The technological process of the grain harvester as a complex functional system

V I Orobinsky, V A Gulevsky and A M Gievsky
Voronezh State Agrarian University named after Emperor Peter the Great, 1, Michurina st., Voronezh, 394087, Russia
E-mail: gulevsky_va@inbox.ru

Abstract. The article discusses the technological process of grain harvesting and its movement inside the grain harvester. The assessment of the most characteristic operations causing micro- and macrotrauma of grain is given. The presented process is considered as the work of a complex system "environment-man-machine". An algorithm is proposed for determining the crushing and injury of grain behind the thresher of a grain harvester, which makes it possible to determine the level of its damage. The most promising ways of technological improvement of the cleaning process have been determined, which will reduce grain injury and improve its sowing quality.

1. Introduction
The key task of the agro-industrial complex of the Russian Federation has been and remains the production of grain. Increasing the yield of grain, leguminous and cereal crops, reducing losses during harvesting and post-harvest processing, improving the quality of seeds and marketable grain is inextricably linked with the development of advanced technologies and machines for harvesting and post-harvest processing using the latest scientific achievements and best practices. Harvesting of the grown crop and its post-harvest processing is the most difficult and time-consuming process in the general production cycle for the production of seeds and commercial grain.

The introduction into production of the latest technologies and improved grain harvesters and technical means for post-harvest processing of the grown crop at the present stage is the most important direction for improving grain-harvesting processes. In the XXI century, grain harvesters remain the main means for harvesting cultivated crops on the farms of the agro-industrial complex of Russia [1-4].

A sharp increase in the throughput of grain harvesters, a decrease in the level of injury and seed loss should be the main direction of design and technological developments. The quality of the products obtained depends precisely on the design solutions and technological parameters of the grain harvesters.

In order to increase the productivity of modern combine harvesters, a long-length rotor with a hydraulic drive is installed for direct unloading of biological mass. The feeding beater allows you to even out the flow of the grain mass and highlight foreign inclusions [2; 5]. The increased area of LSU helps to reduce the level of injury to seeds and increase their sowing qualities. Reversing to change the direction of rotation of the rotor allows you to move the crop in the threshing zone forward or backward.
Uniform feeding of the grain mass into the receiving chamber for threshing is ensured by undulating blades. Reducing the downtime of grain harvesters when unloading grain into vehicles is provided by the combine's bunker increased to 12 m³. A turbine fan provides a uniform pressure of the air flow, creating conditions for high-quality cleaning of the grain heap [2-5].

The crushing of grain is reduced to 0.6% due to the installation on modern combines MSU with a rotating rotor and deck in opposite directions, thereby providing a high degree of separation. The installation of two rotors rotating in opposite directions facilitates the threshing process and increases the efficiency of the separating surfaces, thereby increasing the cleanliness of the hopper grain.

It is known that the sowing quality of seeds depends on the moisture content of the harvested crop at the time of threshing and the degree of injury during harvesting and post-harvest processing [6; 9-11]. The quality indicators of the products obtained during harvesting and post-harvest processing depend on the characteristics of the functioning of the complex environment-machine-person system. With a systematic approach, the production process representing the functioning of a complex system can be divided into a number of independent operations performed by subsystems that have stable connections.

A careful study of these connections makes it possible for correct decision-making in order to increase the efficiency of the use of labor resources and operational management of the production process. In recent years, the solution to the problem of preserving sowing qualities, that is, reducing the level of injury to grain during harvesting and post-harvest processing on the technological lines of grain cleaning units and grain drying complexes, has gone along the path of improving the designs of grain harvesting equipment and technological lines. In the farms of the agro-industrial complex of Russia, various varieties of agricultural crops are grown and, in our opinion, insufficient attention is paid to the study of the strength properties of grain and the possibility of improving them. The physical and mechanical state of the grain at the beginning of the first operation depends mainly on external influences. The performance of subsequent operations depends on external and internal influences.

External and internal influences lead to an increase in the size of macro and micro traumas. With an increase in the number of operations, there is a sharp increase in their size, a decrease in the resistance of grain to destruction.

It is known that the state of grain at a given moment (time interval) depends on the amount and intensity of mechanical influences during the performance of the previous operations of the technological process, thus, in order to obtain high-quality seeds and marketable grain, the totality of all mechanical operations for cyclicity and so on should be considered as a single complex system.

2. Materials and methods

All elements involved in the course of the technological process during the operation of the grain harvester are a single whole. Each element of the technological process chain works for a common goal facing the system as a whole - obtaining the required quality of seeds and marketable grain.

The technological process of work of grain harvesters, grain cleaning units and grain drying complexes contains a number of operations of the production process (subsystems) performed by various elements (working bodies) of the system.

Figure 1 shows a block scheme of the technological process of a combine harvester. During the operation of the grain harvester, each operation is characterized by the content of unmilled grain (torn off, unmilled ears) - \( X_i \), freely threshed grain, coming off the ground - \( Y_i \), and grain allocated on the separating surfaces - \( Z_i \), as well as crushed \( D_i \) and injured grain - \( T_i \) [7-9]. The cut and fed grain mass passing through the harvester is threshed by various working bodies (mainly a threshing apparatus).

Studies [10-11] found that the amount of unmilled grain after the “i” operation will be equal to:

\[
x_i = x_{i-1} \cdot I^{-c_i - \beta_i}
\]
where \( c_i \) is a coefficient that takes into account the threshing of the grain mass due to the first blow of the working body; \( \beta_i \) - coefficient of intensity of threshing of the grain mass in the area of the working body; \( l_i \) is the length of the working body action zone.

\[
y_i = \left[ x_i - y_{i-1} (1 - l^{-c_i-\beta_i}) \right] I^{-\mu_l}
\]

(2)

Then the amount of grain spilled through the sieve will be equal to:

\[
z_i = \left[ y_i - x_i (1 - l^{-c_i-\beta_i}) \right] (1 - I^{-\mu_l})
\]

(3)

where \( \mu_l \) is the coefficient of grain separation through the separating surface; \( L_i \) is the length of the separating surface.

The coefficients \( c_i, \beta_i, \mu_l \) depend on the physical and mechanical properties of the harvested crop and the design and technological parameters of the working bodies.

3. Results

Equations 1-3 obtained as a result of the research carried out make it possible to determine the amount of grain to the working body in question in an unmilled and freely threshed form.

During the course of the technological process at the time of operation of the grain harvester, different amounts of grain with different levels of injury are supplied to various working bodies. When performing the operation under consideration, it’s crushing \( D_i \) and injury \( T_i \) as a percentage of the total is determined by formulas (4) and (5):
\[ D' = [x_{i-1} + y_{i-1} - 0.01(Dx_{i-1} + Dy_{i-1})]D_i \]  
(4)

\[ T' = [x_{i-1} + y_{i-1} - 0.01(Tx_{i-1} + Ty_{i-1})]T_i \]  
(5)

where \( Dx_{i-1}, Tx_{i-1} \) is the content of crushed and injured grain in unhilled ears; \( Dy_{i-1}, Ty_{i-1} \) - the content of crushed and injured grain in the threshed initial heap. \( D_i, T_i \) - crushing and injury of grain by this working body as a percentage of the grain supplied to it.

4. Discussion

From formulas (4) and (5) it can be seen that it is possible to reduce the level of injury to seeds and commercial grain by the considered working body by increasing the efficiency of its separation on the separating surfaces, that is, by reducing and its descent from the previous working body. To reduce the value \( D'_i \) and \( T'_i \) is possible not only by reducing the amount of grain supplied to this working body, but also by the degree of its damage by the working body \( D_i \) and \( T_i \) itself. It is known that grain damage decreases with decreasing impact velocity or elastic modulus of the surface impinging on it. The indicators \( D_i \) and \( T_i \) are significantly influenced by the physical and mechanical properties of the harvested crop and the content of damaged kernels in the original heap. By summing up the indicators for the considered operations of the technological process, it is possible to determine the level of crushing and injury in general behind the thresher of the combine harvester:

\[ D = \sum_{i=1}^{n} \left[ x_{i-1} + y_{i-1} - 0.01(Dx_{i-1} + Dy_{i-1}) \right]D_i \]  
(6)

\[ T = \sum_{i=1}^{n} \left[ x_{i-1} + y_{i-1} - 0.01(Tx_{i-1} + Ty_{i-1}) \right]T_i \]  
(7)

5. Conclusion

The studies carried out show that one of the ways to obtain high-quality seeds is to reduce mechanical stress during the technological process.

The elimination of intermediate, that is, secondary operations, an increase in the efficiency of the separating surfaces in order to more complete separation of grain will significantly reduce its supply to the subsequent working body.

The use of fundamentally new technical solutions in the design of threshing and separating devices, elastic and other innovative materials for the manufacture of working bodies of grain harvesters will significantly reduce the degree of damage to seeds and increase their sowing quality.

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