INVESTIGATION OF VANE-TYPE RETHRESHER OF COMBINE HARVESTER

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Abstract. The volume and composition of the material in the tailings returns is directly responsive to the major combine settings, and dependent on the throughput (feedrate) and crop conditions. The research has shown that tailings returns frequently contain loose grain that does not need to be rethreshed. Loose grain in the tailings is more susceptible to damage when it is returned to an aggressive threshing cylinder or auxiliary rethresher. Published data by other authors showed some evidence that grain damage could be reduced with the use of an auxiliary rethresher instead of returning the tailings to the main threshing cylinder. The amount and composition of the tailings are considered sound indicators of how well a combine is performing. This paper deals with the investigation of structural and technological parameters of the vane-type rethresher in the combine harvester with the throughput of 8 $kg \cdot s^{-1}$. The field trials show that when the combine harvester is operating at low speed more of the threshed grain is passed to the rethresher which results in higher levels of damaged grain. Increasing the forward speed of the combine harvester from 2 $km \cdot h^{-1}$ to 5 $km \cdot h^{-1}$, causes the amount of tailings being fed into the rethresher to be reduced by half. Low throughput and its consequential grain damage can cause dramatic increases in combine losses. Grain damage is also dependent on the rotational speed of the rethresher rotor. High levels of damaged grain in the tailings indicate excessive speed of rethreshing or inadequate throughput. A laboratory experiment was conducted to substantiate the estimated rational value for the rethresher under investigation, namely 1300 min^{-1}. As the results and findings of the research show, this particular parameter of the rethresher located within the combine harvester should be adjusted depending on the operational conditions, as well as the type and characteristics of the crops being threshed. The power consumption was found to be dependent on the rethresher throughput. Changing the feed rate from 0.2 $kg \cdot s^{-1}$ to 1.0 $kg \cdot s^{-1}$ causes the power consumption of the wheat rethresher to increase from 1.53 kW to 2.44 kW.

Keywords: combine harvester, rethresher, grain damage, grain losses, tailings.

Introduction

The main performance quality indicators for the combine harvester are grain damage, grain losses resulting from threshing and cleaning as well as straw walker losses, and grain cleanliness (percentage of impurities in threshed grain collected in a grain tank). These indicators are associated with the technological adjustments of the working components in the combine harvester. To improve grain threshing, the cylinder speed is increased, whereas the clearance between the rasp bars and concave is reduced, which results in higher levels of grain damage. However, even making adjustments to these parameters does not make it possible for none of the threshing units produced so far to thresh out absolutely all grain. Even the threshing units built in the most up-to-date combine harvesters thresh out not all the grain from the ears, i.e., approximately 5-8 % of grains still remain in the ears [1]. The total percentage of the grain successfully threshed out in the header, feeder house and the threshing unit (the major percentage of grain) was found to the amount for 95-98 % [2]. The tailings fed into the cleaning shoe by the grain pan contain about 80-86 % of the threshed out grain, and 10-18 % of not threshed out crop ears [3]. The amount of not threshed out crop ears passed into the cleaning shoe of a combine harvester is dependent on the characteristics of crops being threshed, moisture content, and technological adjustments made to the cleaning shoe. The amount of successfully threshed out grain that is fed to the ear auger after the cleaning shoe (based on the data published by different researchers) is rather different, and normally ranges from 30 % to 55 % [4]. As far back as in 1975, it was found that in the combine harvester *SKD-5*, the tailings fed into the ear auger contained 30 % of threshed out grain, 43 % of not threshed out ears, 14 % of chaff, and 13 % of small cuttings of straw of the total mass [5]. For this reason, each combine harvester uses a system for rethreshing the crop ears. The following two main types of rethreshing systems exist: not threshed out ears are returned from the ear auger to the main threshing unit, where they are being threshed repeatedly together with the entire crop mass fed into the combine harvester; and (another option) not threshed out ears are fed from the auger to the auxiliary rethresher where they are threshed, and the threshed out mass is then directed to the end of the grain pan of the combine harvester. All the rethreshers cause damage to grain, and the level of grain damage depends on the design of the rethresher as well as the amount, composition and moisture content of the tailings fed into the rethresher. One of the major disadvantages characteristic to rotary rethreshers is not adjustable speed of the rotor, whereas the clearance between the rotor vanes and the concave can be varied only in a very small range. Another severe issue with rethreshing systems is that rather great portion of already threshed out (loose) grains enter the ear auger together with the tailings. The more threshed out grains pass into the auger, the higher levels of grain damage are found in the grain tank.

Returning tailings to the main threshing unit has also some disadvantages as follows: it reduces the intensity of the threshing and separation processes due to extra loading, and causes grain damage; micro damages were found to amount for 30 % of the threshed out grain that have been rethreshed together with the crop flow fed from the feeder house [4]. These combine harvesters that have rethreshers built in for rethreshing previously not threshed out crop ears feature lower levels of grain damage [4; 6; 7]. The main reason of grain damage is the so called circular load when a major percentage of tailings containing threshed out grain are continuously returned for rethreshing [8; 9]. For this reason, the productivity of the combine harvester decreases and the grain quality indicators decline. I. Skvorcov suggested that the amount of loose grain should be controlled before the tailings enter the rethresher, as well as in its threshed out crop flow [10]. For this purpose, the piezoelectric sensors were installed, and their readings were used for making adjustments of the combine harvester. The above-mentioned control system enabled to increase the throughput of a combine harvester by 7 %, and to reduce grain losses by approximately 10 % [10]. Depending on the work efficiency of a combine harvester, one (for example, in *Sampo Rosenlew*, *New Holland*, Russian combine harvesters, etc.) or two rethreshers are used (for example, in higher efficiency of *New Holland* combine harvester models *CX* and *CR*). Combine harvesters made in Russia (*Don-1500, Vector, Torum, Acros*) are built-in with a single rotary vane-type rethresher (having 3 rotating massy vanes and concaves of two different types), whereas the rethresher of the combine harvester *Jenisiej-1200* is comprised of 6 rasp bars, the cylinder with the diameter of 280 mm, and the concave. The linear speed of the rethresher built in *Don-1500* series combine harvester amounts for 23 m s^{-1} while being close to the speed of rasp bars of a threshing cylinder. Consequently, grains are subject to damage in the rethresher. Moreover, the concave wrap of the rethresher is as low as 85 degrees, which results in not threshed ears being rethreshed for a relatively short period of time, causing grain losses from rethreshing. S. Kornilov suggested the traditional rethresher to be replaced by the rotary-axial rethreshing unit. The rotor with the diameter of 20 cm was comprised of 3 parts each being responsible for tailings feeding, rethreshing and discharge, respectively. Its medium part was equipped with helical rasp bars; at the rotor speed of 500 min^{-1}, grain damage and losses were found to decrease [11]. Axial rethresher units were proposed by some other researchers, too [12], however this kind of mechanisms is more suitable for rethreshing seeds of grassy crops as they rub seeds instead of beating them out, which allows grain to suffer less damage [13]. For threshing legume grain crops and legume perennial grasses it was suggested to modify the structure of the ear auger instead of using an auxiliary rethresher, to make it capable of performing the function of pod rethreshing [14; 15]. The principle of rubbing crop ears has also been suggested by the researchers B. Kutepov and A. Krachalev [16]. The suggested unit has been comprised of two rolls installed at the end of the tailings elevator, rotating at different speeds. In this particular unit, instead of beating, the rethreshing is accomplished by pressing and rubbing, which allows grain to suffer less damage as the surface of the rolls is covered by the material featuring lower modulus of elasticity than that of grain. Each company involved in producing combine harvesters strives to develop the simplest possible, however advanced and effectively-working rethreshing units. Lithuanian fleet of combine harvesters, however, is still prevailed by aged combine harvesters *Don-1500* by *Rostselmash* and modern *Don-1500B, Vector, Acros*. These combine harvesters are equipped with the rotary vane-type rethreshers where the speed of the rotor cannot be adjusted.

The objective of the investigation – in pursuit of reducing grain damage in a combine harvester, it is purposeful to examine the influence of the structural and technological parameters of the rotary vane-type rethresher on the quality indicators of its performance.

Materials and methods

The object of the investigation – tailings of *Zentos* variety winter wheat (the portion of the crop mass threshed by the combine harvester and passed into the ear auger) and the rotary vane-type rethresher.

When crop ear rethreshers are judged on their energy consumption, research papers show that the rethresher of the combine harvester *Jenisiej-1200* uses 5.5 kWh·t^{-1} of energy for threshing 1 ton of grain, whereas the rotary vane-type rethresher of the combine harvester *Don-1500* uses only 3.6 kWh·t^{-1}, which is by 65 % less [17]. This was the reason behind selecting the vane-type rethresher of this particular structure for the experimental investigation.

For the purpose of the experiment, a stationary experimental rethresher unit was built. Figure 1 shows its schematic layout and general view. The unit was comprised of the tailings feeder with 2 m in length and 0.35 m in width, and the rethresher comprised of the rotor with the diameter of 0.35 m, having 3 vanes. The width of each vane was 0.145 m. The rotor of the rethresher was enveloped by the toothed concave at an angle of 85º. Our research used the rethresher concave of the series production with 12 teeths, as well as the experimental concave with 6 teeths.

Before the experiment, *Solid Works* software was used to find out a moment of inertia for the rotating components of the rethresher. The mass of the rotating components was found to amount for 15.7 kg, and the mass of a single vane amounted for 2.47 kg. The obtained moment of inertia characterizing inertia of the rotor for rotary motion amounted for 0.159 kg·m^2.

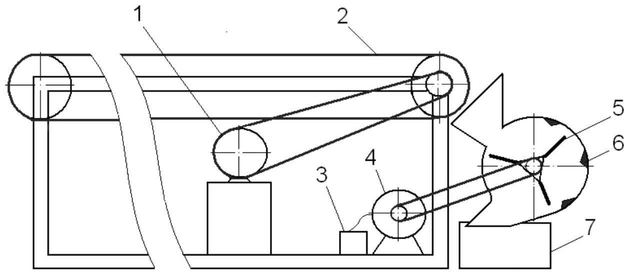

Fig.1. **Schematic overview of the structural parameters and performance indicators of the vane-type rethresher experimental unit:** 1, 4 – electric motors; 2 – belt-conveyor; 3 – power meter; 5 – rotor of the rethresher; 6 – toothed concave; 7 – tailings collection container

The rotor of the rethresher was rotated by 7.5 kW electric motor. The rotor speed was varied in range from 1100 min^{-1} to 1400 min^{-1} using the frequency converter *Delta VFD-8*. The speed of rotation was measured using the tachometer *Chauvin® Arnoux C. A. 1727* with range of measurement 100-10000 min^{-1} and reading error ±1×10^{-4} of the measured value.

The active power required for rotation of the rethresher rotor was measured using the electric power system analysis device *ME-MI2492 (Metrel)* with range of measurement of 0-150 kW, step value of 0.1 kW, and power measurement error of ±3 % of the measured value. The experiments used the standard concave with 12 teeths of the ear rethresher of the combine harvester *Rostselmash DON-1500B* (Fig. 2a) and the experimental concave with 6 teeths (Fig. 2b).

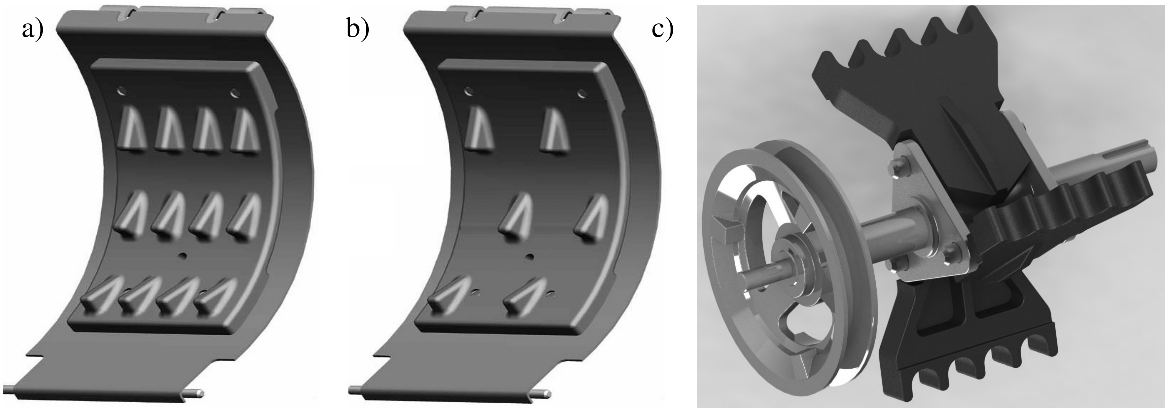

Fig. 2. **Concaves of the ear rethresher (a) and (b) and the rotor (c)**

Laboratory testing used tailings collected directly from the field while harvesting *Zentos* wheat. The tailings were collected at the ear auger of the combine harvester (through an opened cover of ear elevator) while the combine harvester travelled at the rational working speed of 4 km·h^{-1}, and under optimal adjustments (recommended and substantiated by research) of operational components of the combine harvester. The fractional composition of tailings used for the research was as follows: threshed out grain – 67.3 %, not threshed out ears – 2.5 %, and chaff with small pieces of straw – 30.2 %. The moisture content of the tailings was 14.39±0.91 %. The tailings were weighed using portable digital scale *CAS SW-1*. The tailings were evenly spread over a 2 m length conveyor belt and fed into the rethresher at the speed of 0.5 $m \cdot s^{-1}$. Broken, crushed and cracked grains were considered grain damage. In the laboratory, 5 specimens were collected, 100 g each, and analyzed. Damaged grains were weighed using digital scale *SCALTEC* (with reading accuracy of 0.01 g), and the average percentage of grain damage was calculated. Each experiment was repeated 3 times. The research findings were assessed using the methods of dispersion and correlation-regression analysis. Mean values, their standard deviations and confidence intervals with probability level of 0.95 were found.

Results and discussion

The amount and composition of tailings returned for rethreshing is dependent on specific adjustments of the combine harvester parameters, as well as on the amount and the characteristics of crops fed into the combine harvester. The experimental field trials showed that increasing the working speed of the combine harvester from 2 $km \cdot h^{-1}$ (feed rate of wheat q was 2.3 $kg \cdot s^{-1}$) to 5 $km \cdot h^{-1}$ (q = 5.7 $kg \cdot s^{-1}$) caused the amount of tailings in the rethresher to decrease almost by half. The percentage of loose grain (%) returned to the rethresher was also found to decrease, namely from 8.48±2.31 % to 3.90±0.88 %, when calculated as a percentage of all the grains entering the combine harvester in a particular period of time (Fig. 3.). Moreover, the level of grain damage in the grain tank was observed to have decreased from 0.56±0.15 % to 0.37±0.10 %.

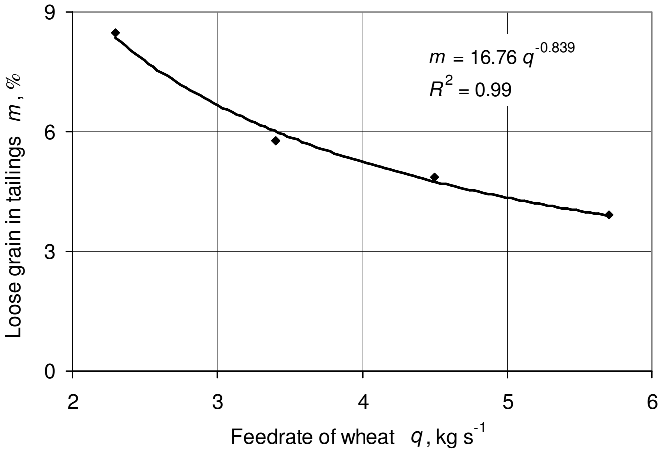

Fig. 3. **Influence of wheat feed rate of the combine harvester *q* to the loose grain part in the rethresher *m***

Investigation of the composition of tailings fed into the rethresher showed that when the feed rate of wheat to the combine harvester was 4.5 $kg \cdot s^{-1}$ (with the combine harvester travelling at the speed of 4 $km \cdot h^{-1}$), on the average, tailings entered the rethresher per second, containing 67.3 % of threshed out grain, 30.2 % of chaff 0.2 kg, and 2.5 % of grain not threshed out of ears. Tailings of this particular fractional composition were used in the following laboratory experiments.

When tailings were fed into the ear rethresher at the feed rate of 0.2 $kg \cdot s^{-1}$, and the rotor was rotated at the speed of 1400 min^{-1}, grain losses of the rethresher were kept at minimum, i.e., amounted for 7 % only (Fig. 4, the original concave with 12 teeths), however, grain damage amounted for 1.37 % (Fig. 5). Considering these two performance quality indicators of the rethresher, the rational speed of the rotor can be estimated to be 1300 min^{-1} (as grain damage is below 1 %). Replacement of the original concave with the experimental one with only 6 teeths caused grain losses of the rethresher to increase by 1.25 percentage point, whereas grain damage decreased by 0.18 percentage point (from 1 % to 0.82 %), when the rotor speed n was 1300 min^{-1}. When operating the 6-toothed concave, 1 % limit of grain damage is achieved at the rethresher rotor speed of 1350 min^{-1}, whereas when operating the 12-toothed concave, the same limit is achieved at the speed of 1250 min^{-1}. In both cases, grain losses of the rethresher amount for approximately 10 % of entire tailings fed into the rethresher.

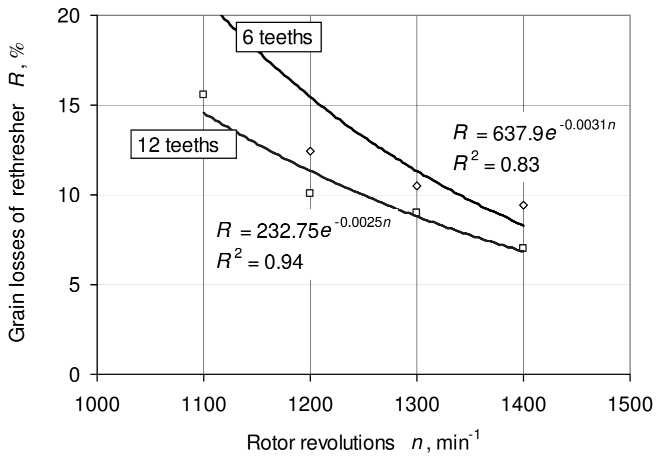

Fig. 4. **Influence of rethresher rotor revolutions *n* to the grain losses of the rethresher *R***

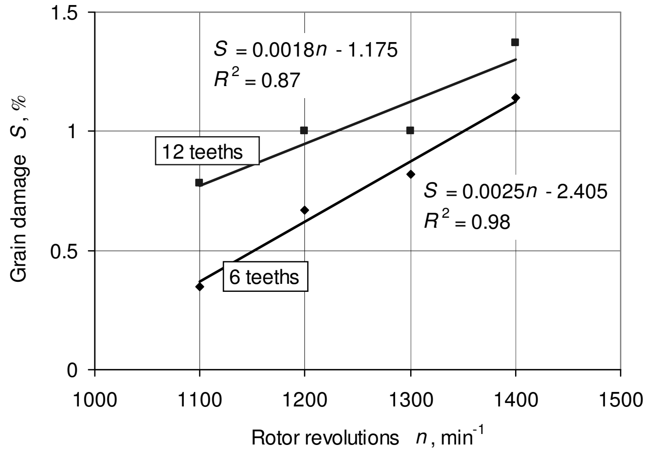

Fig. 5. **The influence of rethresher rotor revolutions *n* to the grain damage of the rethresher *S***

Increasing the feed rate of tailings in the rethresher from 0.2 kg·s^{-1} to 1.0 kg·s^{-1}, at the rethresher rotor speed of 1300 min^{-1}, resulted in the amount of grain damaged in the rethresher to be reduced by half (Fig. 6), however grain losses of the rethresher were found to increase as well, as they nearly doubled (Fig. 7).

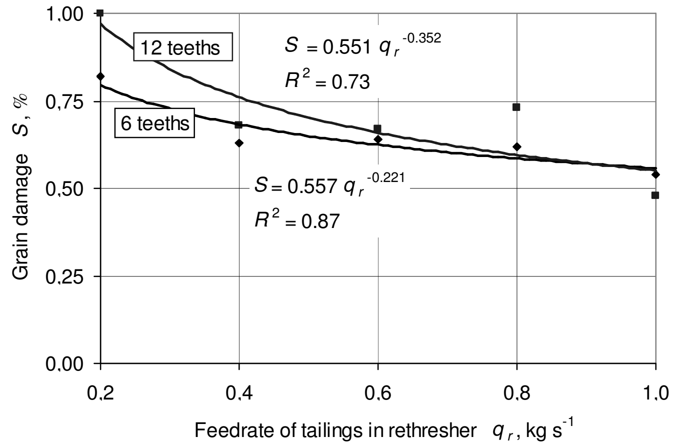

Fig. 6. **Influence of tailings feed rate in the rethresher q_r to grain damage *S***

The research showed that the power consumption required for rotation of no load rethresher rotor at the speed of 1300 min^{-1} amounted for 1.37±0.01 kW. When operated with tailings load, which was increased from 0.2 kg·s^{-1} to 1.0 kg·s^{-1}, the power consumption was found to increase, too (Fig. 8): increase in the amount of tailings 5 times caused the power consumption required for rotation of the rethresher rotor increased by 1.6 times (from 1.53±0.05 kW to 2.44±0.18 kW).

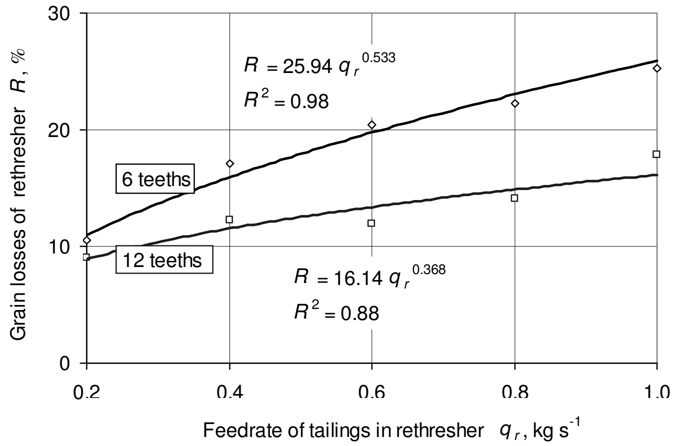

Fig. 7. **Influence of tailings feed rate in the rethresher q_r to the grain losses of the rethresher *R***

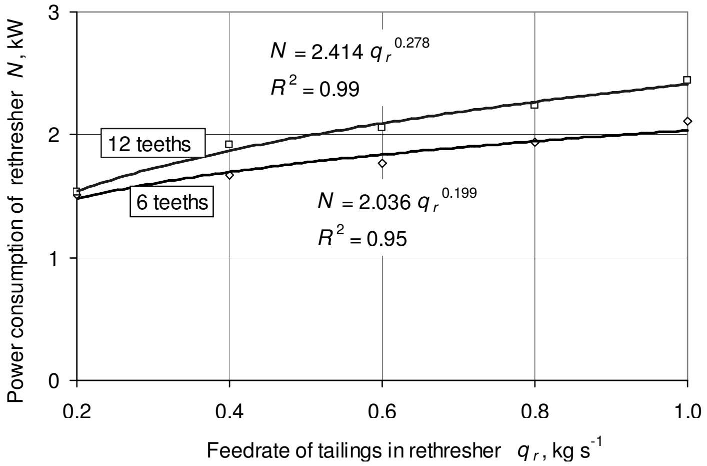

Fig. 8. **Influence of tailings feed rate in the rethresher q_r to the power consumption required for rotation of the rethresher rotor *N***

Conclusions

1. When harvesting wheat variety *Zentos* under rational forward speed of 4 km·h^{-1} (q = 4.5 kg·s^{-1}), on the average, 0.2 kg of tailings entered the rethresher per second, containing 67.3 % of threshed out loose grain, 30.2 % of chaff, and 2.5 % of grain not threshed out of ears.
2. The experimental concave with 6 teeths built in the combine harvester vane-type rethresher under investigation, when compared to the 12-toothed concave of series production, showed lower levels of grain damage, however slightly higher grain losses of the rethresher.
3. The rational speed of rotation of the rethresher rotor for wheat threshing was estimated to be 1300 min^{-1}. According to the research findings (and given the fact that combine harvesters are used to harvest a huge variety of agricultural crops each featuring different technological characteristics), the speed of rotation of the rethresher rotor should be adjusted (changed using variator or hydraulic motor).
4. The power consumption required for rotation of the rethresher rotor is dependent on various factors the major of them being load of tailings on the rethresher: increasing this load 5 times (from 0.2 kg·s^{-1} to 1.0 kg·s^{-1}) causes power need to increase by 1.6 times (from 1.53 kW to 2.44 kW).

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