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Analysis of wood chipping capacity of the Bandit 990XP chipper – case study

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Abstract: According to the data of the Central Statistical Office, there has been an increase in forest cover in Poland from 27.8% to 29.6% over the last 25 years. This increase contributed to an increase in the possibility of wood obtaining and processing for energy purposes. The aim of the study was to analyse the efficiency of a chipping machine manufactured by the American Company Bandit Industries (Bandit 990XP chipper) based on the working day chronometer. The study was carried out in specific conditions related to the place of the chipper application because the machine was used to process the material obtained from standing trees in the framework of park maintenance. As it was shown during the analysed working day, the effective capacity W_1 in the work cycle of the Bandit 990XP machine was 9.2 $m^3 \cdot h^{-1}$ chips. Specific working conditions made it impossible to organize the work smoothly. Ongoing obtaining of the material for chipping from standing trees resulted in low productivity during the exploitation time of the shift W_{08} on the level of 1.3 $m^3 \cdot h^{-1}$ chips.

Keywords: chipper; wood chips; efficiency; dendromass

Until the middle of the 19th century, wood was the main source of energy and construction material. Its economic significance was changed by the industrial revolution, creating a demand for fossil fuels. This trend changed when the negative effects of fossil fuels-based industrialization on the environment were noticed. The assessment of the use of forest biomass for energy purposes indicates high environmental benefits, especially through the impact on the favourable carbon balance (Ghaffariyan et al. 2012; Golos, Kaliszewski 2015; Tylek et al. 2017). The main source of wood biomass (dendromass) for energy purposes is forestry and the wood sector (wood, pulp and paper as well as furniture industries). The source of biomass is also municipal greenery management and agriculture (Parzych 2015). In Poland, after the political transformation in 1989, there has been an increase in the area of forests from 8 884 thousand ha (27.8% forest cover) to 9,434.8 thousand ha (29.6%) (Central Statistical Office 2017) An increase in the total area of forests in Poland contributed to an increase in the possibility of wood obtaining and processing from forests for energy purposes. State and private forests in Poland have huge wood resources, which produce very large amounts of raw material for the production of pellets, chips, building assortments, furniture, chipboards and many other materials related to the use of wood (Table 1).

The assumed commitments to generate electricity from renewable sources cause that the minimum

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Table 1. Wood chips obtained from the State Forests in Poland over the years (Central Statistical Office 2011, 2017; CILP 2017)

Year	2003	2005	2009	2010	2011	2015	2016	2017
Wood chips obtained (thousands per m^3)	223	228	80	120	176.3	193	265	92.5

share of agrobiomass which should be used in generating units where biomass is and will be burned is subject to an increase (in dedicated installations and power >> 20 MW, i.e., 20% in 2015, 40% in 2017 and 50% in 2019 and 2021) (Różański, Jabłoński 2015). The estimated supply of biomass for energy purposes (energy potential) in 2012 was at the level of 18.0 million m^3. In the forestry sector, wood biomass for energy purposes amounted to 6.8 million m^3, including 4.9 m^3 as S4 fuel wood and over 1.8 million m^3 of unused forest residues, about 6.5 million m^3 in the wood sector, 4.5 million m^3 in the municipal sector, including 20% of used furniture and 16% of the elements of used buildings and structures, while the economic potential of energy plantations was estimated at 14.8 million m^3, and 0.2 million m^3 of wood biomass was obtained in this way in 2012 (Parzych 2015). Acquisition of wood raw material for energy purposes is quite complicated, because it consists of many consecutive technological and transport activities, as well as activities related to the acquisition and transport of raw material. Individual processes can be performed on areas intended for storage and handling of raw material, directly in the forest or in power plants using the produced energy material (Sadowski et al. 2012; Pecyna et al. 2014). The evolution of the power industry in Poland has contributed to the development of technology allowing increased efficiency and facilitating the processes of assortment obtainment and processing for power generation purposes. This process is made possible by numerous specialized stationary or movable, hand-fed or whole tree chipping machines, which offer a wide range of possibilities depending on the application and destination of the produced material, such as chips (Więsik 2015). In the case of machines for wood processing for energy purposes, there is often a problem with classification and characteristics of basic components of working hours, divided into categories that characterize the activities performed at a given position. The introduction of uniform classification would greatly facilitate the development of common international strategies for the technical and technological development of forestry work, because measurements carried out according to different methods make comparisons difficult or even impossible (IURO 1995, Szewczyk 2014). The aim of the present study was to analyse the efficiency of a chipping machine Bandit 990XP chipper (Bandit Industries, Inc., Remus, Michigan). The chipper capacity was analysed based on working day chronometry.

MATERIAL AND METHODS

The Bandit 990XP machine analysed in the present study is used by the Company for Greenery Management and Maintenance in Krakow for the cleaning of urban areas, weeded areas and in urban parks. During the study, the machine was used in the park areas belonging to the Social Welfare Home in the Manor Complex in Owczary, in the Zielonki municipality, in the Krakow district. The material to be processed into chips was planned there in the form of dry branches prepared on an ongoing basis mainly from a significant number of historical trees located in the area of the centre. The Bandit 990XP (Figure 1, Table 2) used for chipping is, according to its manufacturer, a compact chipping machine designed for processing material up to 305 mm in diameter, mainly for municipal services, garden equipment rental and greenery maintenance companies. The machine of small dimensions and weight has a high capacity, and thanks to the use of a car tow hook and 3.2 t driving axle with 245/75R 16 tires it is included in the group of mobile chippers enabling work in any place. The machine has a small knife drum with a diameter of 610 mm and has its own drive in the form of Caterpillar Diesel engine (Bandit Inc. 2017). According to the study (Spinelli et al. 2013), this type of cutting unit is characterized by higher efficiency (about 8%), production of smaller chips, with higher fuel consumption per unit of production (up to 19%).

Apart from the chipper, the Wumag WT250 basket lift on the MAN 8.163 car and the MAN 8.163 tipping trailer to which the chipper was attached

Figure 1. Bandit 990XP wood chipper and the MAN 8.163 trailer (photo by P. Lipianin)

while transporting it from place to place were also used during the works (Figure 1). During the chronometry of the working day, a stopwatch was used to determine the time of arrival at the workplace, daily maintenance of the machine, and the passage of the machine to individual target workstations. Additional times accompanying the chipping process and the chipping process itself were recorded in the form of video material (Samsung Galaxy S7 Edge), which was then subjected to a time-lapse analysis in the computer (Windows Media player).

The course of the monitored working day after arrival at the workplace was started by the technical maintenance of the machine, and then it passed to the first workplace. Before chipping, the operator of the Wumag WT250 basket lift together with a sawyer obtained dry branches from standing trees. The main species from which dry branches were removed were European larch (*Larix decidua* Mill.), common maple (*Acer platanoides* L.), false acacia (*Robinia pseudoacacia* L.), common beech (*Fagus sylvatica* L.). For safety reasons, the Bandit 990XP operator kept a safe distance at the bottom of the chipper when cutting dry branches, which resulted in more downtime during operation. The branches were lifted to the chipper as soon as the elevator was lowered and stopped, manipulated or the sawyer in the basket was at a safe distance allowing the chipping material to be safely lifted. Branches were carried to or near the chipper throat prior to startup, minimizing fuel costs. The Bandit chipper was activated as soon as more dry branches were harvested and switched off as soon as they were chipped. At the time of the work completion on

Table 2. Technical specifications of Bandit 990XP chipper (Bandit Inc. 2017)

Parameter	Value
Capacity	305 mm (12”)
Width/height/length/weight	1.8 m/2.4 m/4.0 m/2,380 kg
Axle/braking system	Torflex/hydraulic with inrun
Tanks: fuel/hydraulic oil	81 l/45 l
Pressure in the hydraulic system	17.24 MPa
Hydraulic engine (2 pcs)	15.5 CID
Feeding roll (2 pieces): diameter/height	191 mm /416 mm
Hopper: height/width	736 mm/1,143 mm
Diameter of crushed material	305 mm
Throat size: height/width	390 mm/430 mm
Drum knife system: diameter/width	610 mm/476 mm
Number of knives/knife spacing on the perimeter	4/90°
Engine	63.25 kW (86 KM)

the site, the operators determined the next workstation of the machines in order to limit as much as possible the number of passes for the branches. The course of work at the subsequent workstations did not differ significantly from each other. The separation of chronometric components and the calculation of coefficients and indicators of working day utilization were done in accordance with the agricultural standards BN-76/9195-01 (1976), BN-76/9195-02 (1977), still often used in Poland (Szewczyk 2014). The following chronometric components were distinguished: effective working time of the machine, i.e., chipping T_1; auxiliary time T_2, which included disassembly of the chipper, preparation of the branches (drifting to the throat even on the operating chipper, adjusting the branches in the throat, cutting the raw material), idle passage to the branches (collecting), passage of the chipper to the next position; time of daily technical service T_3; time of removing technological and technical defects T_4; time of rest and meeting one's physiological needs T_5; transport time T_6 divided into travel time from the machine stop to the workplace and back T_{61} and travel time from one workplace to another T_{62}; daily maintenance time of accompanying machines T_7; time loss due to reasons beyond the machine under test T_8, and here the time loss due to organizational reasons T_{81}.

The following variables were calculated on the basis of the measured times:

T_{02} – operational time of the machine (Equation 1):

$$T_{02} = T_1 + T_2 \text{ (s)} \tag{1}$$

T_{04} – working time of the shift (Equation 2):

$$T_{04} = T_1 + T_2 + T_3 + T_4 \text{ (s)} \tag{2}$$

T_{08} – operational time of the shift (Equation 3):

$$T_{08} = T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7 + T_8 \text{ (s)} \tag{3}$$

The following variable were calculated on the basis of the working time balance:

– coefficient of operational time utilization (Equation 4):

$$K_{02} = T_1 \times (T_{02})^{-1} \text{ (–)} \tag{4}$$

– coefficient of working time of the shift utilization (Equation 5):

$$K_{04} = T_1 \times (T_{04})^{-1} \text{ (–)} \tag{5}$$

– coefficient of operational time of the shift utilization (Equation 6):

$$K_{08} = T_1 \times (T_{08})^{-1} \text{ (–)} \tag{6}$$

Using the working time balance of the machine, the effective capacity was calculated:

– effective capacity over the working cycle of the machine (Equation 7):

$$W_1 = V \times T_1^{-1} \text{ (m}^3\cdot\text{h}^{-1}) \tag{7}$$

– effectiveness in operational time (Equation 8):

$$W_{02} = V \times T_{02}^{-1} \text{ (m}^3\cdot\text{h}^{-1}) \tag{8}$$

– effectiveness in operational time of the machine (Equation 9):

$$W_{04} = V \times T_{04}^{-1} \text{ (m}^3\cdot\text{h}^{-1}) \tag{9}$$

– effectiveness in operational time of the shift (Equation 10):

$$W_{08} = V \times T_{08}^{-1} \text{ (m}^3\cdot\text{h}^{-1}) \tag{10}$$

At the end of the working day, the volume V_{ch} of chips on the vehicle bed was measured in order to calculate the volume of the assortment obtained V. The calculations assumed that 1 m^3 of forest chips (medium chips) corresponded to 0.5 m^3 of log wood harvested (Francescato et al. 2008).

RESULTS AND DISCUSSION

The chronometer of the five-hour working day of the chipping machine made it possible to specify the basic components of the operational shift time of the chipper (Table 3, Figure 2).

The effective time T_1 is low, the total working time of the chipping machine lasted only 43 minutes and amounted to 14% of the total working time of the chipper lasting 5 hours. This low value was affected by the large share of auxiliary time T_2, which constituted 20% of the total working time and lasted

Table 3. Working day components

Parameter	Result	Parameter	Result	Parameter	Result
T_1	2,580 s (43 min)	T_4	–	T_{62}	960 s (16 min)
T_2	3,660 s (61 min)	T_5	2,760 s (46 min)	T_7	–
T_3	900 s (15 min)	T_{61}	1,500 s (25 min)	T_8	5,880 (97 min)

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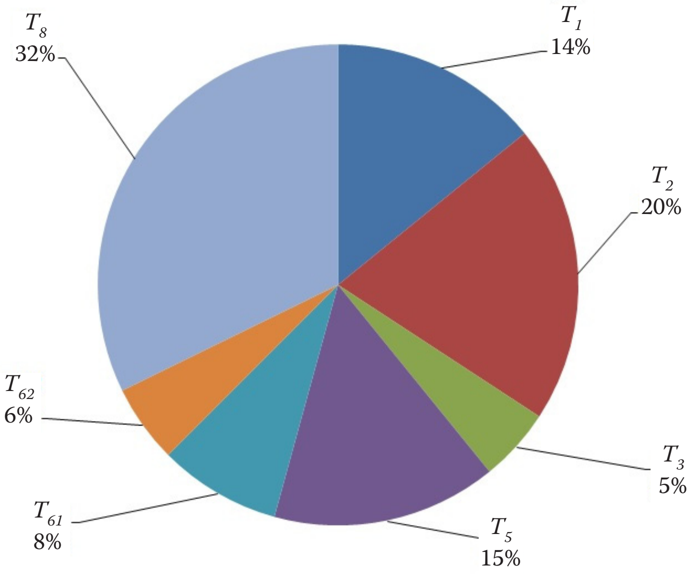

Figure 2. Percentage shares of individual components of the working time on a working day

T_1 – effective working time of the machine, i.e., chipping; T_2 – auxiliary time; T_3 – time of daily technical service; T_5 – time of rest and meeting one's physiological needs; T_{61} – travel time from the machine stop to the workplace and back; T_{62} – travel time from one workplace to another; T_8 – time loss due to reasons beyond the machine under test

a total of 1 h 1 min. This time included activities related to collecting branches (average diameter of the branches was 5 cm) and placing them in the chipper throat. Earlier preparation of the material would significantly reduce the time associated with branches collecting during the chipper work. On the other hand, the daily maintenance time for the Bandit 990XP T_3 was short, only 16 minutes, accounting for 5% of the total working time. There were no breakdowns during the work T_4, the machine was serviced on days preceding the work, it underwent a comprehensive technical inspection, which significantly influenced the failure-free work. The rest period T_5 was 46 minutes, or 15% of the total working time. Due to the difficulty of branch cutting from the hydraulic lift basket, workers needed more time to recover, which was also reflected in a long break for the chipper operator. Additional courses would allow workers to change between working positions that vary in difficulty levels. Transport T_6 consisted of the employees' getting to the workplace T_{61} and the passage of the chipping machine between successive positions (the chipping machine was fastened to MAN tipping trailer, the travel time applies to the entire set) T_{62}. Due to several days of work, the machine was left in the parking lot of the centre where the work was performed, so T_{61} takes into account only the employees' travel time, which was 25 minutes (8%), while the time of moving between workstations T_{62} was 16 minutes (6%).

Leaving the machine on the premises of the centre was a very good solution, because the time of arrival of a passenger car with employees is much shorter due to better mobility than in the set consisting of a tipper and a chipping machine. The vast majority of the working day (1 hour 37 min.) was a loss of time independent of the machine (T_{81}), and associated with the work of a sawyer, which accounted for as much as 32% of the entire working day. Such a large share of this time was caused by the fact that the branches to be chipped were systematically harvested from standing trees. During harvesting, the chipper operator had to keep a safe distance to avoid being hit by falling branches in order to maintain safety measures. The forced waiting time for the chipper operator ended only when harvesting was completed, followed by the possibility of collecting the chipping material in or near the chipping machine throat. The introduction of the two-team work system would significantly increase both the efficiency and profitability of the machine. While one of the teams would obtain raw material for chipping, the other would chip the material already prepared. The K_{02} operational time utilization coefficient is of low value, which was only 0.41, most of the operational time of the machine was not used effectively, which was caused by the high share of auxiliary time T_{02} in the operational time of the machine. Similarly, the K_{04} working time utilization coefficient is low at only 0.36, despite no failure during the whole day of machine operation working time T_{04}. The coefficient of utilization of the total exploitation shift time K_{08} is only 0.14. The total volume of wood chips V_{ch} harvested on the working day was 6.6 m^3,

Table 4. Machine working day balance

Parameter	Result	Parameter	Result	Parameter	Result
T_{02}	6,240 s (1h 44 min)	K_{04}	0.36	W_1 (V/V_{ch})	4.6/9.2 $m^3·h^{-1}$
T_{04}	7,140 s (1h 59 min)	K_{08}	0.14	W_{02} (V/V_{ch})	1.9/3.8 $m^3·h^{-1}$
T_{08}	18,240 s (5h 8 min)	V_{ch}	6.6 m^3	W_{04} (V/V_{ch})	1.7/3.3 $m^3·h^{-1}$
K_{02}	0.41	V	3.3 m^3	W_{08} (V/V_{ch})	0.7/1.3 $m^3·h^{-1}$

while the volume of wood raw material harvested V was 3.3 m^3 (Table 4).

The theoretical processing capacity of wood raw material W_1 in the effective working time of the machine was 4.6 $m^3·h^{-1}$ (9.2 $m^3·h^{-1}$ of wood chips harvested), while the processing capacity of wood raw material in the operational working time W_{02} is only 1.9 $m^3·h^{-1}$ (3.8 $m^3·h^{-1}$ of wood chips) and it is not a satisfactory result. The efficiency of raw material processing in the general, operational, working time of the machine W_{08} is low amounting to only 0.7 $m^3·h^{-1}$ (1.3 $m^3·h^{-1}$ chips), similarly like the effectiveness in the operational time of the machine W_{04} – 1.7 $m^3·h^{-1}$ (3.3 $m^3·h^{-1}$ of wood chips). It should be noted that low productivity is influenced by many factors. Research shows that the efficiency of chipping machines is affected by the size of individual parts of the chipped tree, species, material moisture content, sharpening of cutting knives (Kováč et al. 2011; Spinelli et al. 2013) and work organization (Röser at al. 2012). The system of the work applied and the high level of difficulty in carrying out sanitary work on standing trees were of key importance in this case, as well as the length of the working day, only 5 hours. Extending the working day to 8 hours would significantly increase the profitability of the machine, however, provided that a second break is introduced or an employee working on a chainsaw is replaced. The work organization could also be changed so that the individual operations will not interfere with each other by preparing the material for chipping. The performance obtained at the operational shift time W_{08} is difficult to compare with the information provided for other machines due to poorly described operating conditions and the way the effectiveness is determined. For example, according to the manufacturer's data, a Teknamotor Skorpion 350 SDB chipper of similar power has an output of up to 16 $m^3·h^{-1}$ (Teknamotor Inc. 2019). In turn, for the Heizohack HM5-400 machine of similar power for the processing of birch trees with the diameter of 10 cm, the output was determined at 2.97 $m^3·h^{-1}$, for the processing of pine trees with the diameter of 10 cm it was 2.97 $m^3·h^{-1}$, while for the processing of 17 cm it was 4.41 $m^3·h^{-1}$ (Webster 2005). The capacity obtained in the course of the study does not differ from that given in the literature.

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CONCLUSION

Based on the chronometer of the working day, it can be concluded that:

(*i*) The operational working time T_{02} was only 20% of the monitored working day.

(*ii*) The daily technical maintenance time T_3 was short (5%) and included only the folding out of the machine, filling the tank and start up.

(*iii*) There was a long break T_5 (15%), which was necessary due to the difficulty of the sawyer work.

(*vi*) The place where the work was carried out was located at a considerable distance from the base. Due to several days of work, leaving the machines in place was advantageous as the share of transport time was only 8% on a working day.

(*v*) The effective capacity W_1 in the work cycle of the Bandit 990XP chipper was 9.2 $m^3·h^{-1}$ chips, while the processing capacity of wood raw material in the operational working time W_{02} was 3.8 $m^3·h^{-1}$ of wood chips, and effectiveness in the operational time of the machine was W_{04} 3,3 $m^3·h^{-1}$ of wood chips.

(*vi*) Working conditions made it impossible to organize work smoothly. Ongoing obtaining of material for chipping from standing trees resulted in a low coefficient of the working shift time utilization amounting to K_{08} = 0.14 and the efficiency during the working shift W_{08} was on a level of 1.3 $m^3·h^{-1}$ chips.

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(*vii*) The low capacity of the chipping machine in the working shift was also affected by the short working shift time (5 h).

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