EXPERIMENTAL INVESTIGATION OF SHREDDER CUTTER HEAD VIBRATION PARAMETERS

Mareks Smits, Eriks Kronbergs
Latvia University of Agriculture
mareks.smits@llu.lv, eriks.kronbergs@llu.lv

Abstract. Herbaceous energy crops will be the main basis for solid biofuel production in agricultural ecosystem in future. The main conditioning operation before compaction of herbaceous biomass compositions for solid biofuel production is shredding and milling. Naturally herbaceous biomass after harvesting is a material of low density ≈ 60 kg·m^{-3} and not favourable for transportation on long distances. Shredding can increase the bulk density to 280 kg·m^{-3}. For common reed shredding an experimental bale shredder Tomahawk 404 was used, which was equipped with a 37 kW electrical motor and inverter which changes the frequency in the range from 20 to 60 Hz. According to this frequency range, the velocity of the shredder rotor changes from 200 to 600 rpm. The aim of the experiment was to investigate the shredder cutter head vibration parameters in supply frequency range. It was stated that unladen (unloaded) cutter head bearing housing unit vibration acceleration depends on the rotor drive shaft second stage of rotational speed. The results of the experiments shows, that at the rotation speed of 200 rpm, acceleration values of unladen and laden (loaded) cutter head bearing housing assembly vibrations are the same. However, the speed of rotation 600 rpm loaded rotor bearing housing assembly vibration acceleration value is more than twice lower than the unladen rotor bearing housing assembly vibration acceleration value. Therefore, it can be concluded that in order to determine the maximum cutter head unbalance induced bearing housing assembly vibration acceleration values, they would be measured for unladen cutter head.

Keywords: biomass shredder, cutter head vibration.

Introduction

Using of herbaceous energy crops for energy production in Latvia is an important perspective because they can be cultivated on agricultural land and are not damaging drainage systems. Energy crops should first be recommended to grow on currently unused agricultural land. As shown by the Rural Support Service of Latvia, which conducted a survey of agricultural land in 2013, there are approximately 314 thousand hectares uncared for agricultural lands [1]. These lands must be mentioned as potentially disposable land resources for energy crop growing in addition to the number of all unused land. The quantity of cereal straw biomass, which can be removed without significantly affecting the carbon cycle, varies from 20 % to 50 % of the quantity of crop residue available – it is equal 174 000 tons of straw [2] annually in Latvia. It should be noted that only 20-50 % of the volume fraction of the straw can be used as fuel. The rest of the amount must reach the straw back into the soil as an organic fertilizer, in order to maintain the humus content in it. Beside the cereal and rape straw residues, reed canary grass (Phalaris arundinacea) is used for energy production. This mentioned herbaceous biomass usually by different balers is compacted in a shape of round bales. Due to the bulkiness of straw, baling compaction is important to reduce the necessary storage space requirements.

For further transforming these herbaceous biomass bales into shape of solid fuel briquettes or pellets the next necessary step is grinding (shredding) technology. Energy plant shredder prototype must provide a biomass particle size that is needed for further briquetting or granulation process. The particle size smaller than 3 mm is desirable to provide compacting processes. To obtain such particle size of the energy plant straw material, the shredder must contain a straw cutter head and further grinding unit. The impact method is used in grinding, where hammer blades rotate at a linear velocity of 5000 to 7000 m·min^{-1} [3] along a sieve with a mesh size which affects the acquired particle sizes. Such rotor cutter heads have to be balanced during entire term of their operation. Any disbalances of the cutter heads cause vibrations, which overload the shaft bearings and noise occurs in the shredder operation. Cutter rotor balancing, when it is mounted in the shredder, requires a sensor assembly montage on the bearing housing assembly. For subsequent grinding operations sensor signals are characterizing the bearing housing vibration values. The sensor signal can be used for cutter rotor speed controls, ensuring that the vibration levels do not exceed the permissible.

In this investigation new round bale shredder unladen cutter head bearing housing vibration parameters and vibration parameters are determined, when the cutter head is laden with common reed (Phragmites Australis) bundle shredding. For this reason the experimental round bale shredder was equipped with common reed bundle feeder mechanism. Latvian lakes are overgrowing with common reeds. Common reed biomass growth reached 10 $t \cdot ha^{-1}$ per year, and they are a valuable raw material resource for solid fuel production. Therefore, the aim of the investigation is to modify the round bale shredder for stalk material (reeds and hemp) bundle shredding.

Materials and methods

The modified new round bale shredder Tomahawk 404, equipped with the common reed bundle feeder mechanism (Fig. 1) was used for the experimental study of cutter head vibrations. The bundle feeder mechanism can be easy dismantled; therefore, this shredder is as a prototype for size reduction equipment of herbaceous biomass both in the shape of bales or bundles. The shredder was driven with a 37 kW electrical motor from inverter which changes the frequency in the range from 20 to 60 Hz. According to this frequency range, the velocity of the shredder rotor changes from 200 to 600 rpm.

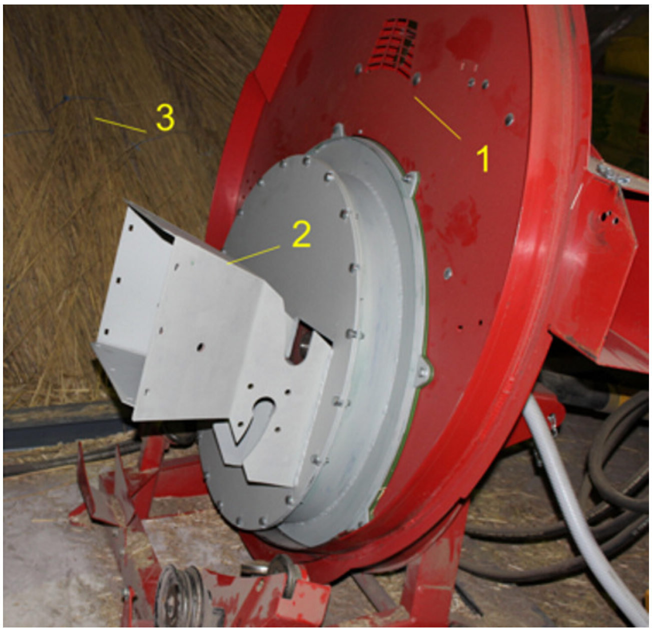

Fig. 1. **Modified bale shredder:** 1 – frame; 2 – bundle feeder mechanism; 3 – common reed bundles

The task of the experiments was to investigate the shredder cutter head two ball bearing 6211 RS housing vibration parameters in supply frequency range. For this reason vibration sensors were mounted (Fig. 2) on the bearing housing. On the cutter head rotary shaft 1 bearing housing 2 with permanent-magnet 3 a piezoelectric sensor 4 (VIB 6147) is mounted. The second permanent magnet 5 keeps the stand 6 with a laser - trigger sensor 7 (VIB 6631), the axis of which is oriented towards the reflective sticker 8, which is glued to the cutter rotor shaft 1. In order to successfully operate the sensor 7, the shaft 1 has black matte coverage. Both sensor cables 9 are connected to the SmartBalancer 2 field balancing unit and signal analyzer, using crimped guard tube 10. Installation is carried out so that the cables do not touch the rotating parts.

During the experiments SmartBalancer 2 is receiving signals from the mentioned sensors, recording and analysing them. For obtaining the cutter head shaft bearing housing vibration parameters SmartBalancer 2 is adjusted in “Analysis”mode.

The main obtained parameters:

- rotor bearing housing assembly vibration acceleration (Acceleration);
- rotor bearing housing assembly vibration velocity (Velocity);
- rotor bearing housing vibration displacement node (Displacement);
- rotor drive shaft rotational speed (Speed).

The SmartBalancer 2 operating program in “Analysis” mode performs readings of vibration parameters as Root Mean Square (RMS) values (see Fig. 3).

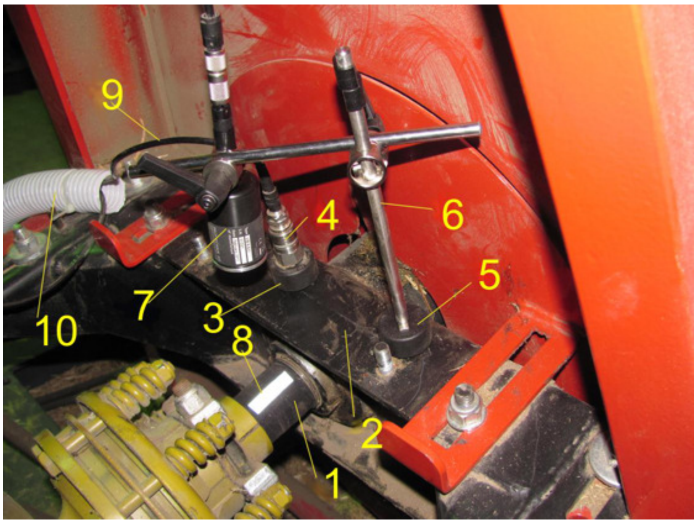

Fig. 2. **Vibration sensor montage on bearing housing**

The experiments were conducted in supply frequency range from 20 to 60 Hz from the inverter to the electric motor of 37 kW. According to this frequency range, the velocity of the shredder rotor changes from 200 to 600 rpm. The experiments were conducted in two stages:

- unladen cutter head,
- laden cutter head with common reed bundle shredding.

Common reed stalks with moisture 10 % and stalk material density 615 kg·m^{-3} were used in the experiments. Bundles with the height within 1.2-1.5 m, upper diameter – 0.08 m, lower diameter – 0.18 m were used in the common reed bundle cutting experiments.

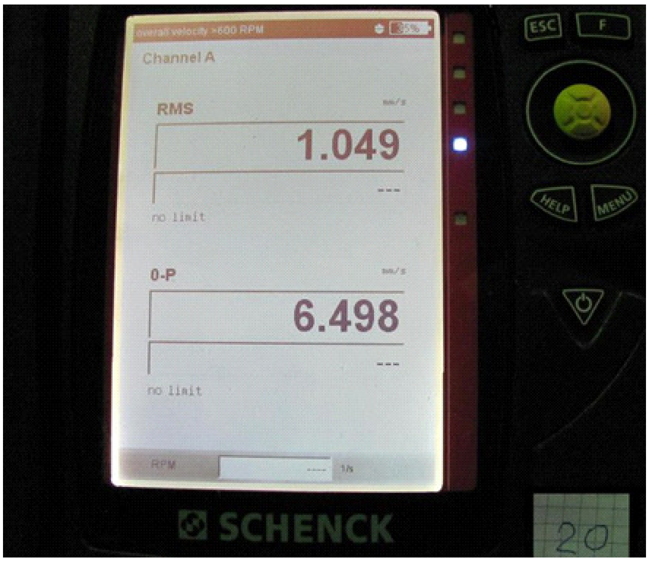

Fig. 3. **Example of vibration velocity (RMS) reading**

Results and discussion

From the experimental studies in unladen and laden shredder cutter head bearing housing assembly vibration acceleration root mean square (RMS) values, as the function of the drive shaft rotational speed, is shown in Fig. 4.

The graph shows that at a rotation speed of 200 rpm acceleration values of unladen and laden cutter head rotor bearing housing assembly vibrations are the same, but at the speed of rotation 600 rpm the loaded rotor bearing housing assembly vibration acceleration value is more than twice less than the unladen rotor bearing housing assembly vibration acceleration value. This can be explained by the shredding mass friction damping effect on the cutter head rotor. Therefore, it can be concluded that in order to determine the maximum cutter head unbalance induced to bearing housing vibration acceleration values, they should be tested for unladen cutter head rotor.

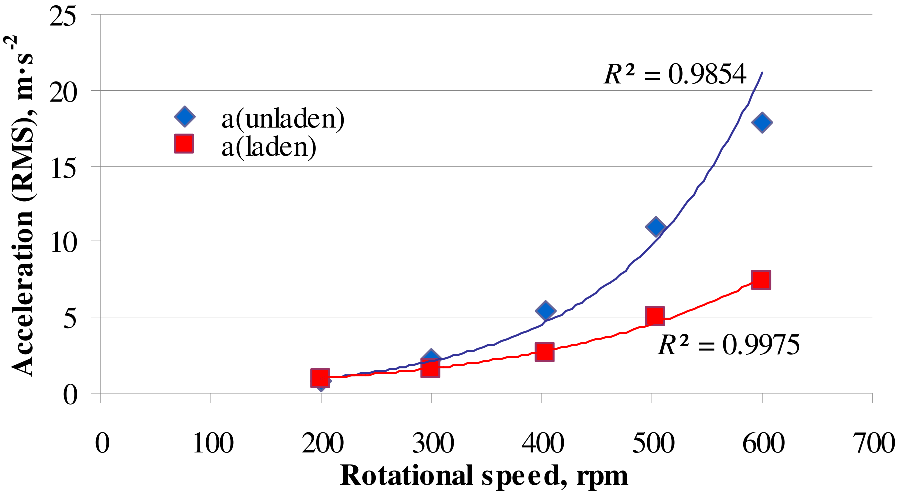

Fig. 4. **Cutter head bearing housing vibration acceleration (RMS) values**

Unladen and laden shredder cutter head bearing housing assembly vibration velocity root mean square values, as the function of the drive shaft rotational speed, is shown in Fig. 5.

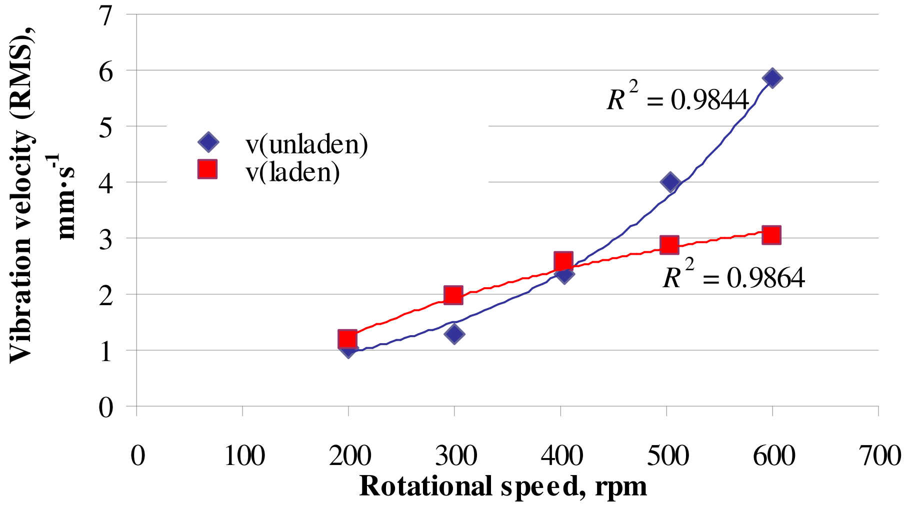

Fig. 5. **Cutter head bearing housing vibration velocity (RMS) values**

The graph shows that at a rotation speed of 600 rpm the laden rotor bearing housing assembly vibration velocity value is more than twice lower than the unladen rotor bearing housing assembly vibration velocity value. This may be similar to the previously explained shredding mass friction damping effect on the laden cutter head rotor. At the speed of rotation of less than 400 rpm the laden cutter head rotor bearing housing assembly vibration speed values are virtually indistinguishable from the unladen rotor vibration velocity values.

Unladen and laden shredder cutter head bearing housing assembly vibration displacement root mean square values, as the function of the drive shaft rotational speed is shown in Fig. 6.

From the graph (Fig. 6) it is evident that at a rotation speed of 600 rpm the laden cutter head rotor bearing housing assembly vibration displacement value is less than the unladen rotor bearing housing assembly vibration displacement value. However, the bearing housing vibration displacement value difference for laden and unladen cutter head rotor is not so significant as it is with the acceleration values.

According to the balance quality requirements [4] for a range of rotors of the same type, the rules of similarity apply for the rotor mass and rotor speed. The permissible residual unbalance is proportional to the rotor mass and inversely proportional to the service speed. It is possible to calculate the permissible residual unbalance for a new rotor size on the basis of a known one. Therefore, it can be concluded that the experimentally determined shredder cutter head rotor bearing housing vibration parameters may be used for evaluation of other new cutter head design permissible residual unbalance. Mounting of vibration sensors on the cutter head bearing housing and use of SmartBalancer 2 can be recommended for bearing wear monitoring because vibration spectrum and acceleration enveloping function analysis is included in the software.

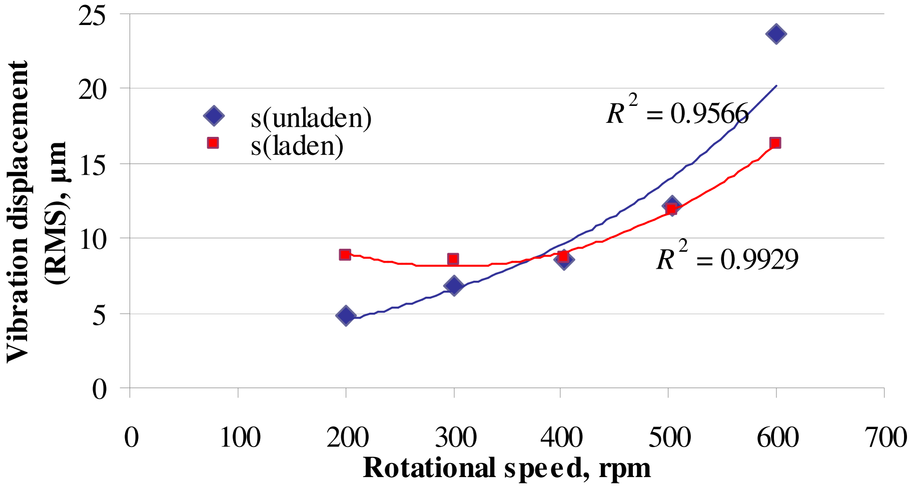

Fig. 6. **Cutter head bearing housing vibration displacement (RMS) values**

Conclusions

1. At a rotation speed of 200 rpm acceleration values unladen and laden cutter head rotor bearing housing assembly vibrations are the same, but at the speed of rotation 600 rpm the loaded rotor bearing housing assembly vibration acceleration value is more than twice less than the unladen rotor bearing housing assembly vibration acceleration value.
2. At a rotation speed of 600 rpm the laden rotor bearing housing assembly vibration velocity value is more than twice lower than the unladen rotor bearing housing assembly vibration velocity value.
3. The bearing housing vibration displacement value difference for laden and unladen cutter head rotor is not so significant as it is with the acceleration values. At a rotation speed of 600 min^{-1} the laden cutter head rotor bearing housing assembly vibration displacement value is less than the unladen rotor bearing housing assembly vibration displacement value.
4. The experimentally determined shredder cutter head rotor bearing housing vibration parameters can be used for evaluation of other new cutter head design permissible residual unbalance.

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