}{\omega_r} \quad [Nm] \tag{5}$$

where:

$\omega_r$ – angular velocity of the working drum, 1/s $\omega_r = \pi \cdot n_r / 30$, 1/s.

The sum of circumferencial forces $\Sigma F_r$ on cutter tips was calculated as follows:

$$\Sigma F_r = \frac{M_r}{R_r} \quad [N] \tag{6}$$

The circumferencial force $F_r$ on one cutter tip was calculated based on the assumption that 3 out of 8 cutters on the side surface of the working drum hit the ground and the total number of cutters was 93.

$$F_r = \frac{\Sigma F_r}{z \cdot \frac{3}{8}} \quad [N] \tag{7}$$

## RESULTS

Based on the formulas presented above, the following figures characterizing the process of milling were calculated (Table 2).

The theoretical productivity of the milling of logging residues was 0.22 ha/h.

Table 2. Technical parameters calculated for the crusher
Tabela 2. Zbiorcze zestawienie określonych parametrów technicznych rozdrabniarki

| Parametr<br>Parametr | Symbol | Unit<br>Jednostka | Value<br>Wartość |
|---|---|---|---|
| Theoretical productivity*<br>Teoretyczna wydajność* | $W$ | $m^2$/h | 2 205 |
| Rotational speed of the working drum<br>Prędkość obrotowa wału roboczego | $n_r$ | 1/min | 546 |
| Linear speed of cutter tips<br>Prędkość obwodowa wierzchołków zębów roboczych | $v_r$ | m/s | 14.87 |
| Power on the working drum<br>Moc na wale roboczym | $P_r$ | kW | 96.86 |
| Torque on the working drum<br>Moment obrotowy na wale roboczym | $M_r$ | Nm | 1 694 |
| Angular speed of the working drum<br>Prędkość kątowa wału | $\omega_r$ | 1/s | 57.18 |
| Sum of circumferencial forces on cutter tips<br>Suma sił obwodowych na wierzchołkach zębów | $\Sigma F_r$ | N | 6 515 |
| Circumferencial force on one cutter tip**<br>Średnia siła obwodowa przypadająca na jeden ząb** | $F_r$ | N | 187 |

*The tractor speed was: $V_j$ = 1.4 km/h.

**The average force per one cutter was calculated, based on the assumption that three out of eight cutters in one line on the drum were hitting the residues.

*Zmierzona prędkość jazdy wynosiła: $V_j$ = 1,4 km/h.

**Średnią siłę obwodową przypadającą na jeden ząb roboczy obliczono, zakładając, że chwilowo pracują trzy zęby z ośmiu leżących w jednej płaszczyźnie na bębnie roboczym.

## CONCLUSIONS

1. The field observations and analysis of the process of the milling of logging residues showed, that the phenomena occurring during that process are very complicated, with reference to various physical and chemical properties of the milled materials.
2. The theoretical productivity of milling was 0.22 ha/h and was close to the average value observed in the forest district, where the tests were carried out.
3. At the working drum rotational velocity of 540 rpm ($\omega_r$ = 57.18 1/s), assuming that 16% of the tractor's power was used for driving, the average force on one cutter was about 200 N. The instantaneous forces may however, reach values which are even several times higher, when the cutters hit unyielding objects like stones or hard stumps.
4. The linear velocity of the cutter tips was about 16 m/s, compared to very limited driving speed of the tractor (0.39 m/s).

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## MECHANIKA ROZDRABNIANIA POZOSTAŁOŚCI ZRĘBOWYCH MASZYNĄ MERI CRUSHER MJS-2,5 DT


**Streszczenie.** Obiektem analizy była rozdrabniarka Meri Crusher MJS-2,5 DT, która była agregatowana z ciągnikiem Valtra T-190. Rozdrabniarka o szerokości roboczej 2500 mm była agregatowana z ciągnikiem o mocy 190 KM. Określono ilość biomasy zawartej w pozostałościach zrębowych przeznaczonych do rozdrabniania, wydajność i pracochłonność rozdrabniania. Przy parametrach technicznych rozdrabniarki (prędkość obrotowa bębna, liczba elementów roboczych, średnica bębna roboczego, prędkość jazdy) wyznaczono prędkość obrotową wału roboczego, prędkość obwodową elementów roboczych, moc i moment obrotowy na wale roboczym oraz wydajność. Na podstawie analizy zjawisk występujących podczas pracy rozdrabniarki (analiza ruchu elementów roboczych) oznaczono sumę sił i średnią siłę obwodową przypadającą na jeden element roboczy.

Wykazano, że średnia siła obwodowa przypadająca na jeden element roboczy wyniosła około 190 N.

**Słowa kluczowe:** pozostałości zrębowe, rozdrabniarka, pracochłonność

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