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Influence of Physical and Constructive Parameters on Durability of Sieves of Grain Cleaning Machines

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ABSTRACT

The influence of parameters of technological loading, properties of grain mixes and constructive parameters of sieves on the values of the formed equivalent stresses and their durability is given. The change in equivalent stresses was studied both on serial sieves with basic triangular holes and on sieves with activators – innovative holes in the form of an epicycloid. Finite element method based on Pro/ENGINEER product and research data is used to predict the durability of perforated sieves. It was found that the use of activators on sieves, due to their innovative forms, increases the durability of the perforated sieve by 12.3%. The developed technique allows to analyze different designs of sieve openings by the criterion of their durability.

Keywords: durability, perforated sieves, wear, finite element method, stress.

INTRODUCTION

The sieves of grain cleaning machines wear out during operation due to the abrasive action of the grain material. Grain is an abrasive material that causes wear of the working bodies of machines and equipment for post-harvest processing [1, 2]. Grain material consists of grains of the main crop and impurities, which are separated in the holes depending on their size. According to the shape of sieve is classified into flat, cylindrical and conical. The design of sieves provides a perforated surface with holes and jumpers, fields (non-perforated areas around the perimeter). Wear of sieves in thickness leads to the appearance of deformations (cracks) on the jumpers between the holes, which reduces the quality of separation of grain material into fractions by size. During the operation of sieves in the cleaning mode, a similar phenomenon leads to the ingress of impurities into the pure grain. When the sieve works in the calibration mode, this leads to mixing of the seed fractions. Wear depends on a number of factors and appropriate research is needed to reduce it.

Flat vibrating sieves are the most common among grain cleaning machines. As a rule, the perimeter of sieve is inserted into the frame or attached to it, i.e. have a rigid fastening. In the given work the research of durability of flat sieves is considered.

In addition, promising ways to intensify the process of sifting grain materials, which involve the use of sieves with activators of different types [3]. The developed sieves have epicycloid and volume activators which promote intensive sifting of grain materials components through the holes. Such measures have increased the productivity of grain cleaning machines by 30–92% compared to the use of sieves with base holes: round, triangular and rectangular [4, 5]. For a complete analysis of the efficiency of both the developed and basic sieves, as well as of the future constructions, it is necessary to determine their reliability indicators.

An important task of complete engineering calculation is to assess the reliability of the detail at known stresses at body points [6, 7]. The vibrating sieves of grain separation machines are subject to dynamic loading by a layer of grain material. Such external forces are distributed on the surface of sieve. The intensity of the internal forces, which oppose the external ones, causes stresses. The external forces that try to change the displacement of body parts or cause their displacement are opposed by the internal stresses. Deformation of the detail occurs when the boundary loads in the points of the body are exceeded.

Existing methods for determining the durability of sieves involves their long-term experimental tests (up to 4 years) and taking into account the elements of deformation – cracks. In this case, the research doesn't have a complex character, because they do not take into account the parameters of sieves and the properties of the grain mixes. The absence of methods for determining the durability of sieves with holes of different design for practical use requires appropriate research.

The relevance of this area of research is useful not only for grain processing enterprises, but also for machine-building plants engaged in the production of sieves. Therefore, the problem of determining the durability of sieves depending on their parameters and properties of grain mixtures is one of the main tasks in post-harvest processing of grain, the solution of which will predict and manage the efficiency of grain cleaning machines.

The object of research is the method of determining durability of sieves of grain cleaning machines. In particular, the purpose of the study is development and testing of methods for determining the durability of sieves with different types of holes, which takes into account their parameters and properties of grain mixtures. On the other hand, a problem of damage – both in biological material and in the sieves themselves is considered.

RESEARCH METHODS

Agricultural sieves are usually made of galvanized steel by cold stamping. Sieves with the following parameters were adopted for research: thickness 1.0 mm, width of sheet 990 mm, increased accuracy of rolling sheet type "A", with a cut edge (O) and with crystallization pattern "CR", first class zinc coating. Galvanized steel is made of carbon cold-rolled coiled steel, and for its galvanizing use zinc grades C0 and C1 with the addition of aluminum, lead and other metals. Lead alloying due to the introduction of zinc grade C2 is allowed. The deviation in the thickness of the zinc coating for 1 class does not exceed 10 micrometers.

Among the main mechanical properties of galvanized steel should be noted: yield point of σ_y = 230 MPa, elongation not more than 20%. In this case, for plastic materials, the ultimate stress is the yield point.

Analysis of systems for numerical finite element calculations [8, 9] allowed to select the appropriate computer software: T-FLEX, Mechanical Desktop, APM WinMachine, KOMPAS 3D – APM FEM, Solid Works, ANSYS, Pro/ENGINEER, NX Nastran, Abaqus/CAE. In the effect, the Pro/ENGINEER and Abaqus/CAE turned out to be the best platforms for the current study.

Simulation spatial studies of the reliability characteristics of vibrating sieves with activators were conducted in the software environment Pro/ENGINEER (Wildfire 4.0 version, M120 release) which had the means to model and implement algorithms for finite element models.

The negative factors that affect the reliability of sieves may include: abrasive action of grains on the metal sieve surface due to movement and constant contact; own and forced fluctuations of sieve surface caused by vibration; technological limitations of sieve thickness, its holes and bridges.

In the vibration sieves models (Fig. 1), the parameters of the holes are set with the definition of their shape and location steps. Thus, round, triangular and rectangular holes are used to simulate the reliability of basic sieves. For research it was limited to one standard size of basic and designed with activators sieves. Approbation of the developed methodology was carried out during the sifting of grain mixtures on basic flat sieves with triangular holes and developed sieves with activators. The research was conducted with the following sieve parameters: a) kinematic: A=0,0075 m; ω = 48,12 rad/s; b) constructive: angle of inclination θ=8°; length and width L=0,79 m, H = 0,99 m.

At researches, to determine the degree of reliability of the developed vibrating sieves relative to the basic ones, the parameters of the holes varied. When separating buckwheat grain mixtures for base sieves with triangular holes, the parameters are accepted: placement periods – $l_1 = l_2$ = 0,006 m; side of an equilateral triangle

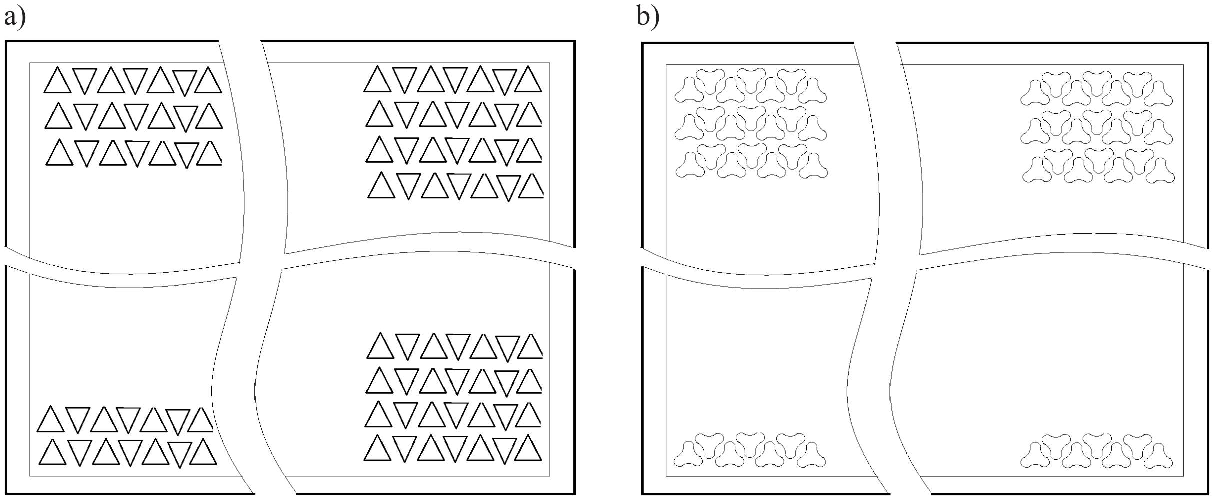

Fig. 1. Fragments of sieves for building a computational model: (a) basic, (b) developed with activators

4,5 mm. Also accepted parameters of sieves with three fold epicycloid activators: radius of a fixed circle 0,0018 m, module k = 3.

To determine the load acting on the surface of the vibrating sieve the properties of the grain mixture and sieve loading were taken into account: bulk density of buckwheat grain mixture 660 kg/m^3; average height of the layer of buckwheat grain mixture h^* = 0,012 m.

The study of the reliability of the developed vibrating sieves with holes of complex geometry is based on the use of the finite element method. The widespread use of the finite element method to study the reliability of complex mechanical systems is explained by the ability to take into account the action and variability of various external forces, mechanical characteristics of materials, etc. [9–13]. Thus, in [14–19] using the finite element method, it was found that the shape of the perforation holes of the parts affects the value and nature of the distribution of equivalent stresses. The influence of the parameters of hexagonal, round and ellipsoidal holes was investigated in the works.

The main idea of the method is that the continuous value of stress, which is determined in a given space, can be approximated by a discrete model. The last one was constructed on the plural of piecewise continuous functions that are defined on a finite number of subdomain. In this case, the piecewise continuous functions are determined using the values of a continuous quantity in a finite number of grid points, the area of which are considered. In the developed method, the original structure was replaced by a set of a large number of simple objects: triangles, tetrahedra, shells and similar finite elements. Within these elements, the law of stress values change is known and is established by the corresponding parameters in the grid point. This allows the transition from a system with an infinite number of degrees of freedom to a system with a finite number of them. In this case, all loads, geometric parameters and physical characteristics, as well as initial deformations are reduced to grid points. The end result of calculations by this method is a determined stress-strain state at any point of the structure.

Studies of the reliability of sieves will be carried out according to the following methodology, which is typical for finite element method [9, 11, 20]: according to the initial data the functional is constructed; the division of the system into finite elements and the choice of coordinate functions were performed; construction of matrices of rigidity and masses; identification of the distributed load to the nodes for each finite element; construction and solution of canonical equations.

The use of this methodology algorithm for vibrating sieves has difficulties due to design features: a large number of holes, complex geometry of sieve elements (holes, geometrical activators and jumpers), the presence of stress concentrators, etc. Therefore, it will be important to create a reliable, accurate finite element model of sieve design, as well as a software environment for preparing spatial models.

The methodology for determining the durability of the vibrating sieves is as follows. The use of the software product Pro/ENGINEER allowed to determine stresses at the points of the vibrating sieve under conditions of varying different parameters. According to the used experimental data the change of thickness of vibrating sieves in the course of their operation in time was defined. Comparison of stresses at the points of the vibrating sieve with different degrees of wear (change in thickness) with the stress limits. These stresses are characteristic of the metal from which sieve is made. Thus, the output has an algorithm for determining the durability of the basic or developed vibrating sieve.

The research in the automatic system Pro/ENGINEER involved the use of the following stages: introduction of a computational design model in 3D graphics (Fig. 2); introduction of metal properties of a vibrating sieve; introduction of the scheme of sieve fixing and its loading with grain material (Fig. 3); finite element partitioning of the system; system calculation and adjustment of parameters (number of grid nodes, etc.); obtaining the stress field on the vibrating sieve.

The partitioning of the system under study (vibrating sieve) includes geometry analysis and choice of finite element type. As a result of partitioning the original calculation system into a set of finite elements, the model forms a plate-shell structure. A fragment of the developed vibrating sieves model with epicycloidal holes and a partitioning grid is shown in Fig. 2.

The next step after the introduction of sieve initial design parameters and the choice of material was to determine the loads on sieve working surface. During the operation of the grain cleaning machine, the working surface of sieve is covered with a layer of grain mixture. This layer of grain mixture was determined by thickness and density. Thus, for a grain mixture of buckwheat with a density of 660 kg/m^3, on a sieve by size of 790×990 mm with a layer thickness of 12 mm, the load is 6,2 kg over the entire surface. In this way, the load is distribution over sieve area, which has a rigid fixation around the perimeter (Fig. 3).

The next step was the calculation at the characteristic points of the shells equivalent stresses that occur under the action of loads At the same time, special attention is paid to the maximum stresses that occur in sieve.

Since sieve is subject to wear and changes in its thickness during operation, this was taken into account in reliability studies. It is known that during operation the thickness of sieve is variable (decreases) [21, 22], at the same time the stresses increase. If the condition of strength is not fulfilled, the actual stresses exceed in our case the yield strength of the material, then there is a deformation of the structure.

By determining the period of sieve operation, during which its wear will be limiting, it becomes possible to establish its durability. It is necessary to perform comparative researches of basic and developed sieves.

To determine the durability, it is necessary to obtain the dependence of the wear of sieves during their operation. The following methodology is used to construct a diagram of sieves wear by thickness.

Measurement of the thickness of sieve was performed with a micrometer type MKG, which is designed for deep measurements of sheet metal parts and strips. Characteristics of the micrometer: model – 25/300; measurement range 0–25 mm; maximum depth of measurements 300 mm; scale factor 0.01 mm; relative error ±0.012 mm; State Register of Ukraine № 1988–09; in accordance with Technical Conditions 33.2–30291682–002–2004 «Micrometers

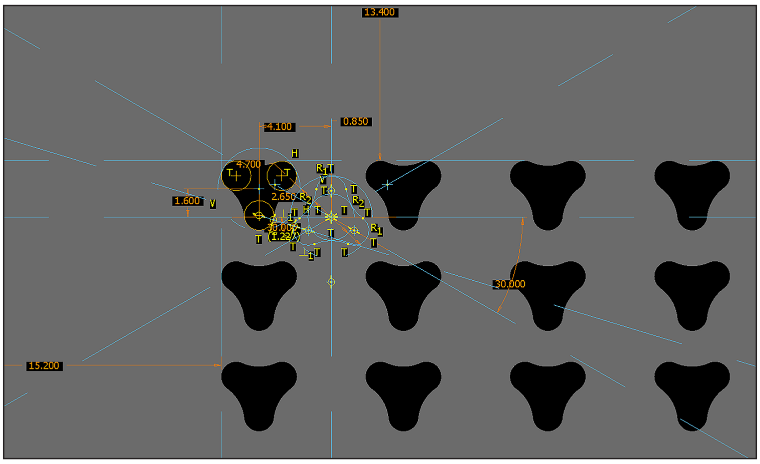

Fig. 2. Fragment of the developed vibrating sieve model with a three-fold epicycloid form of holes

a)

b)

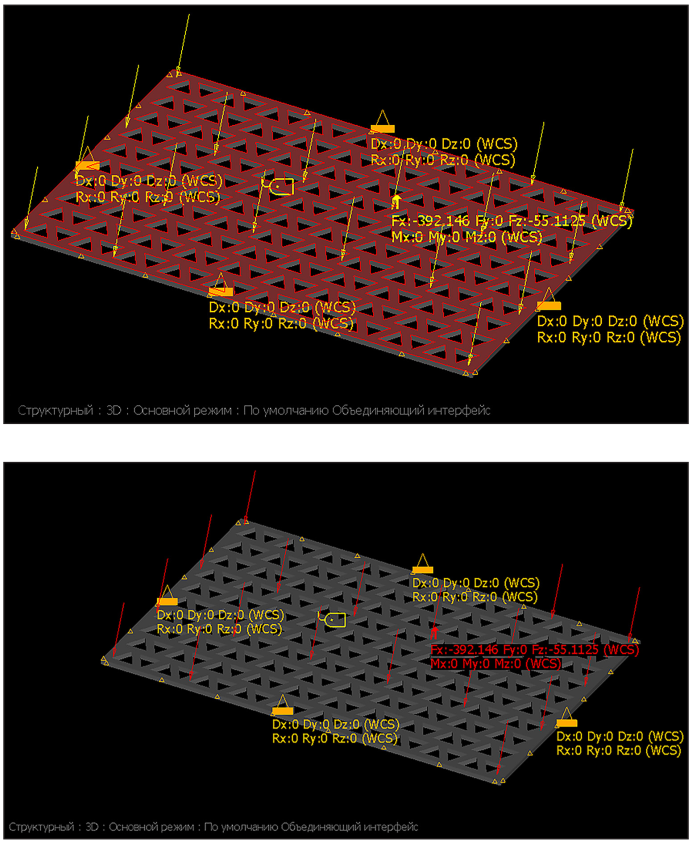

Fig. 3. Fragments of sieve fixing scheme (a) and its loading (b)

"MICROTECH". Kharkiv, Ukraine». Determination of the average thickness of sieve was performed on the diagonals and axes of sieve at a distance from the edges of 50, 150 and 300 mm (Fig. 4). The obtained results were averaged by values.

Basic and developed sieves under production conditions were subjected to thickness measurements during the following operating time: 0, 500, 1000, 1500, 2000, 2500, 3000, 3500 hours of work. At the same time, on sieve size 790×990 mm specific productivity (load) is: 2 t/h (during pre-cleaning of buckwheat grain mixture).

To simulate the wear process of sieve surface in the developed models of the Pro/ENGINEER software environment introduced a decrease in the average thickness of sieve at constant values of other parameters of the sifting process. The final stage of reliability research was the comparison of simulation data and experimental studies. The durability of basic and developed vibrating sieves was established according to the established limiting thicknesses of sieves.

Thus, the developed method taking into account the technological indicators of the sifting process, the properties of grain mixtures and design parameters of sieves and activators allows to determine and predict changes in the durability of vibrating sieves.

RESULTS AND DISCUSSION

Calculations at the characteristic points of the shells of equivalent stresses that occur under the action of load, allowed to obtain the corresponding stress fields on the surface of the vibrating sieve (Fig. 5).

It was established that the maximum stresses (displacements) were observed in zones which were located at a distance from zones which had greater rigidity on a bend – rigidly fixed edges zone 1 (Fig. 5).

The maximum stresses in this zones are 10–27 MPa. It should be noted that this stress field is obtained for new sieves that do not have operational wear on the surface thickness. Due to the oscillations of the central part of sieve, due to vibrations, increase the stress in the central zones – zone 2 (Fig. 5). The maximum stresses in these zones reach 6.3–9 MPa, which also requires their detailed study.

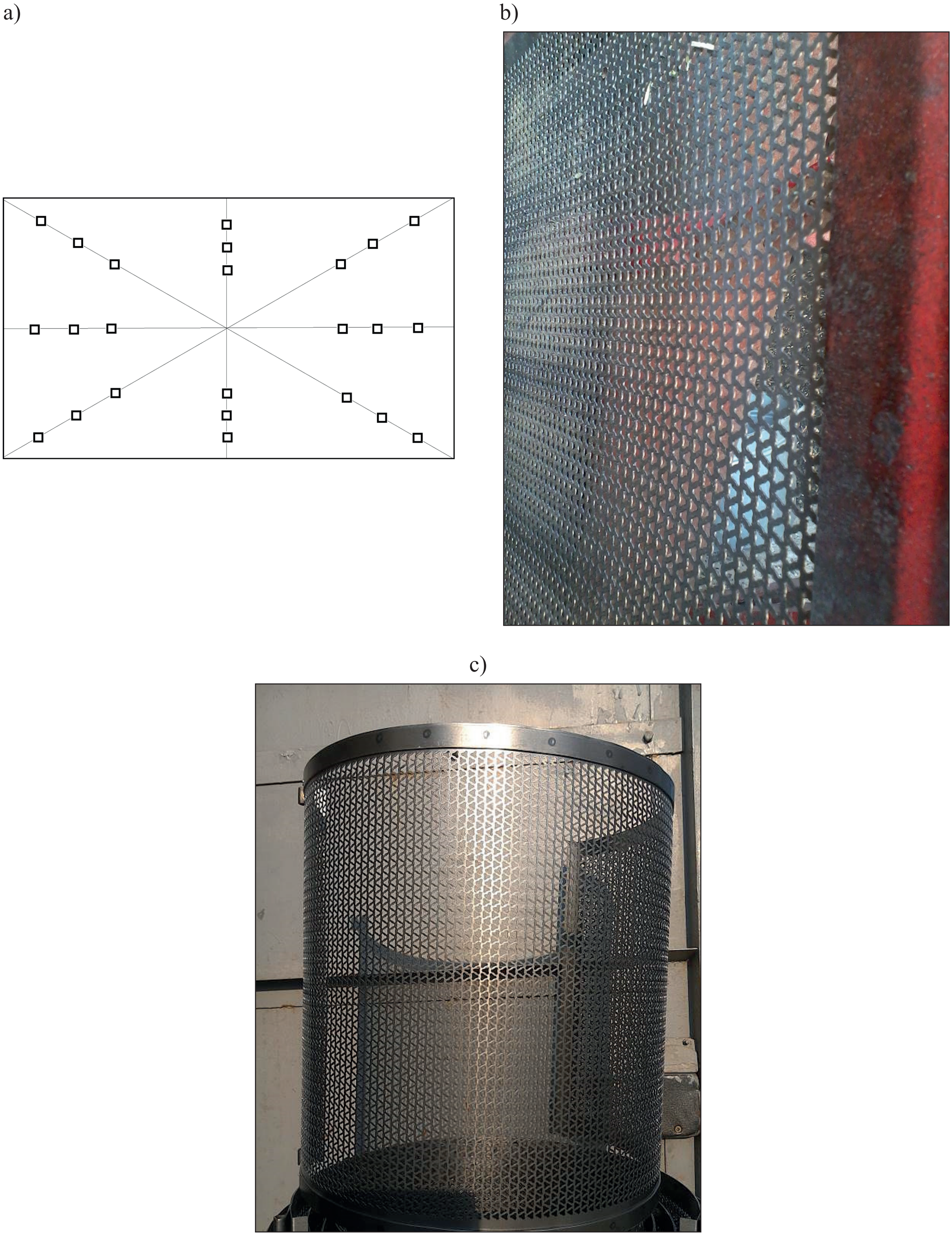

Fig. 4. Experimental determination of average thickness of sieves: (a) the scheme of measurements, (b, c) fragments of flat and cylindrical sieves with epicycloid activators (2000 hours of an operating time)

Increasing the modeling scale allowed to establish the nature of the stresses on the structural elements – the jumpers of the basic (Fig. 6a) and the developed vibrating sieves with activators (Fig. 6b). Analysis of the simulation image showed that the maximum stresses are concentrated around the vertices of the triangular hole in the basic sieves. The formed stress concentrators exceed other stresses on sieve by 10–11 times, which emphasizes the clear nature.

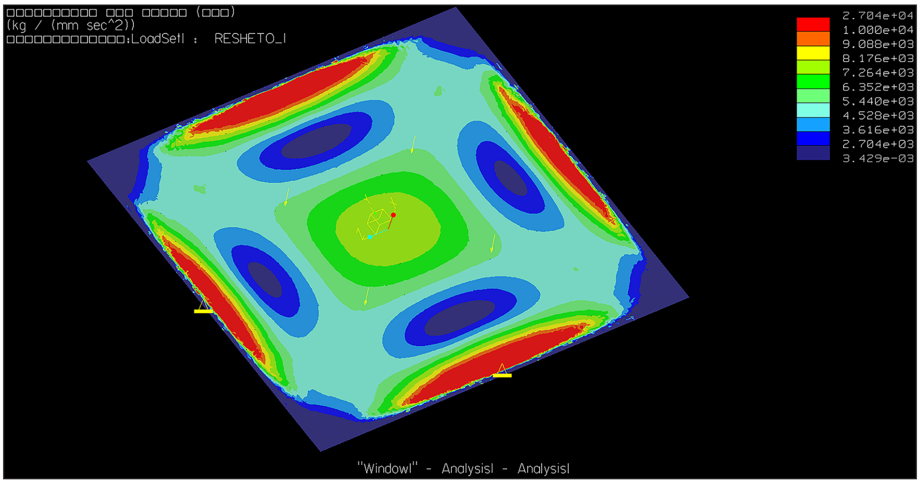

Fig. 5. Character of stress on a vibrating sieve surface: 1 – peripheral zones, 2 – central zones

The wear of sieve during its operation is determined by the change in surface thickness, and hence the increase in stresses in the established places (Fig. 6).

It is also established that rounded elements of holes of a three-fold epicycloid shape have a positive effect on the extensiveness of stresses occurrence. The maximum stress zones (highlighted in red) on the designed sieves with activators (Fig. 6b) are much smaller in area and do not intersect with each other, compared to basic sieves with triangular holes (Fig. 6a). This confirms the increased reliability of the designed sieves with activators.

The processed simulation results were presented in the form of dependences of maximum equivalent stresses for sieves with basic and developed with activators on their average thickness (Fig. 7) and the distribution of equivalent stresses (at 10 hours of operation) in areas of new sieves (Fig. 8).

Analysis of the simulation results (Fig. 7, 8) it was determined that the equivalent stresses depend on the thickness of sieve. Using designed sieves with activators reduces stress on 20…24,1% compared to basic sieves with triangular holes. The boundary thickness of basic sieve (at which the strength condition is performed) is 0.45 mm, after which deformation is observed – the appearance of cracks, generally. The boundary thickness of the developed sieve, at which the maximum stress is equal to 230 MPa, occurs with wear up to 0.4 mm (Fig. 7).

The second stage was the experimental determination of dependence of sieve surface wear during their operation in the form of patterns of change in the average thickness (Δh_r) of sieve (Fig. 9). It is established that in the initial period of sieves operation, the intensity of wear by thickness Δh_r considerable and decreases after 1000 hours of operation. This can be explained by beginning of operational life of sieve material caused by irregularities of sieve surface, the influence of holes edges, surface roughness of jumpers between holes. The further period is characterized by the normal wear of all areas of sieve surface until the beginning of its critical wear after 3000 hours of operation, which is consistent

a) b)

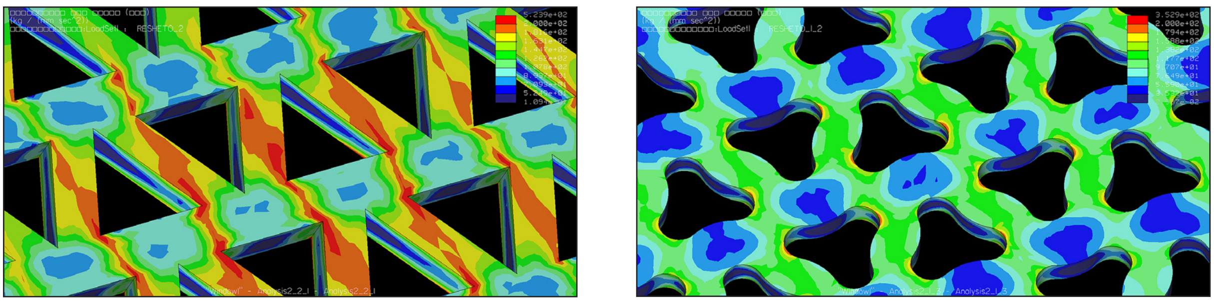

Fig. 6. The nature of the stresses in the central zones of sieves: a – basic sieves with triangular holes; b – developed sieves with activators

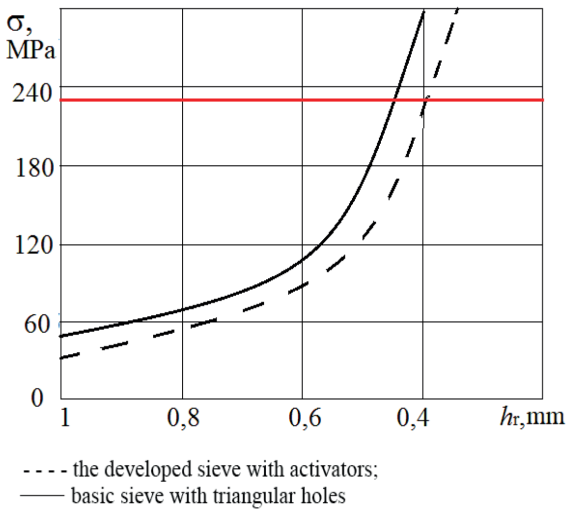

Fig. 7. Dependences of the maximum equivalent stresses in sieves from its average thickness

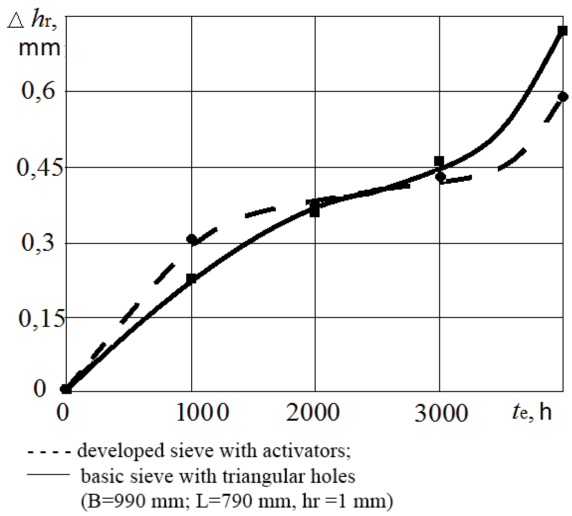

Fig. 9. Dependences of wear of vibrosieves on thickness throughout time of its operation:

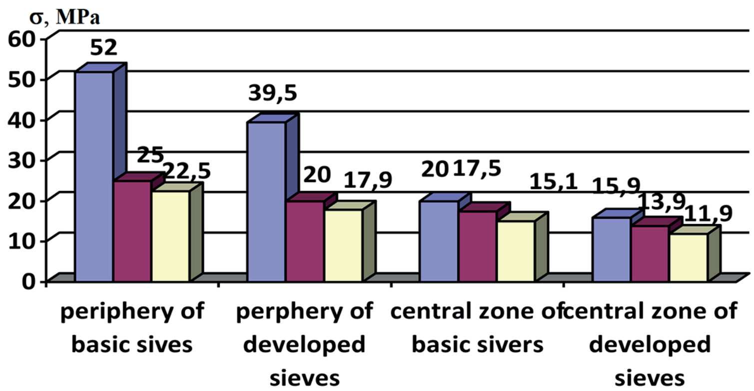

Fig. 8. Distribution of equivalent tension on the sections of basic and developed vibrosieves

with a sharp increase in stress (Fig. 7). Explanation of this is given in the work [16], where the change of holes profile due to the movement of grain mixtures is established. Also, uneven wear of jumpers between holes depending on the direction of movement of grain mixture and reduction of intensity during operation.

Slight increase in wear by the thickness of designed sieve with activators (up $\Delta h_r = 0.035$ mm by 5%) is explained by its increased throughput (productivity) by 40%,due to increased sifting efficiency of buckwheat grain mixtures, compared to the basic sieve (when loading sieve 790×990×1 mm – $q = 2$ t/h).

The final stage of reliability research was the comparison of modeling data (Fig. 7) and the results of experimental researches (Fig. 9). According to the determined boundary thicknesses of sieves (Fig. 7) and with the help of experimental dependences (Fig. 9), the predicted durability of sieves is established: basic with triangular holes – 3250 hours; developed with activators – 3650 hours, which is 12.3% more.

Thus, the regularities of changes in stresses and durability of sieves are established using the finite element method based on the Pro/ENGINEER software product, which take into account the technological parameters of sifting process of grain mixtures, their properties and design parameters of activators. The obtained results will allow to effectively design perforated sieve surfaces of grain cleaning equipment taking into account the features of their operation and the problems of their reliability.

CONCLUSIONS

Using the finite element method based on the software product Pro/ENGINEER and experimental data, the method of predicting the durability of perforated sieves for a separate option was tested [21]. This allowed to establish the dependences of equivalent stresses and durability of sieves, which consider their parameters and loads, properties of grain mixtures, optimal design parameters of perforated surfaces. It is established that the use of individual highly productive perforated surfaces with complex geometric holes in the form of a threefold epicycloid instead of triangular holes, which can increase durability by 12,3%.

The problem of sieves reliability is one of the main problems in post-harvest grain processing, the solution of which will allow to predict and control the efficiency of grain cleaning machines. The durability of sieve is determined by the presence of deformation in form of cracks between holes, which arise depending on set of factors, among which: loading grain mixes, wear of sieves on thickness, vibration action, etc. Use of the finite element method and experimental studies made it possible to obtain regularities for changing equivalent stresses at sieve points, which are adequate to real processes on condition of carrying out the minimum operations. By means of the offered method, consistent patterns of change of equivalent stresses in basic sieves with triangular openings and developed with openings in the form of a three-fold epicycloid are determined. The developed method allows to predict durability and to analyze designs of sieves with different openings in a section of durability of sieves.

Development of durability methods of perforated surfaces (sieves) requires approbation of the obtained method taking into account a number of factors: properties of sieves' materials, characters of loading and sieves' vibrations, differentiation of geometrical forms of sieves. The end result of the studies can be the use in practice of complex diagnostic parameters that characterize reliability and do not require measuring equipment.

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