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Method of justification of the grain cleaning assembly performance

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Abstract

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The performance potential of the existing grain cleaning assemblies meant for nominal and stable gross grain flow in view of the agrotechnical harvest time is not realized to the full extent. It is preconditioned by the instability of the technical and technological parameters of the harvesting processes. It results in a disproportion between the harvesting and the grain cleaning process, which is manifested in accumulation of bulks of grains within open areas in uncontrolled conditions or preconditions over-estimation of the rated performance of the grain cleaning assemblies. Their required performance can be decreased and the alignment of functioning of the process system can be increased by introduction of compensating and back-up components in view of the seasonal and daily performance indicators of the combine harvesters.

Keywords: service life of combines; performance of combine harvesters; harvesting process; grain flow rate; grain moisture content; storage hopper

Organization of the harvesting process largely predetermines the final crop output. The sophisticated and expensive harvesting and grain cleaning process requires an alignment of all the process links (Läänemets 2011; Pexa 2011; Akbarnia 2014). The hourly performance of the harvesting complex can vary throughout a day within a wide range and depends on the main natural and production factors, such as: technical condition of combine harvesters, transport support, crop yield, grain particle size and moisture content (Pugachev 1983; Kroulík et al. 2011; Risius et al. 2017). The variability of the total hourly performance of combine harvesters throughout a day poses special requirements to justification of the grain cleaning assembly performance. For alignment of the harvesting complex and the grain cleaning assembly performance in view of the natural and production conditions it is necessary to develop an economic and mathematical model based on the minimum cost criterion.

MATERIAL AND METHODS

The current production situation calls for an improvement of the methodological approaches to design engineering of the process system based on a uniform complex of harvesting, transportation and post-harvesting grain handling. At design engineering of the flow lines for post-harvesting grain handling the basis is generally formed by the average pro-

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ductivity of fields ignoring the technical equipment level of the harvesting complex and the weather conditions (Shepelev, Okunev 2006; Okunev 2011). The performance of the process line of harvesting and post-harvesting grain handling is unstable due to the fluctuations of the grain mass throughout the day (Bracacescu et al. 2012; Qiao et al. 2016; Wang et al. 2016). The performance of combine harvesters is considerably decreased in the morning and in the evening. In the modern conditions, in the hours, when the performance of combine harvesters reaches the maximum value, enterprises use a reserve area to ensure straight-line grain receiving. This results is expenses caused by additional transshipment operations in the open area (C_p^o) due to the misalignment in the performance of the harvesting and grain cleaning lines, which can be presented as follows:

$$C_p^o = C_T + C_c + C_o + P_d + C_l \quad (1)$$

where: C_T – transport expenses (RUB); C_C – open area construction and maintenance expenses (RUB); C_O – expenses on loading and reloading operations (RUB); P_d – damage caused by grain losses (RUB) (Tavakoli et al. 2009); C_l – labor costs (RUB)

Let us present the cost crop losses at application of the open area as follows:

$$P_d = Q_{tr}\left(1 - K_l\right)C_g \quad (2)$$

where: K_l – coefficient considering product losses caused by additional transshipment operations in the open area; C_g – cost of grain (RUB/t)

The grain volume subject to transshipment in the open area can be calculated by the graphical integration method:

$$Q_{tr} = \int_{t_1}^{t_2}\left(\frac{g(t) - z(t)}{gt}\right)dtQ_d^{hc}k_{tur} \quad (3)$$

where: t_1, t_2 – beginning and end of operation of the harvesting complex; $Q^{hc}{}_d$ – daily performance of the harvesting complex; k_{tur} – useful shift time utilization rate; $g(t)$ – function of the harvesting complex performance of time

Function of the harvesting complex performance of time depends on the moisture content, impurity, lodging, content of straw, yield of the grain mass, number of combine harvesters, shift time utilization rate, weather conditions and is described by the following equation:

$$g(t) = K_0 + K_1 t + K_2 t_2 + K_3 \exp(t) \quad (4)$$

The function of the grain cleaning assembly performance $z(t)$ of the time of operation is described by the following equation:

$$z(t) = K_0 + K_1 t + K_2 t_2 + K_3 \exp(t) \quad (5)$$

where: K – general linear regression coefficient

The specific technical equipment of the harvesting process is calculated by the formula:

$$N_{te} = \frac{N_c 1{,}000}{W} \quad (6)$$

where: N_c – number of combine harvesters (pcs); W – total harvested area (ha)

The hourly performance of the harvesting complex ($Q^{hc}{}_h$) is calculated by the expression:

$$Q_h^{hc} = 0.1\, Q_h^{ha} Y K_m T K_s K_{wc} N_c \quad (7)$$

where: $Q^{ha}{}_h$ – hourly performance of the harvesting assembly; Y – yield (t/ha); K_m – moisture-content coefficient of the grain mass; T – shift time (h); K_s – shift coefficient; K_{wc} – weather conditions coefficient

Considering Eq. (7), the harvesting complex performance will be as follows:

$$Q_h^{hc} = 0.1\, BVk_{tur} Y K_m T K_s K_{wc} \frac{WN_{te}}{1{,}000} \quad (8)$$

where: B – width of the grain head (m); V – combine harvester's speed (km·h^{-1})

The hourly performance of the grain cleaning assembly ($Q^{ca}{}_h$) depending on the grain moisture is described by the expression:

$$Q_h^{ca} = Q_p^{rp} K_m K_r K_z \quad (9)$$

where: $Q^{rp}{}_p$ – rated performance of the grain cleaning machines (t·h^{-1}); K_m, K_z, K_r – degradation factor due to the moisture content and impurity of the grain and the engineering reliability of the machines

When rather large grain volumes are received for handling it is expedient to use a compensating component in the form of an interoperable storage hopper, which will allow to partially break the rigid connection between harvesting and post-harvesting grain handling (Oko et al. 2010). Its volume (V_b) is calculated by the expression:

$$V_b = Q_p^{ca}\left(t_d - t_o\right) \quad (10)$$

https://doi.org/10.17221/14/2017-RAE

where: Q^{ca}_{p} – performance of the grain cleaning assembly (t h^{-1}); t_d – operation time of the grain cleaning assembly throughout a day (h); t_o – operation time of the harvesting complex (h)

A significant reserve to compensate the misalignment of the process links is installation of additional pre-cleaning machines. Max. efficiency of reduction in the expenses for the additional grain transshipment operations is achieved at the cost of the application of a complex variant of the grain cleaning assembly in conjunction with the storage hopper and grain heap pre-cleaning machines.

For justification of the grain cleaning assembly performance in view of the technical equipment it is proposed to use the following expression (Shepelev, Shepelev 2007):

$$Q_{TE} = \left(Q_r^{ca}\mu + B_b + B_b^{ca} + B_b^{cm} + B_h\right)\alpha + B + Z_{at}\left(\frac{f\left(\varepsilon\left(Q_r^{ca}\right)\right)}{Q_{tr}}\right) \Rightarrow \min \qquad (11)$$

where: $f(\varepsilon) = 0$, if $\varepsilon < 0$; $\varepsilon = Q_{tr} - Q^{r}_{ch}t_r - V - V_b$; t_r – operation time of the backup machines (h); *Qcar* – reserve performance of the grain cleaning assembly (t/h); μ – dependency of the balance cost of the backup grain cleaning assembly on its performance (RUB); B_b – balance price of the receiving apparatus (RUB); *Bcab* – balance price of a base grain cleaning assembly (RUB); B^{cm}_{b} – balance cost of the pre-cleaning machines (RUB); B_h – balance cost of the storage hopper (RUB); α – coefficient reflecting the distribution costs for the acquisition, physical deterioration and recovery machines and units depending on their life; *B* – conventionally proportional expenses (RUB); Z_{at} – expenses caused by the additional transshipment operations in the open area (RUB·ha^{-1}).

RESULTS AND DISCUSSION

Based on the Eq. (9) we calculated the influence of the technical equipment level of the harvesting process on the grain cleaning assembly performance. The simulation results have shown a dependency of the grain cleaning assembly performance on the number of combine harvesters of class 3 with the capacity of 5 kg·s^{-1} per 1,000 ha and the combine harvester's useful shift time utilization rate. It has been determined that with the increase of the technical equipment of the harvesting processes from one to three pcs·ha^{-1} the rated performance of the grain cleaning assembly is increased from 12 to 28 t·h^{-1} at the combine harvester's useful shift time utilization rate of 0.45 (Fig. 1). With the increase of the combine harvesters' useful shift time utilization rate from 0.45 to 0.65 the grain cleaning assembly performance is increased from 20 to 35 t·h^{-1} at pcs·ha^{-1}.

The statistical data collection and the production verification of grain cleaning assemblies when receiving products with compensating elements were carried out in agricultural enterprises of the steppe and forest-steppe zones of the Southern Urals.

Theoretical researches have shown that the assembly performance is considerably influenced by the shift time utilization rate, which, in its turn, depends on the service life of the harvesting assemblies (Shepelev, Shepelev 2007; Okunev et al. 2015).

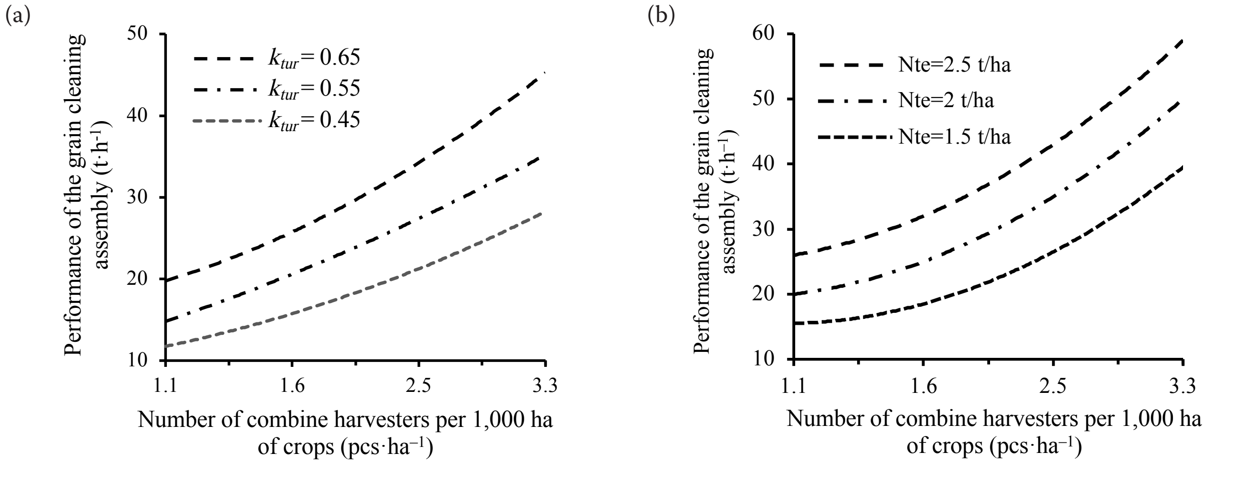

Fig. 1. Dependency of the hourly performance of the grain cleaning assembly on the technical equipment of the harvesting processes at (a) varied shift time utilization rate (k_{tur}) and (b) varied yield (N_{te})

https://doi.org/10.17221/14/2017-RAE

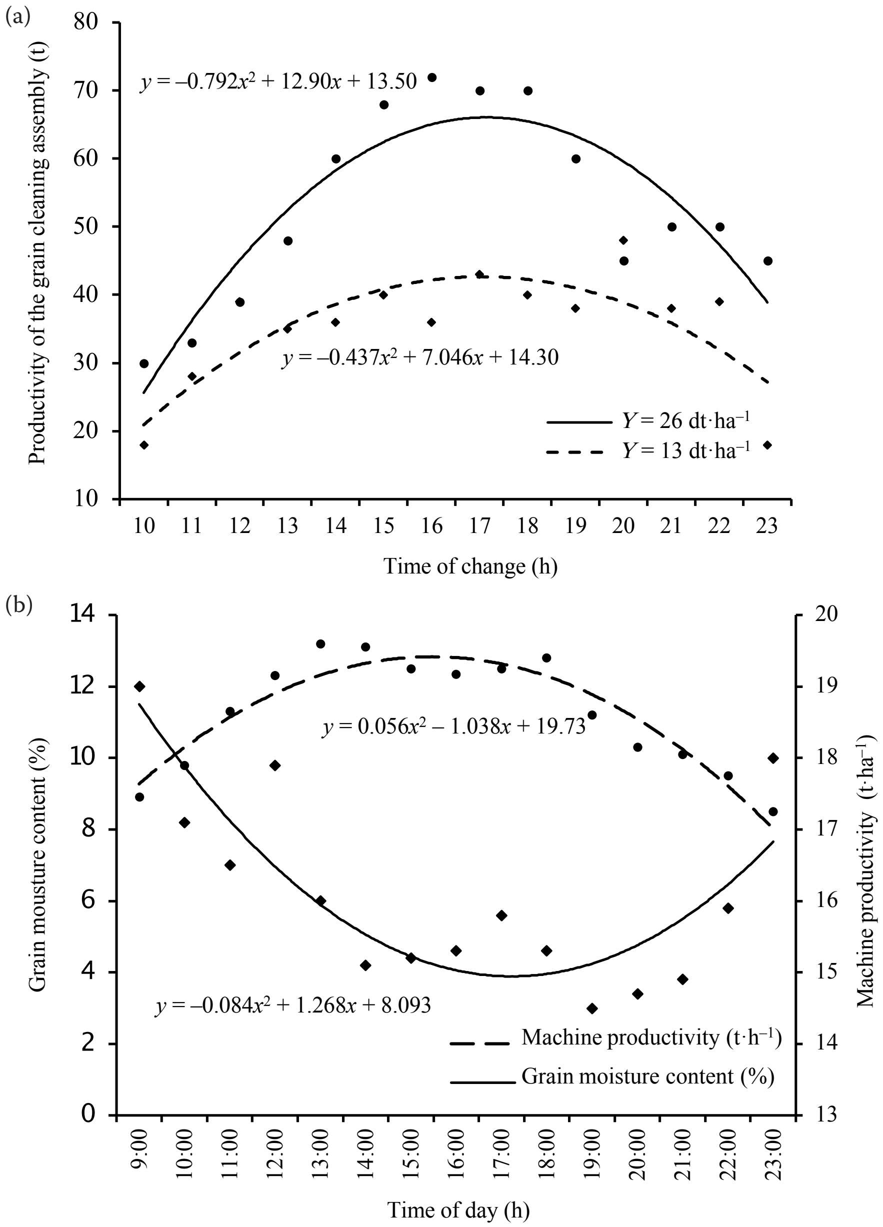

Fig. 2. Changes in productivity and grain moisture during a day of (a) the harvesting assembly and (b) the grain cleaning assembly

The statistical material having been analysed, we have obtained the regression equation of the dependency of the daily performance (Q_d) and the shift time utilization rate (k_{tur}) of the harvesting assemblies of class 3 on the service life:

$$Q_d = 5.3te^{-0.612t} + 11.6 \quad (12)$$

$$k_{tur} = 0.179te^{-0.612t} + 0.386 \quad (13)$$

where: t – the service life of grain harvesting assemblies

The analysis of the materials shows that with the increase of the service life of the harvesting assemblies from 2 to 10 years their daily output and the useful shift useful time utilization rate are decreased in 1.1 to 1.3 times.

To reveal the daily productivity fluctuations of harvesting-transporting and grain-cleaning lines, the statistical data were collected in the basic enterprises (Fig. 2).

The unevenness rate of fluctuations of the hourly harvesting-transporting line productivity is 0.93...0.96, with the variation coefficient being 32...33% and the shift time utilization rate of combine harvesters ranging within 0.50...0.62. The productivity of the grain cleaning assembly U12 2.4 PETKUS is established to reduce by 30% during morning and evening hours, with the variation

https://doi.org/10.17221/14/2017-RAE

coefficient averaging 23% and the unevenness rate of fluctuations being 0.81.

The decrease of the performance indicators of the combine harvesters when their service life increases is due to their technical availability decreasing (Shepelev et al. 2015). Therefore, when justifying their seasonal loading it is necessary to take into account their operational reliability. Thus, works Shepelev et al. (2016) and Shepelev et al. (2015) and Shepelev et al. (2015) contain recommendations to increase reliability of the combine harvesters due to repair and maintenance operations.

An expression to describe the dependence of the ZAV-20 shift time utilization rate (τ^{z}_{tur}) on the volume of the compensator is obtained:

$$\tau^{z}_{tur} = -0.0009V_b^2 + 0.017V_b + 0.358 \qquad (14)$$

where: V_b – volume of the compensating reservoir (t)

The production inspection showed that for a grain cleaning assembly with the 20 t·h^{-1} productivity, it is most reasonable to use a bunker-compensator with a volume of 100–120 m^3. In general, the use of bunker-compensators for grain receiving makes it possible to increase the utilization rate of a harvesting-transporting line during a season by 1.1–1.2 times and of the grain-cleaning assembly by 1.2–1.3 times, respectively (2b).

Due to the use of the bunker-compensator, it was possible to avoid losses of 50–60 t of products when cleaning and to increase the daily productivity of the grain cleaning assembly by 20%.

The regression equation of the shift time utilization rate of the grain harvesting-transporting line at different volumes of the compensating reservoir is the following:

$$\tau_{htl} = 0.21 \times V_b^{0.154} \qquad (15)$$

The productivity changes of the combine harvester assembly "Yenisei-1200" (Q_{ha}) and the grain cleaning assembly (Q_{ca}) during a day with 5% grain dockage is determined:

$$Q_{ha} = -0.04t^2 + 0.63t + 0.87 \qquad (16)$$

$$Q_{ca} = -0.06t^2 + 0.97t + 5.1 \qquad (17)$$

Thus, the experimental studies confirmed the theory on improving the construction of grain cleaning lines, their operating modes and the reasonability of used compensating and reserve technological elements to increase the daily productivity of the grain cleaning line by 25 to 30%. The introduction of the developed methods ensured an annual effect of agricultural enterprises up to 15–30 EUR/ha.

CONCLUSIONS

It has been determined that for each 1000 hectares of the harvested area the performance of grain cleaning assemblies of 5.0 to 6.0 t·h^{-1} and the volume of the compensating hopper of 40 to 50 m^3 are needed, at the specific technical equipment of the harvesting processes of 3 pcs per 1,000 ha. At alignment of the operational and technological parameters of the flow harvest line its performance is increased by 10–15% and the rated performance of the grain cleaning complex is decreased by 30–40%.

Thus, we have developed an economic and mathematical model, which allows to justify rational parameters of the grain cleaning assembly. The experimental researches in a production environment have proved the results of the theoretical researches.

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