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Methodology for Service Life Evaluation of Screens Welded Structures

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Abstract. The methodology of research on welded assemblies for fastening vibrators is based on modern software products, in particular SolidWorks Simulation in combination with SolidWorks Motion and hot spot stress (HSS) technology. It has been determined that the research on welded assemblies using the SolidWorks Education Edition software package is expedient, considering the most unfavorable situation, when there is a lack of fusion of edges. The solid-state model displays a lack of fusion as a gap between the welded parts. The research on the stress-strain state of welded structures using the finite element method shows that when the computational mesh cell size is reduced, the stress increases significantly, indicating the model singularity and the need for further application of the HSS technology. Research has revealed that the maximum stresses occur in those points of the welds where the longitudinal middle rib is connected to the plate and pipe. It has been determined that the service life of welded joints will exceed $2 \cdot 10^6$ cycles. To assess the accuracy of calculating the dynamic forces arising during the screen operation, the modeling results using the SolidWorks Motion program are compared with those classical methods that use the Lagrange equation of the second kind. It turned out that the calculation error does not exceed 30 %.

Keywords: simulation, process innovation, SolidWorks, hot spot stress, service life.

1 Introduction

Development and improvement of scientific methods for calculating the design parameters of technological machines is one of the critical aspects of the research activity of the staff at the National Technical University Dnipro Polytechnic [1, 2]. Thus, many works of university specialists reflect searching for scientific ways to optimize the parameters of reinforced thin-walled structures of machines based on modern computer modeling tools and computational experiments [3, 4].

Scientific works performed under the guidance of prof. V. Franchuk has had the main scientific results related to improving the functioning of vibrating screen feeders in the mining-metallurgical industry [5, 6]. These studies focus on the theoretical basis for the functioning of technological purposes, calculation methods, and design principles for these objects.

During the screen operation, at the junction points of the welded elements, which are stress concentrators, alternating-sign loads occur, destroying the structures due to their fatigue.

In the calculation practice, the weld dimensions are determined from reference books that do not contain data on the applied loads, so the research is focused on the thickness of the sheets for welding of the parts.

Today, computer programs are usually used to design a machine that does not provide for constructing physical models of objects [7, 8].

The transition from traditional methods of designing welded structures using material strength indicators to more accurate calculations using the finite element method involves increased precision and requires deeper knowledge of computational mechanics and software. This approach allows for more accurately considering local stresses and deformations in welded joints, which is especially important for structures subjected to high loads or complex operating conditions. Moreover, using the finite element method fosters a deeper understanding of the interaction between different parts of the structure, ultimately leading to improved reliability and safety of welded constructions.

In general, there are two methods for calculating the parameters of welded structures: the hot spot stress (HSS) technology [9], which allows for determining the stress

from a specified weld geometry, and the Throat Shear Method, which is used to design a weld. In this case, there is a condition under which one of the welded parts should necessarily be modeled as a shell.

During the operation of this program, it is not required to set the weld dimensions, in contrast to the HSS technology, and instead of the stress, four internal forces along the shell are calculated, in particular, a bending moment along the length of the weld edge, as well as one normal and two tangential forces. The required size and width of the weld are determined based on the results of the force calculation.

Under the guidance of prof. K. Zabolotny, a method has been developed to use modern CAD/CAE programs to analyze the parameters of the SkUb5.0x1 screen operation during coal sludge dehydration. This method constructs simplified models using the SolidWorks resource and SolidWorks Motion software application to simulate the device dynamics.

In order to reduce the number of errors in the designer's work, an automatic designer's workplace has been developed for designing screens of this type. The SolidWorks API application and the C# programming language are used for this. Based on the Godot graphics engine, a program interface has been developed to input screen parameters.

The presence of welded joints in vibrating machines, which are stress concentrators and experience variable loads, imposes restrictions on their service life, and the strength and durability calculation for each of these structures creates a challenging scientific and technical problem.

The research aims to substantiate the methodology for assessing the service life of the HVCH-31 C screen welded metal structures.

2 Literature Review

It is possible to calculate the stress-strain state parameters in the machine structure using modern numerical analysis methods, particularly by the finite element method. It should be noted here that when studying the parameters of welds in machine parts by the finite element analysis (FEA), it has been noticed that a decrease in the size of the finite-element computational mesh cells shows a significant increase in stress, which may indicate a singularity of the problem.

To avoid this undesirable effect, it is proposed to use the HSS calculation technology, which makes it possible to refine the calculation results obtained using the finite element method. In the finite-element analysis of welds using the HSS method, the joints of metal sheets are depicted as shell, three-dimensional, or even better as square elements. The size of each computational mesh cell is selected so that at the place of the weld, it is equal to no more than half the sheet thickness. The mesh step length is such that the obtained stress values are determined in different mesh cells. When modeling welds, stress concentrators using the HSS technology are placed at the base of each such weld, and the interpolation line is drawn

perpendicular to it. The nominal values of stresses that have arisen in the concentrator are determined by linear interpolation. Further, using the information about material fatigue, the results obtained are multiplied by the effective index of the concentration coefficient value calculated based on experimental data.

In the literature sources [10, 11], numerical restrictions on the stress indicators at the so-called hot spots of the object were determined. In particular, four different methods of assessing these characteristics are known.

The rib's welded joint to the steel deck plate was studied in this case. These methods were used to calculate the stresses in this critical junction using Siemens HX.12 software based on FEA. The influence of restrictions and the analysis of the accuracy of the results obtained in this case were observed in different conditions.

Research on modeled shell elements has generally yielded more consistent stress calculation results using HSS than solid elements.

A part of the problem has not been solved, related to the fact that software packages such as SolidWorks Simulation are only able to fix the singularity effect in the weld, but they cannot assess, given the stress-strain state parameters, the service life of the welded structure without analyzing the type of deformations in the studied place.

SolidWorks Simulation software uses tetrahedral 3D finite elements and triangular 2D shell models. The primary purpose of elements in the form of shells is to reduce the task-performing resource intensity. It is known that reinforced thin-walled structures work in bending, so there should be at least three finite elements in the sheet thickness, which 2D shell one can replace.

For the design of welds using the SolidWorks Simulation program, the "butt-weld" tool is provided, which allows for modeling welded joints in the form of solid-state shell elements and displays the joints of shell elements between each other. A mandatory requirement for a weld-type joint is that the first of the welded bodies is a shell element with an edge along which the weld should be placed.

The "butt-weld" tool provides two types of joints: a T-butt weld or fillet weld, which joins faces arranged at an angle relative to each other, and a butt weld, in which the joining of parallel faces is modeled. Both types of welded joints can be either one-sided or two-sided. A "butt-weld" type joint can be used to model actual junctions of this type.

Using the "butt-weld" tool, according to the specified joint size, the following parameters of the weld section (its length and width) are determined automatically, thanks to which the joint can withstand specific loads with the set safety factor and strength of the weld.

This tool can be adapted to American or European welding standards. In the first case, the following conditions should be entered: welding safety factor, the expected value of the welding leg, and the strength of the material used for this, which is taken from the data of the electrodes or recorded manually. After applying the European standards, it is determined from which material the made part is less strong among the jointing parts [12].

In addition, the correlation coefficient and partial safety factor values are entered. Therefore, when constructing and substantiating the calculation scheme for examining a weld, it is necessary to consider a particular machine structure.

The scientific idea of this research is to combine modern computer analysis methods based on the finite element method. This method is known to operate in many computer complexes developed, for example, by specialists from Dassault Systems.

The research aims to establish a methodology for assessing the service life of the HVCH-31 C screen welded metal structures. To achieve this goal, the following objectives were addressed:

- analyzing classical calculation methods – to investigate and identify limitations in traditional methods used for calculating parameters of vibrating screens, such as treating the screen box as a solid body and the consequent inability to determine stress in assemblies and assess the durability of vibrator fastening elements;

- development of a new methodology – to create a new methodology for modeling the stress-strain state in vibrator fastening assemblies using modern software tools like SolidWorks Simulation, the SolidWorks Motion method, and HSS technology. In order to achieve the objective, several sub-objectives were addressed: study of welds with lack of fusion and stress analysis in reduced mesh size;

- methodology testing and application – to test the developed methodology through practical application, specifically by calculating the forces in the fastening assemblies of the HVCH-31 C screen box welded structure. The following parameters are defined: maximum stress locations and durability assessment of fastening assemblies.

3 Research Methodology

3.1 The calculation technique

An overview of the primary material. Modeling of the stress-strain state in the screen fastening assemblies.

Figure 1 shows the design scheme of the assembly for fixing the vibrators in the tested screen.

The entire assembly structure is fastened to the screen body using flanges 6. The tensile force generated by the vibrator is applied to plate 2, and then through the longitudinal and transverse ribs, this force passes to the pipe. The most significant force falls on the longitudinal ribs, while the middle rib experiences the maximum load.

The screen has a single-shaft inertial vibration exciter of non-directional action (position 1), and its drive is not mounted in the gravity center of the screen (Figure 2).

Box 2 has three degrees of freedom: the gravity center moves horizontally (along the x-axis), vertically (along the z-axis), and with rotational oscillations around the gravity center (in the transverse direction, around the y-axis).

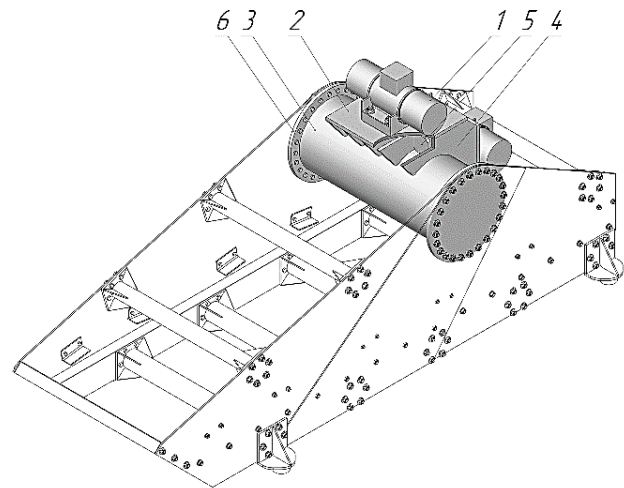


Figure 1 – Screen model: 1 – fastening assembly; 2 – vertically and horizontally arranged plates; 3 – the pipe connected to the plates by welding; 4 – transverse ribs; 5 – longitudinal ribs

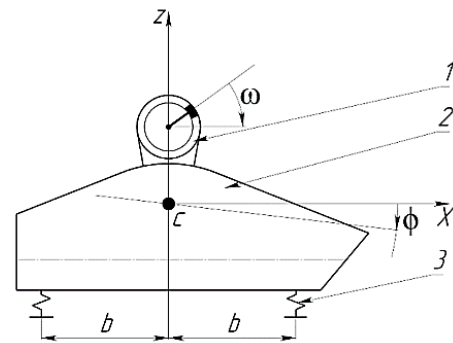


Figure 2 – Calculation scheme for the screen

Due to the low rigidity of elastic element 3, it is decided to neglect their incorrect position relative to the gravity center in the vertical direction.

When operating in dynamic mode, the screen is affected by the total sinusoidal force directed at an angle of 45° and generated by vibrators; it has the following components: distributed weight and inertia forces and spring reactions. Neglecting inertial forces, the reaction force in one spring is 9.7 kN. At the same time, the dynamic calculation performed by the SolidWorks Motion shows that the maximum force in the junction is 7.0 kN.

To assess the calculation results performed using the SolidWorks Motion, the dynamic reaction forces in springs are determined analytically using the Lagrange equation of the second kind:

$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{q}_i} \right) - \frac{\partial T}{\partial q_i} + \frac{\partial \Pi}{\partial q_i} + \frac{\partial D}{\partial \dot{q}_i} = Q_i, \quad (1)$$

where i – the degree of the screen box freedom; t – time, s; T – kinetic energy, J; Π – potential energy, J; D – Rayleigh's dissipation function, J; Q_i – generalized force, J/[q].

The kinetic energy of the system is as follows:

$$T = \frac{m\dot{x}^2}{2} + \frac{m\dot{z}^2}{2} + \frac{J_y\dot{\varphi}^2}{2} + \frac{m_0(\dot{x}+\dot{x}_0+h\dot{\varphi})^2}{2} + \frac{m_0(\dot{z}+\dot{z}_0)^2}{2}, \quad (2)$$

where m – screen box weight, kg; m_0 – unbalanced weight, kg; h – distance from the box gravity center to the vibrator shaft, m; J_x – inertia moment of the box movement relative to the y -axis, $\text{kg}\cdot\text{m}^2$; φ – generalized angle coordinate, rad; x, z – generalized coordinates, m ($x_0 = r \sin(\omega t)$, $z_0 = r \cos(\omega t)$); r – distance to the unbalanced load's gravity center, m; ω – angular velocity of the motor-vibrator rotor rotation, rad/s.

The potential energy of the system is as follows:

$$\Pi = \frac{c_x x^2}{2} + \frac{C_z/2(z-b\varphi)^2}{2} + \frac{C_z/2(z+b\varphi)^2}{2}, \quad (3)$$

where c_x – longitudinal rigidity of the elastic element, N/m; c_z – transverse rigidity of the elastic element, N/m; b – distance from the gravity center to the elastic element, m.

Rayleigh's dissipation function is as follows:

$$D = \frac{\mu c_x \dot{x}^2}{2} + \frac{\mu C_z/2(\dot{z}-b\dot{\varphi})^2}{2} + \frac{\mu C_z/2(\dot{z}+b\dot{\varphi})^2}{2}, \quad (4)$$

where μ – dissipation factor, N·s/m.

Using the equation above and taking into account that $Q_i = 0$, after some transformations, the equation is composed that describes the screen motion, namely:

$$\begin{cases} (m + m_0)\ddot{x} + m_0\ddot{x}_0 + m_0h\ddot{\varphi} + C_x x + \mu C_x \dot{x} = 0; \\ (m + m_0)\ddot{z} + m_0\ddot{z}_0 + C_z z + \mu C_z \dot{z} = 0; \\ (J_y + m_0h^2)\ddot{\varphi} + m_0h\ddot{x}_0 + m_0h\ddot{x} + C_z b^2 \varphi + \mu C_z b^2 \dot{\varphi} = 0. \end{cases} \quad (5)$$

The second of the equations does not depend on the others. Therefore, it is solved independently, that is:

$$(m + m_0)\ddot{z} + C_z z + \mu C_z \dot{z} = m_0 r \omega^2 \cos(\omega t), \quad (6)$$

where $m_0 r$ – the kinetostatic moment determined as follows: $m_0 r = \frac{F_v}{\omega^2}$, kg·m; F_v – coercive force, N; ω – vibrator shaft rotation velocity, rad/s.

It is determined that the solution is as follows:

$$\begin{cases} (C_x - M\omega^2)A_x - \mu\omega C_x B_x - m_0 h \omega^2 A_\varphi = m_0 r \omega^2; \\ \mu\omega C_x A_x + (C_x - M\omega^2)B_x - m_0 h \omega^2 B_\varphi = 0; \\ -m_0 h \omega^2 A_x + [C_z b^2 - (J_y + m_0 h^2)\omega^2]A_\varphi - \mu\omega C_z b^2 B_\varphi = m_0 r h \omega^2; \\ -m_0 h \omega^2 B_x + \mu\omega C_z b^2 A_\varphi + [C_z b^2 - (J_y + m_0 h^2)\omega^2]B_\varphi = 0; \end{cases} \quad (17)$$

$$A_x = \frac{\Delta A_x}{\Delta}; B_x = \frac{\Delta B_x}{\Delta}; A_\varphi = \frac{\Delta A_\varphi}{\Delta}; B_\varphi = \frac{\Delta B_\varphi}{\Delta}, \quad (18)$$

$$\Delta = \begin{vmatrix} (C_x - M\omega^2) & -\mu\omega C_x & -m_0 h \omega^2 & 0 \\ \mu\omega C_x & (C_x - M\omega^2) & 0 & -m_0 h \omega^2 \\ -m_0 h \omega^2 & 0 & [C_z b^2 - (J_y + m_0 h^2)\omega^2] & -\mu\omega C_z b^2 \\ 0 & -m_0 h \omega^2 & \mu\omega C_z b^2 & [C_z b^2 - (J_y + m_0 h^2)\omega^2] \end{vmatrix}; \quad (19)$$

$$\Delta A_x = \begin{vmatrix} m_0 r \omega^2 & -\mu\omega C_x & -m_0 h \omega^2 & 0 \\ 0 & (C_x - M\omega^2) & 0 & -m_0 h \omega^2 \\ m_0 r h \omega^2 & 0 & [C_z b^2 - (J_y + m_0 h^2)\omega^2] & -\mu\omega C_z b^2 \\ 0 & -m_0 h \omega^2 & \mu\omega C_z b^2 & [C_z b^2 - (J_y + m_0 h^2)\omega^2] \end{vmatrix}; \quad (20)$$

$$z = A_z \sin(\omega t) + B_z \cos(\omega t). \quad (7)$$

Having equated the coefficients related to the same harmonics of oscillations, after transformations, the following system of equations can be obtained:

$$\begin{cases} (C_z - M\omega^2)A_z - \mu\omega C_z B_z = 0; \\ \mu\omega C_z A_z + (C_z - M\omega^2)B_z = m_0 r \omega^2. \end{cases} \quad (8)$$

Now, it is possible to compose the following equations for amplitudes of screen oscillations:

$$A_z = \frac{m_0 r \omega^2 \mu\omega C_z}{(C_z - M\omega^2)^2 + (\mu\omega C_z)^2}; \quad (9)$$

$$B_z = \frac{m_0 r \omega^2 (C_z - M\omega^2)}{(C_z - M\omega^2)^2 + (\mu\omega C_z)^2}, \quad (10)$$

where $M = m + m_0$ – the total weight of the screen, kg. The solution can be taken in the following form:

$$z = a_z \cos(\omega t + \vartheta_z), \quad (11)$$

where the amplitude of oscillations is

$$a_z = \sqrt{A_z^2 + B_z^2} = \frac{m_0 r \omega^2}{\sqrt{(C_z - M\omega^2)^2 + (\mu\omega C_z)^2}}, \quad (12)$$

and phase angle –

$$\vartheta_z = \arctg \frac{B_z}{A_z} = \arctg \frac{C_z - M\omega^2}{\mu\omega C_z}. \quad (13)$$

The system equations is transformed as follows:

$$\begin{cases} (m + m_0)\ddot{x} + m_0 h \ddot{\varphi} + C_x x + \mu C_x \dot{x} = m_0 r \omega^2 \sin(\omega t); \\ (J_y + m_0 h^2)\ddot{\varphi} + m_0 h \ddot{x} + C_z b^2 \varphi + \mu C_z b^2 \dot{\varphi} = m_0 r h \omega^2 \sin(\omega t). \end{cases} \quad (14)$$

It is assumed that the solution to the equation takes the following form:

$$x = a_x \sin(\omega t + \vartheta_x); \quad (15)$$

$$\varphi = a_\varphi \sin(\omega t + \vartheta_\varphi). \quad (16)$$

Substituting this result into a system of differential equations for describing the box motion and equating the coefficients relative to the same harmonics of oscillations, a system of algebraic equations is composed, from which the unknown values A and B can be determined:

$$\Delta B_x = \begin{vmatrix} (C_x - M\omega^2) & m_0 r \omega^2 & -m_0 h \omega^2 & 0 \\ \mu \omega C_x & 0 & 0 & -m_0 h \omega^2 \\ -m_0 h \omega^2 & m_0 r h \omega^2 & [C_z b^2 - (J_y + m_0 h^2) \omega^2] & -\mu \omega C_z b^2 \\ 0 & 0 & \mu \omega C_z b^2 & [C_z b^2 - (J_y + m_0 h^2) \omega^2] \end{vmatrix}; \quad (21)$$

$$\Delta A_\varphi = \begin{vmatrix} (C_x - M\omega^2) & -\mu \omega C_x & m_0 r \omega^2 & 0 \\ \mu \omega C_x & (C_x - M\omega^2) & 0 & -m_0 h \omega^2 \\ -m_0 h \omega^2 & 0 & m_0 r h \omega^2 & -\mu \omega C_z b^2 \\ 0 & -m_0 h \omega^2 & 0 & [C_z b^2 - (J_y + m_0 h^2) \omega^2] \end{vmatrix}; \quad (22)$$

$$\Delta B_\varphi = \begin{vmatrix} (C_x - M\omega^2) & -\mu \omega C_x & -m_0 h \omega^2 & m_0 r \omega^2 \\ \mu \omega C_x & (C_x - M\omega^2) & 0 & 0 \\ -m_0 h \omega^2 & 0 & [C_z b^2 - (J_y + m_0 h^2) \omega^2] & m_0 r h \omega^2 \\ 0 & -m_0 h \omega^2 & \mu \omega C_z b^2 & 0 \end{vmatrix}. \quad (23)$$

The solution can be written as (15)–(16), where

$$a_x = \sqrt{A_x^2 + B_x^2}, \quad a_\varphi = \sqrt{A_\varphi^2 + B_\varphi^2}; \quad (24)$$

$$\vartheta_x = \arctg \frac{B_x}{A_x}, \quad \vartheta_\varphi = \arctg \frac{B_\varphi}{A_\varphi}. \quad (25)$$

It is easy to determine the dynamic forces arising in the springs by knowing the dependence, describing the screen box movements along the z-axis, and using d'Alembert's principle.

Concerning the operating mode of the screen, the values of these parameters correspond to the forces calculated using the SolidWorks Motion program with an accuracy of up to 80 %. As can be seen, this application is advisable for modeling dynamic processes on a screen when determining the loads arising in the elastic elements of the structure.

3.2 Study of welds with lack of fusion

To calculate the stress-strain state parameters in screen elements using SolidWorks Simulation methods, the solid-state model of this structure can be simplified by removing some minor details that do not affect the calculation results. Therefore, the following simplifications can be made: the bolt joints and holes for them, a sieve and corners for its support and fastening, and elastic elements will not be displayed in the model. The motor-vibrator is also not shown, but interaction areas with the plate are highlighted using the "Parting Line" function (Figure 3).

Next, we study the most dangerous version of the model, when the welds are made without edge finishing, while they have the so-called "lack of fusion" zone.

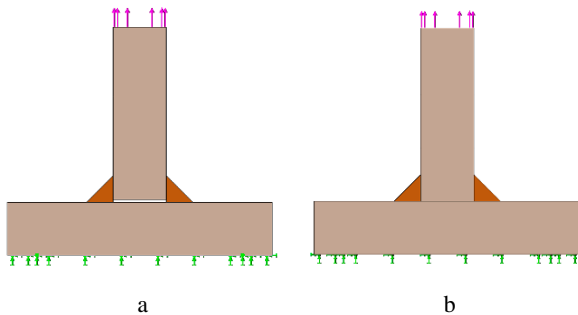


Figure 3 – Calculation scheme for modeling "lack of fusion" as a gap (a) and crack (b)

As a result, there is a gap between welded parts and welds, and this leads to the emergence of a stress concentrator, such as a crack, which can reduce joint durability.

During the screen operation, the tensile force from the vibrator is applied to plate 2 (Figure 2), then through the longitudinal 4 and transverse 5 ribs, this force passes to the pipe 3. The most significant force falls on the longitudinal ribs, and the middle rib turns out to be the most loaded. The simplest model for interacting a plate with a longitudinal rib is considered a T-formed welded joint with a lack of fusion.

The SolidWorks program has two principles for modeling lack of fusion. Firstly, this defect can be displayed as a 1 mm wide rectangular slit. Secondly, the lack of fusion is modeled as a linear crack (Figure 4).

In this case, the crack is modeled taking into account the contact condition of the position of the adjacent faces, called "no penetration". This condition requires a longer calculation time during program operation. In the situation under study, when welds are affected only by tensile force, it is possible to pass to the contact condition of the "penetration is allowed" type.

3.3 Stress analysis in reduced mesh size

In the calculation scheme of a welded joint, modeled according to one or another principle, such a state is provided when a force is applied to the upper end of the rib, and the lower face of the plate is fixed (Figure 3 a, b). To use the FEM in the study of a welded T-formed structure, it is necessary to substantiate the computational mesh parameters. In the computational experiment, the order is set, according to which the average size of each mesh cell is taken from a range of values of 10, 5, and 1 mm. In addition, an additional calculation is made, in which the control of the mesh parameters is introduced, the average cell size of which is 1 mm, setting the transition rate from layer to layer 1.5. Enter the following names of operations: "problem with a gap" is the model calculation shown in Figure 3 a, and "problem with a contact" is the model calculation in Figure 3 b.

The experimental results are presented in Table 1 and in Figure 4. The mesh quality means the maximum ratio between the dimensions of the sides of its cells.

According to the stress-strain state calculation results in Table 1 and Figure 4, the following conclusions can be drawn. The finite-element mesh step should equal the width of the gap between the welded parts. The mesh will have a little over a million nodes in this case. Using the “mesh control” tool decreases the accuracy of stress calculation by 2 % but significantly reduces the volume of the task. The “problem with a gap” experiment shows a 40 % increase in stress levels. If the size of the mesh cells is reduced, then the stress values increase infinitely, necessitating interpolation calculation methods.

Table 1 – Dependence of the maximum equivalent stress and mesh quality on its parameters

| Problem | Mesh type | σ_{max} , MPa | Number of nodes | Mesh quality |
|---------|-----------|----------------------|-------------------|--------------|
| Gap | 10 | 5.1 | $2.28 \cdot 10^3$ | 14.1 |
| | 5 | 5.3 | $1.48 \cdot 10^4$ | 6.0 |
| | 1 | 7.25 | $1.15 \cdot 10^6$ | 4.8 |
| | 5y1 | 7.17 | $2.41 \cdot 10^4$ | 8.4 |
| Contact | 10 | 2.407 | $2.15 \cdot 10^3$ | 7.5 |
| | 5 | 3 | $1.47 \cdot 10^4$ | 4.7 |
| | 1 | 5,2 | $1.16 \cdot 10^6$ | 5.0 |
| | 5y1 | 4.917 | $2.84 \cdot 10^4$ | 4.9 |

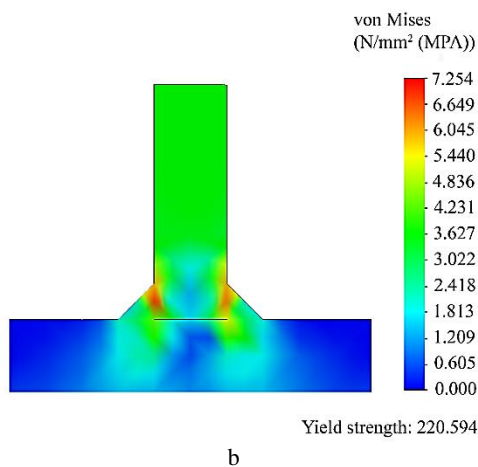
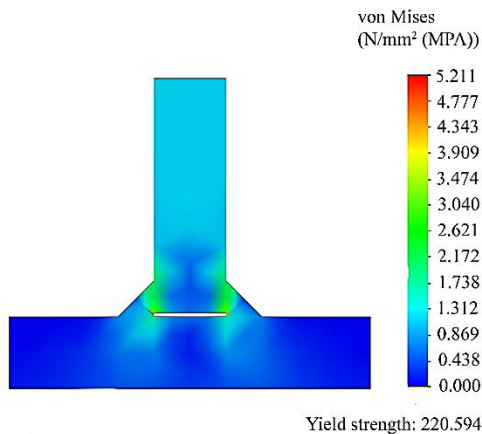


Figure 4 – Dependence of the field of equivalent stresses in a welded joint on the type of mesh operation: a – problem with a gap; b – problem with a contact

According to the HSS method [13], two parting lines are drawn in the rib at distances of $0.5s$ and $1.5s$ from the place where the base metal passes to the weld – point 1 (s is the thickness of the welded plates) (Figure 5).

Calculate the average stresses σ_1 – point 4 and σ_2 – point 5, occurring at the places of the modeled edges, and find the stress at the singularity point σ_{HSS} – point 2 by linearly interpolating the values σ_1 and σ_2 . The calculation results are summarized in Figure 5 and Table 2.

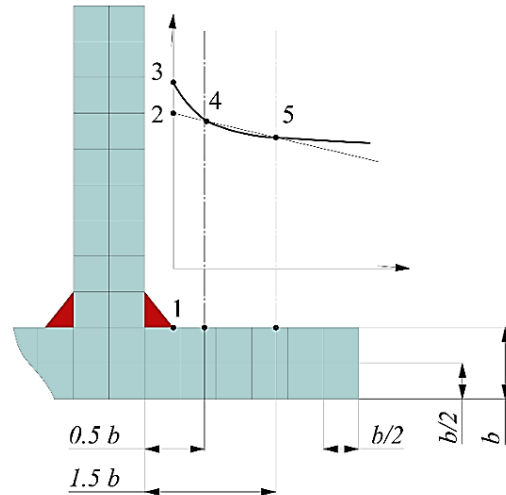


Figure 5 – Determination of stresses in “hot spots” of the junction by the HSS method

Table 2 – Calculation results of the stress by the HSS method

| Modeling type | σ_{max} , MPa | σ_{HSS} , MPa | Degrees of freedom | Mesh quality |
|---------------|----------------------|----------------------|--------------------|--------------|
| Gap | 2.27 | 1.30 | 2284 | 14.1 |
| Contact | 2.07 | 1.27 | 2148 | 7.48 |

In the upper part of the screen body, the stresses of the welds will correspond to the forces generated by the vibrators, and in the lower part of the screen body (provided that inertia forces are neglected), the stresses calculated according to the static mode of this device operation will exceed the dynamic ones by 10–15 %.

Since the main task of calculating the welded structure, SSS parameters is to determine the stresses in the assembly for fastening vibrators, in order to reduce the complexity of the calculations, inertia forces can be neglected, and the static calculation of forces in the screen body can be performed, given its position on the fixed supports. The static stress analysis shows that the screen box is fixed rigidly on the base.

Consequently, the interaction of the vibrators with the fastening assembly is modeled based on the perturbation force $F_p = 12.3$ kN, as provided by the technical characteristics of the vibrator.

4 Results

Methodology testing and the application obtained earlier are used to analyze the screen design. It will be the modeling of a lack of fusion in the assembly for fastening vibrators when there is a gap between the parts of the structure.

Next, we create solid-state models of welds between the following parts: plate – transverse rib; longitudinal rib – pipe; transverse rib – pipe; transverse rib – pipe; flange – pipe.

The model assumes that tensile forces, each equal to 3.08 kN, are applied to four circular bolt fastening sections of each vibrator, while the assembly fastening is modeled as a fixation of the cylindrical faces of flanges.

To determine the areas with the maximum equivalent stress in the weld, a study is performed using a finite-element mesh with a size of 5 mm for each cell.

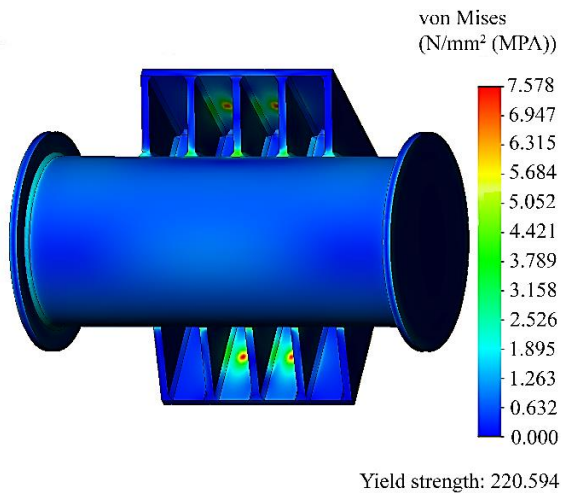


Figure 7 – Results of equivalent stress calculation based on 5 mm mesh

From data analysis, the following conclusions can be drawn. First, the maximum stresses occur at the junction points of the vibrators and the plate, which requires the calculation of forces in bolt joints by standard methods.

Second, the maximum stress in the welds occurs where the longitudinal middle rib is connected to the plate and pipe; therefore, in order to assess the durability of these welds, it is necessary to draw additional parting lines at a distance of 10 and 30 mm from the weld edge and apply the HSS method.

As evidenced by the research, the maximum stress occurs in the first weld of the structure.

In the calculation scheme for determining equivalent stresses using a solid-state screen model, tensile forces of 3.08 kN act on the bolt joint in the vibrator fastening, and four circular sections from the bottom of its sidewalls correspond to the points of the structure junction with stiffening springs.

The calculation results presented in Figure 8 show that the assembly for fastening vibrators to the screen is the most loaded.

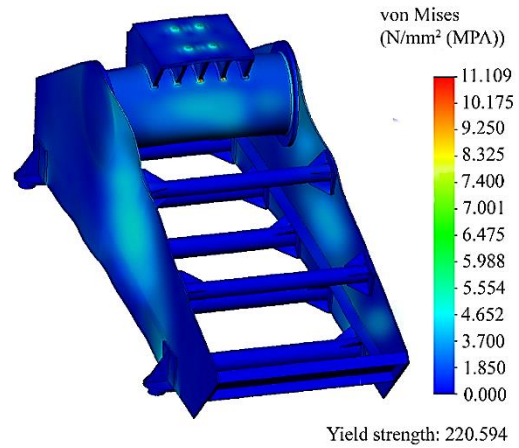


Figure 8 – Stress-strain state of the studied structure

The values of these indicators were analyzed in detail earlier when studying the design of the assembly of the vibrator fastening to the screen. It is known that the ultimate tensile force σ_{-1P} of AISI 1055 carbon steel is 220 MPa, considering normalization.

Determine the permissible stress in the weld of the fastening assembly in this way:

$$[\sigma] = \frac{\sigma_{-1P}}{k \cdot K_{eff}} = \frac{220}{1.5 \cdot 3.5} = 41.9 \text{ (MPa)}, \quad (26)$$

here $K_{eff} = 3.5$ – effective value of the stress concentration factor; $k = 1.5$ – safety factor [13].

Therefore, if the stress arising in the structure is lower than the value $[\sigma]$, then the durability of the welded joints will exceed $2 \cdot 10^6$ cycles, and since the maximum stresses in the welds found by the HSS method are 2.5 MPa, then the duration of the welded screen structure use will not be lower than $2 \cdot 10^6$ cycles [13].

5 Discussion

The following research works can prove the reliability of the proposed methodology. The research [14] optimized jaw crusher parameters, applying the HSS method and static analysis. This approach aims to analyze the stress-strain state of the motionless jaw of a crusher. The main focus of the research is identifying the zones with maximum stress concentration in the construction, which is the key to further optimization.

With the HSS method, it became possible to improve the construction significantly by optimizing the material thickness and reducing the total motionless jaw mass. The author emphasizes that these modifications have made it possible to substantially reduce structural mass by 3 times, improving the crusher's performance and contributing to its efficiency. These results are significant for theoretical and practical developments in the design and optimization of industrial equipment.

Also, the research works [15, 16] studied the stress-strain state of the tubbing erector manipulator, characterized by multiple degrees of freedom. It is based on the use of advanced mathematical and computer modeling methods. Within the framework of this work,

software packages are used to calculate both dynamic and static loads that the mechanism parts undergo during the working cycle of erecting.

Emphasis is placed on the use of SolidWorks Motion and SolidWorks Simulation tools. These tools allow for detailed stress-strain state analysis, including monitoring of stress changes during the tubing erecting cycle. However, the study does not analyze the welds. The HSS method is only used to identify the most stressed areas – stress concentrators, and the analysis of singularity occurring at the transition points from molten weld material to base material is excluded. This aspect is essential for ensuring the reliability and durability of welded joints since it prevents possible defects and ensures a more accurate calculation of loads on welded structural elements.

The research demonstrates the practical application of SolidWorks Simulation in engineering analysis, emphasizing its effectiveness in modeling complex mechanical systems and welded constructions. In this regard, SolidWorks Simulation is a key tool in the papers, providing in-depth analysis and understanding of structural behavior in different conditions. This tool helps to identify potential design flaws and optimize constructions to improve their reliability and durability.

After analyzing the research works [17, 18], it is clear that they rely on classical methods for calculating screens. They use mathematical models and principles of theoretical mechanics while neglecting the spatial representation of the construction. As a result, the physical processes occurring on screens are perceived as challenging. This applies especially to essential aspects such as analyzing stresses and strains caused by the screen operation in the assemblies. Despite the importance of these processes, they are not considered in the presented research. As a result, while the mathematical analysis of the screen model is an important step, it does not cover all the complexity and versatility of the physical processes occurring during screen operation.

On this basis, it can be concluded that conducting full-scale research on welded vibrating screen constructions using modern computer technologies and the HSS method is an urgent scientific task.

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6 Conclusions

During the screen operation, there are areas with a high-stress gradient in the welds of its body, that is, their concentrators. An analysis of the classical methods for calculating the vibrating screen parameters has shown many other disadvantages. For example, if a box is considered a solid body, then it is not possible to determine the stress in its assemblies and assess the durability of the vibrator fastening elements.

In the developed methodology for modeling the stress-strain state arising in the assembly for fastening vibrators, SolidWorks Simulation, SolidWorks Motion, and HSS technology are used.

The methodology has been tested on calculating the forces in the fastening assemblies of the HVCH-31 C screen box welded structure. In this case, it has been determined that for the study of welds, it is necessary to take the situation with the lack of fusion of edges, which is modeled in the form of a gap between welded parts. The results of the stress-strain state analysis show that a decrease in the size of the computational mesh cells leads to an increase in stresses, which indicates the singularity of the problem and the need for further application of the HSS method.

It has become known that the maximum stresses in welds occur where the longitudinal middle rib is connected to the plate and the pipe. It has also been determined that the assembly's use duration for fastening vibrators in the modernized screen structure is at least $2 \cdot 10^6$ cycles.

The research results were implemented during the modernization of screens at the LLC Ukrprommineral enterprise.

In the future, the method will be used as one of the stages of structural analysis in the virtual modeling method of two-drive inertial screens.

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