STRENGTH TESTING OF STRIPPING CYLINDER'S TOOTH
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ОПРЕДЕЛЕНИЕ ПРОЧНОСТИ ЗУБА ОЧЕСЫВАЮЩЕГО БАРАБАНА

Buryanov Alexey, Chervyakov Ivan, Kolin'ko Alexey [1]
Federal State Budgetary Scientific Institution «Agricultural Research Centre «Donskoy» / Russia
Tel: +79515253806; E-mail: bern7771@rambler.ru
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ABSTRACT
When designing stripping headers, an important parameter is the value of the required strength of the stripping tooth. A method and means for measuring the forces acting on the stripping teeth, necessary for strength calculations, are proposed. To illustrate the application of the proposed method, an example of determining the force acting on a tooth when stripping winter wheat of the "Luchezar" variety with a moisture content of 10.7% under specific conditions is given.

РЕЗЮМЕ
При проектировании очесывающих жаток важным параметром является величина необходимой прочности очесывающего зуба. Предложена методика и средства для измерения усилий возникающих на очесывающих зубьях, необходимых для прочностных расчетов. В качестве иллюстрации применения предложенной методики приведен пример определения усилия, возникающего на зубе при очесе озимой пшеницы сорта Лучезар влажностью 10.7% в конкретных условиях.

INTRODUCTION
At present the technology of tow harvesting becomes more popular as there aren't enough combines in the farms because of their high cost. The adoption of No-Till technology promotes it too. Producers and scientists in many countries work at designing and producing stripping reapers, validating their parameters and modes of operation. The use of the towing technology for grain harvesting leads to reducing harvesting time and increasing the productivity of machines by 1.5–2.0 times *(Dridiger V.K. et al.*, *2020)*. In addition, it allows reducing environment damage due to less emissions in the atmosphere since fuel consumption decreases to 40% *(Dridiger V.K. et al.*, *2020; Chegini G.R. and Mirnezami* S.V., *2016; Milyutkin V.A. et al.*, *2014; Siemens M.C. and Hulick* D.E., *2007; Yuan J. and Lan Y.*, *2007)*.

There is no precise information for calculation of tooth strength taking into account safety factor *(Lizhang X. and Yaoming* L., *2011)*. There are some works in which either the scientists of our institute or other authors determine the stress for wheat ear stripping. But there has been determined only the stress per one plant, drawn through the slit manually. In this case the speed of ear drawing was rather lower than if it took place in the real process. The towing technology for grain harvesting is used not only for wheat harvesting but also for other grain crops, which differ either by inflorescences forms and sizes or by other characteristics *(Aldoshin N.V. et al.*, *2016; Golpira H. et al.*, *2013)*.

Therefore, a number of scientists, who work at the adaptation of tow reaper for physical-mechanical properties of different crops and varieties and who suggest new forms and sizes of the stripping teeth and the stripping slit width, have to use the data about inflorescences destruction efforts that have been obtained by indirect methods *(Alabushev A.V. et al.*, *2020; Buryanov A.I. et al.*, *2018; Egorov* G.A., *1985; Chegini* G.R., *2013)*. As a result, the construction of the stripping tooth has had either excess or insufficient strength. When the stripping teeth with insufficient strength are used, they are bent or broken, depending on the metal they are made of; this leads to harvesting loses as tooth angle of inclination has been changed.

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[1] *Alexey Buryanov – d. tech. sc., professor, main research officer; Ivan Chervyakov – junior research officer*; *Alexey Kolin'ko– junior research officer*

The using of the stripping teeth with excess strength leads to the increasing of reaper's specific quantity of metal, its weight and, consequently, to cost increasing. In emergency situation, the holding teeth arrangement, including the stripping cylinder, may be broken because of the excess strength of the tooth. It involves the expensive repair or replacement of the stripping cylinder. Probably, there are a lot of things on the field that can lead to the damage of a reaper *(Chegini G.R. and Mirnezami* S.V., *2016; Savin V.Y.*, *2019; Savin* V.Y., *2020).*

Safety tests of the reaper with the teeth made of "soft" metal that is able to change its shape if a solid thing gets into the reaper have been performed. In this case their bending doesn't cause the structural damage of the stripping cylinder. In case when the teeth, made of excess strength steel 65G by 4 mm thickness, were used, the teeth had been broken and their sections had been cut off from the stripping cylinder and the cylinder itself had been partially broken. Moreover, neither the safety of the personnel nor that of the combine harvester is supported. The tests were carried out at the trailed tow reaper and they were recorded with the stationary video camera, fig.1.

Fig. 1 – Testing of the stripping unit safety using the excess strength tooth made of steel 65G

As you can see in fig.1, if the excess strength teeth collided with a solid thing, the integrity of the stripping cylinder was damaged, a number of teeth were cut off the cylinder, they flew out of the reaper and teeth parts could be reached at a distance of about 8 m. A deformation of the stripping cylinder was registered after inspection of the reaper's construction. One can say with certainty that using the excess strength teeth at the tow reaper is dangerous both for the personnel and for the other working parts of the harvester. Methods and means for measuring the stresses that appear on the stripping tooth, to further calculate the strength, are suggested.

MATERIALS AND METHODS

The laboratory setup was made for the experimentations; it was made on the basis of a laboratory setup for experimentations of grain stripping process which was patented as utility model *(Buryanov A.I., et al.*, *2014*), fig. 2.

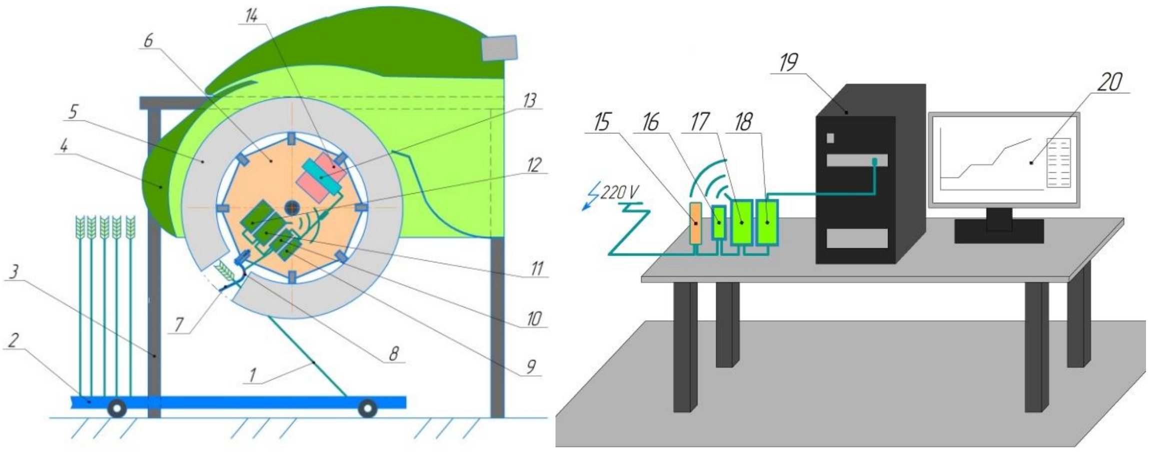


Fig. 2 – The laboratory setup drawing for determination of stripping tooth strength

Legend: 1 – stripped winter wheat plant (or other crop); 2 – movable field; 3 – laboratory setup supports; 4 – fairing; 5 – guide channel for combined plants; 6 – stripping cylinder; 7 – stripping tooth; 8 – strain sensor, fixed at the stripping tooth; 9-12 – measuring complex ZetLab; 13 – power element; 14 –counterweight for stripping cylinder's balancing; 15-18 – measuring complex ZetLab receiving the signal; 19 – personal computer (notebook); 20 – software package ZetLab

Laboratory setup (fig.2) consists of supports *3*, fairing *4* which is fastened on them, stripping cylinder *6* with guide channel *5*, measuring complex ZetLab which consists of *9, 10, 11, 12* blocks, power element *13* and stripping tooth *7* with strain sensor section *8*. A signal of measuring is conveyed through radio channel to the ZetLab complex receiving part *15, 16, 17, 18* and then to the PC *19*, where it is processed with ZetLab software package. A guide channel *5* is necessary for the plants to be headed strictly to the slit between the teeth after passing the tooth with the strain sensor *8*. The channel is made of transparent material, which makes it possible to watch the measurements and record them with a high-speed video camera. The camera Sony DSCRX 100M5 was used in this case.

The sections of the measuring complex were adjusted before the experiment. The strain sensor had been calibrated with the interval 5 N to 100 N. A dynamometer MEGEON-03020 and mechanical dynamometer were used for calibration. The process of calibration was made using ZetLab software; it allowed getting the signal recording in such units of measurement such as newton, at once. Update rate of the measuring channel was 1000 Hz, which is the maximal one for the measuring unit.

There are four blocks in the measuring complex ZetLab, made by the company LLC "Electronic technologies and metrology systems" (fig.3): autonomous recorder ZET 71733, smart strain sensor with interface CAN ZET 7111, smart interface converter radio channel CAN ZET 7172-S, power converter ZETLab 7001. Lithium-ion cell, which is fixed on the cylinder, supplies with power all the blocks. Counterbalances were used to decrease cylinder beating.

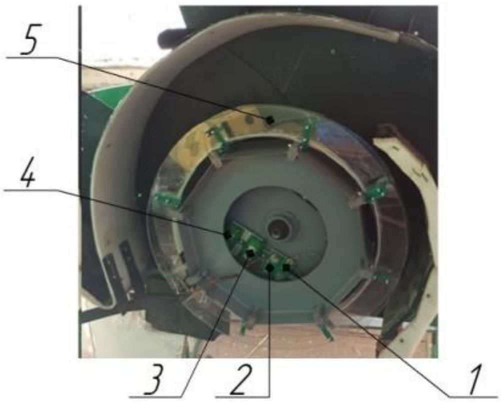


Fig. 3 – The laboratory setup drawing for testing the stripping tooth strength

1 – power converter ZET 7001, 2 – smart sensor with interface CAN ZET 7111; 3 – autonomous recorder ZET 7173; 4 – smart interface converter radio cannel - CAN ZET 7172-S; 5 – guide channel

Autonomous recorder ZET 7173 (fig.3) makes it possible to record a signal in a file ''.ana" during the measuring; a signal is recorded to internal memory with update rate 1000 Hz. The file of signal recording was copied on the PC for its further analysis in the software package "Statistica", ZETLab, Excel.

For the experiment, the movable field 2 (fig.2) was filled with winter wheat plants. The plants of winter wheat had been prepared before. The part of the field was chosen at a distance no less than 50 m from forest belts and roads. Cut plants were shaped into a bundle; a number of plants was counted according to the number of tests and the quantity of plants needed to determine humidity.

Average humidity of grain was measured by means of "Willi 65" device right before the testing.

The field part length was 4 m. Plants have been chosen according to the fairing, stripping cylinder height; there were 90 pcs per 1 movable meter.

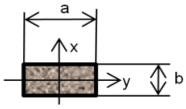
The stripping cylinder driver was turned on till its steady-state regime, then recording camera and driver of movable field were turned on, too.

It is possible to calculate the necessary tooth strength using the received data about the strength. Let us use simplified tabular procedure (*Anuryev V.I.*, *1979)* for this purpose, choosing the tabulated value for working stress when using alloyed hot-rolled steel 40CrNi (*Anuryev V.I.*, *1979)* of commercial quality at variable load from 0 to maximum and from maximum to 0 (pulsing) equal $\sigma_{bend} = 235.4$ N/mm^2.

$$M_{bend} = F_{max} \cdot l_{st.} \text{ , N·mm} \tag{1}$$

where:

F_{max} is maximal strength at stripping tooth, N; $l_{st.}$ is distance acting on a tooth, mm.

Resisting moment W for a tooth, a load acting on the axis X 

is (*Anuryev V.I., 1979)*:

$$W_{res.} = \frac{a \cdot b^2}{6}, \text{ mm}^3 \tag{2}$$

where a is tooth width, mm.; b is tooth thickness, mm.

Acceptable bending moment $M_{ac.bend}$ is (*Anuryev* V.I., *1979)*:

$$M_{ac.bend} = \sigma_{bend} \cdot W_{res.}\ , \text{ N·mm} \tag{3}$$

where σ_{bend} is working stress, N/mm^2; $W_{res.}$ is resisting moment, mm^3.

Load factor $K_{strength}$ then is (*Anuryev V.I., 1979)*:

$$K_{strength} = \frac{M_{ac.bend}}{M_{bend}}. \tag{4}$$

The load factor must be greater than 1. Then the strength of the tooth will be sufficient for stable operation.

RESULTS

Method of determination of the optimal strength on stripping tooth was tested under the following conditions and modes of operation:

- movable field speed was 0.9 m/sec.;
- width of the combing slit 8.0 mm;
- winter wheat variety "Luchezar";
- a number of plants, placed on 1 m of the movable field, – 90 pcs;
- length of the field part, filled with plants, was 4±0.1 m;
- winter wheat grains' humidity was 10.7±0.5%;
- 1000 grains mass 42.3 gm;
- plants' height up to ears was 0.77±0.03 m;
- average length of an ear was 0.083±0.004 m;
- height of the fairing low edge corresponded to the average height of plants to the ear 0.77 m;
- rotating frequency of the stripping cylinder – 40.1 sec.

Winter wheat plants were prepared before; the plants, having mentioned characteristics, were chosen so as to get average amount of strength, appeared at stripping.

The movable field speed and cylinder rotating frequency were chosen according to the measuring complex possibilities. Transit time of the stripped area – 4.3 sec. at the rotating frequency of the movable field 0.9 m/sec. and its length 4.0 m. Stripping cylinder performed 28 turns at rotating 40.1 sec., and stripping tooth met stripped plants 28 times, meanwhile the number of measuring points of the strength directly was 7; then the teeth moved the stripped heap. The length of the field's part was chosen according to the time of the video recording with the camera Sony DSC-RX100M5 at exposure 1/10000 and resolution (1920×1080 dpi). The results of tooth strength measured at mentioned parameters and plants characteristics are shown in fig.4.

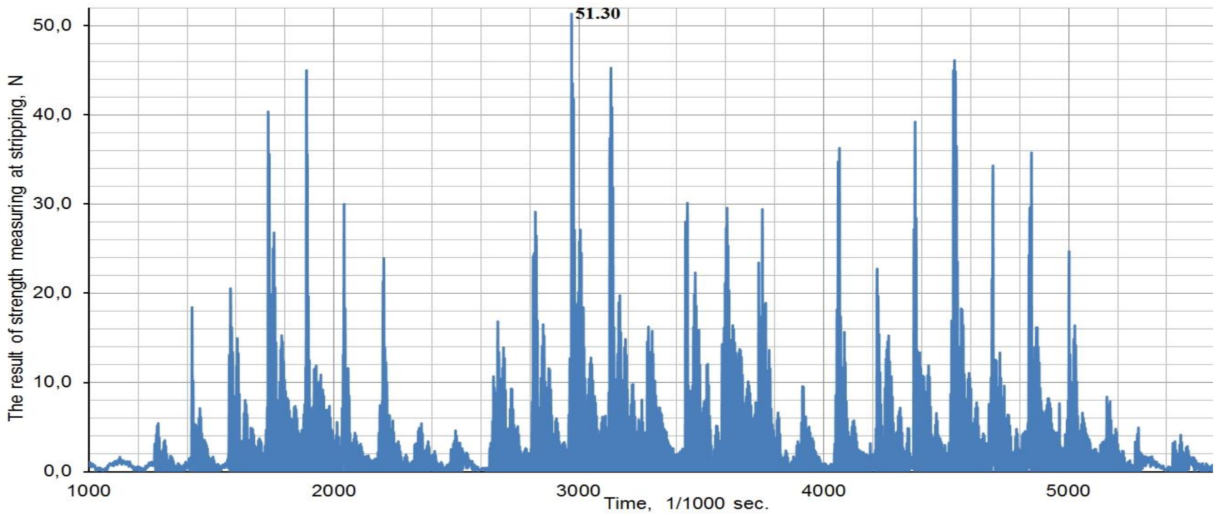
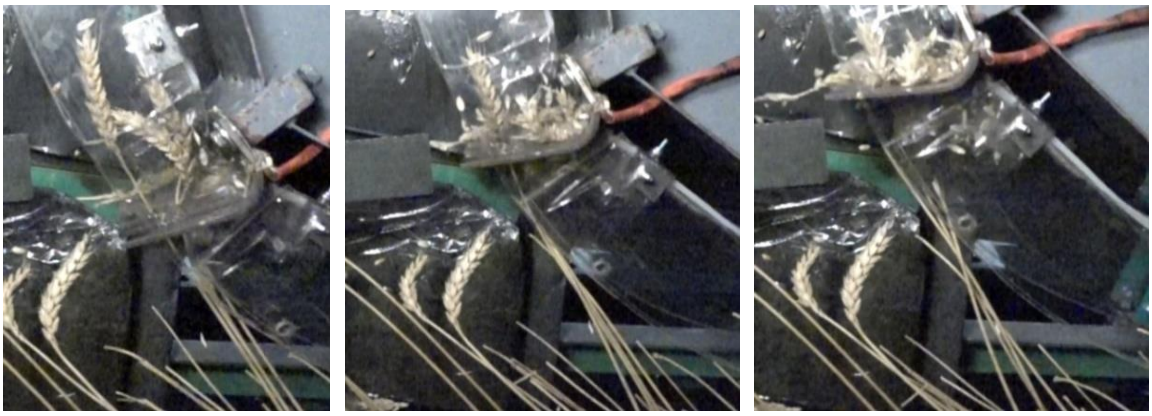


Fig. 4 – The result of stripping tooth strength measuring during winter wheat variety "Luchezar" stripping

The number of stripped plants was different and had random character at every cycle. Frames of speed video recording are shown in fig.5.



a) b) c)

Fig. 5 – The frames of tow process

Legend: a – plants gripping with stripping teeth; b – winter wheat plants tow by teeth; c – stripped heap displacement by teeth

At maximal strength $F_{max} = 51.3$ N (fig.4), acting on a tooth at a distance $l_{st.} = 50$ mm from a tooth, assuming that a tooth is a straight beam which is rigid at one side, maximal bending moment M_{bend} is (1):

$$M_{bend} = F_{max} \cdot l_{st.} = 51.3 \cdot 50 = 2565 \text{ N·mm}. \quad (5)$$

Resisting moment W for a tooth with a section a=16 mm, b=2 mm according to the formula (2):

$$W_{res.} = \frac{a \cdot b^2}{6} = \frac{16 \cdot 2^2}{6} = 10.7 \text{ mm}^3. \quad (6)$$

Acceptable bending moment $M_{ac.bend}$ according to the formula (3):

$$M_{ac.bend} = \sigma_{bend} \cdot W_{res} = 235.4 \cdot 10.7 = 2518.8 \text{ N·mm}. \quad (7)$$

Then, the load factor is (4):

$$К_{strength} = \frac{M_{ac.bend}}{M_{bend}} = \frac{2518.8}{2565} = 0.98. \quad (8)$$

As the calculation indicates, the strength of a tooth made of strip of steel 40CrNi with 2 mm thickness, when a tooth width is 16 mm, will be insufficient. Considering almost equal meanings of acceptable bending moment and maximal strength on a bend, one can say that, increasing tooth thickness to 3 mm, acceptable bending moment elevation will be obtained and load factor will exceed 1.0.

If *a=16* mm, *b=3* mm then:

$$W_{res.} = \frac{a \cdot b^2}{6} = \frac{16 \cdot 3^2}{6} = 24.0 \text{ mm}^3, \quad (9)$$

$$M_{ac.bend} = \sigma_{bend} \cdot W_{res} = 235.4 \cdot 24.0 = 5649.6 \text{ N·mm}, \quad (10)$$

$$К_{strength} = \frac{M_{ac.bend}}{M_{bend}} = \frac{5649.6}{2600} = 2.2. \quad (11)$$

In terms of the above, a stripping tooth, made of steel 40CrNi with 16 mm width and 3 mm thickness, is able to ensure the right working conditions. It should be noted that the strength of grain and ear bundle depends on humidity and variety of the crop that time; besides, it is necessary to repeat tests at different conditions. The suggested method and means of testing allow obtaining the necessary data to calculate the strength of the stripping tooth in all modes of operation and under different conditions. It will make it possible to achieve the required reliability and safety of the stripping unit without using the excessive solidity and metal intensity in the construction.

CONCLUSIONS

It is necessary to use a reliable information about occurring stresses on the stripping tooth making a calculation of stripping devices strength for qualitative and safe work. The stress should be obtained under different modes of operation and with different qualities of the harvested crops. The suggested methodology is recommended for strength determination that occurs at the cylinder's teeth of a reaper which is designed for a certain crop or their set, considering zonal conditions.

So, maximal stress on a tooth is 51.3 N when stripping winter wheat “Luchezar” with 10.7% humidity, feed 0.9 m/sec. rate, 40.1 sec^{-1} cylinder rotary speed, and, for the effective process of stripping, a tooth can be made of steel 40CrNi with 16 mm width and 3 mm thickness.

REFERENCES

[1] Alabushev, A.V.; Buryanov, A.I.; Pakhomov, V.I.; Kolinko, A.A.; Chervyakov, I.V., (2020), Development of a method to control threshing process based on properties of harvested crop variety and external factors, *IOP Conference Series: Earth and Environmental Science*, Vol. 422, no.1, 012005p, DOI: 10.1088/1755-1315/422/1/012005.

[2] Aldoshin, N.V.; Zolotov, A.A.; Tsygutkin, A.A.; Lynin, N.A.; Malla, Bahaa, (2016), Harvesting of mixed crops of grain crops by the combing method, (Уборка смешанных посевов зерновых культур методом очёса), *Bulletin*, *(Вестник)*, no.1, pp. 7–13;

[3] Anuryev, V.I., (1979), *Handbook of the designer - machine builder, (Справочник конструктора - машиностроителя)*, vol. 1, Mechanical Engineering, (Машиностроение), Moscow, 728p.

[4] Buryanov, A.I.; Buryanov, M.A.; Dmitrenko, A..; Kolesnikov, G.E.; Chervyakov, I.V., (2014), *Laboratory installation for the study of parameters and modes of the process of stripping grain crops*, RU, No. 136743.

[5] Buryanov, A.I.; Chervyakov, I.V.; Kolinko, A.A.; Pakhomov, V.I.; Ionova, E.V.; Khlystunov, V.F., (2018), Methods and results of determining the natural strength of the bond between grain and ear during ripening and full ripeness, (Методы и результаты определения естественной силы связи зерна с колосом в период созревания и полной спелости), *Grain economy of Russia*, *(Зерновое хозяйство России)*, Vol. 60, no 6, ISSN 2079-8725, pp. 21–25, DOI 10.31367/2079-8725-2018-60-6-21-25;

[6] Chegini, G.R., (2013), Determine of Optimum Operating Conditions of Combine Harvester with Stripper-Header, *World Applied Sciences Journal*, Vol.23, no.10, pp.1399–1407, DOI: 10.5829/idosi.wasj.2013.23.10.1829;

[7] Chegini, G.R.; Mirnezami, S. V., (2016), Experimental comparison of combine performance with two harvesting methods: stripper header and conventional header, *(CIGR Journal)*, pp. 192–200;

[8] Dridiger, V.K.; Gadzhiumarov, R.G.; Yagovitova, E.A., (2020), Harvesting of winter wheat by the brushing method in the No-till technology, (Уборка озимой пшеницы методом очёса растений в технологии No-till), *Achievements of science and technology of the agro-industrial complex*, *(Достижения науки и техники АПК)*, no 10, ISSN 0235-2451, DOI 10.24411/0235-2451-2020-11012.

[9] Egorov, G.A., (1985), *Technological properties of grain, (Технологические свойства зерна)*, Agropromizdat, (Агропромиздат), 334p.

[10] Golpira, H.; Tavakoli, T.; Baerdemaeker, J.D., (2013), Design and development of a chickpea stripper harvester, *Spanish Journal of Agricultural Research (*Span J Agric Res), Vol. 11, no 4, ISSN: 1695-971-X/eISSN: 2171-9292, DOI 10.5424/sjar/2013114-3393, pp. 929–934;

[11] Lizhang, Xu; Yaoming, Li, (2011), Modelling and experiment to threshing unit of stripper combine, *African Journal of Biotechnology*, Vol.10, no 20, ISSN: 1684–5315, pp.4106–4113;

[12] Milyutkin, V. A.; Strebkov, N. F.; Soloviev, S. A.; Makarovskaya, Z. V., (2014), Technical solutions for No-till and Strip-till technologies, (Технические решения для технологий No-till и Strip-till), *News of the Orenburg State Agrarian University*, *(Известия Оренбургского государственного аграрного университета)*, ISSN 2073-0853, pp.61–63;

[13] Savin, V.Y., (2019), Determination of the force required for stripping the wheat ear, (Определение усилий, необходимых для очеса колоса пшеницы), *Mordovia University Bulletin*, *(Вестник Мордовского университета)*, Vol.29. no.3, Russia, ISSN: 2658-4123, DOI:10.15507/2658-4123.029.201903.456-466456–466;

[14] Savin, V. Y., (2020), Determining the effort of barley stripping, (Определение усилия зачистки ячменя), *Gazette of the Moscow State Agricultural Engineering University named after V.P. Goretkin*, *(Вестник Московского государственного агроинженерного университета имени В.П. Горячкина)*, Vol.97, no.3, pp.17–21, DOI: 10.26897/2687-1149-2020-3-17-21;

[15] Siemens, Mark C.; Hulick, Donald E., (2007), Development of an Alternative, Reaper/Flail Based Harvesting System for Biomass Collection and No-Till Seeding - 2nd Year, *Electronic-only Proceedings of the International Conference on Crop Harvesting and Processing*, no 701P0307e, 13p, Louisville, Kentucky USA, DOI 10.13031/2013.22592.

[16] Yuan, J.; Lan, Y., (2007), Development of an Improved Cereal Stripping Harvester, *CIGR Ejournal*, Vol. 9.