Metrological control of welded sheet joints

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Abstract. The results of metrological control of welded sheet joints of studies at low-frequency processing are presented. During fusion welding, a field of residual elastic stresses is created in structures, which are extremely unevenly distributed in them. To equalize the stresses, stabilization is performed using special vibration exciters (vibrators) based on low-frequency mechanical vibrations. This provides dimensional stabilization of welded structures made of low carbon steel. The author investigated the process of vibration hardening of welded sheet joints with several combinations of adjustable parameters. As a result, graphs of accelerations and vibration amplitudes of the exciter and the system were obtained. An assessment of the influence of alternating stresses on the value of residual stresses in the welded joint is given. The theoretical studies of the vibration molding process have been confirmed.

1. Introduction
In the manufacture of sheet metal products, fusion welding is widely used. Under the influence of high temperatures in the zone of the welding joint, the physical and mechanical properties of the metal change, residual stresses and deformations arise. Residual stresses change the safety factor of the joint and change the geometry of the products. When sheet welded joints are operated in the vibration mode, redistribution of residual stresses occurs and a change in linear dimensions and the appearance of defects are possible. To ensure the reliability of the operation of welded sheet structures, it is necessary to ensure a rational vibration mode and low-frequency vibration treatment of welded joints.

The works of domestic scientists are devoted to the vibration treatment of welded joints. In works [1-4] the issues of vibration processing of large-sized metal structures are considered. Information on the removal of residual stresses by the method of heat treatment and vibro-shock processes in special devices and equipment is given. The modes of vibration impact on welded joints of metal balls are given. The operation of a welded sheet structure under the influence of a vibration field has significant differences in terms of the oscillatory process and its parameters of the amplitude of oscillations and vibration accelerations. The vibration treatment modes are significantly influenced by the shape of the welded product. The manufacture of products in the form of a hopper is characterized by the angle of inclination of the walls, which must be taken into account when carrying out calculations. Structural analysis is performed for fatigue using the limiting values of vibration processing parameters. In the process of vibration treatment, the distribution of residual stresses and a decrease in their concentration level occur.

In works [5-7] the questions of influence of low-frequency processing of welded joints on the microstructure of the material of the welded material are investigated. When welding products from steel 09G2S, the impact strength is 1.487 and 0.118. Low frequency processing reduces the structural
heterogeneity of the joint. The dispersion of impact toughness is significantly reduced, and the tendency to form a main crack is reduced. The main crack propagates as a viscous one with a subsequent transition to an elastic state. These works provide information on large-sized metal structures. Sheet joints have other parameters in terms of flexibility and, in comparison with large-sized metal structures, have errors that must be taken into account by introducing additional coefficients.

The issues of automation of control of vibration treatment of welded joints are given in [8-9]. These works contain information on mathematical modeling of processes occurring during the operation of welded metal structures. At present, Matlab*Simulink is widely used in the design of welded metal structures. Research in Matlab*Simulink is of great importance, since it allows you to get a large variation of the enumerated parameters. This significantly reduces design time and results with great precision. However, modeling works alone are not enough. It is required to confirm the correctness of the theoretical studies carried out experimentally.

The results of computer simulation of the vibration process of welded sheet joints are given in publications [10-11]. The weak points of the currently available types of mathematical modeling of the process under study are computational difficulties in the course of continuous monitoring, the study of dynamic systems to which this object belongs.

Improving the method for controlling the parameters of welded sheet joints under vibration is an urgent task in increasing the reliability and durability of welded sheet structures.

Purpose of work: increasing the reliability and durability of welded sheet structures.

2. Methods and materials

Figure 1 shows a welded hopper with vibration treatment equipment. A vibration exciter with an adjustable vibration frequency is attached to the metal structure. Vibration exciter IV-05-50 with a power of 0.5 kW, a driving force of 5.0 kN, a rotation speed of 3000 rpm. To measure the frequency characteristics, a digital accelerometer with USB was used, made on the basis of an Analog Devices digital MEMS accelerometer microcircuit with nonvolatile memory on the board (figure 1).

![Figure 1. Device for vibration treatment of welded structures: 1 - welded structure; 2 - accelerometer; 3 - vibration exciter; 4 - control panel.](image)

Vibration processing parameters. $m_1 = 1$ kg - unbalance mass; $m_2 = 100$ kg - weight of the metal structure; $f_0 = 50$ Hz - rotation frequency; $r_0 = 10$ cm - distance from the axis of rotation to the center of
gravity of the unbalance; $C = 10 * 10^3 \text{Ns/m}$ - damping coefficient; $K = 20 * 10^6 \text{N/m}$ - coefficient of elasticity. The $C$ values used in the process are 0.5, 10 and 100 kN/m, and the $t$ values are 10, 100 and 200 s.

3. Results

Vibration machines perform their functions due to the excited mechanical vibrations of the working bodies. In this case, the kinematic and power excitation of vibrations is transmitted to the equipment used in the technological process. Power excitation is carried out by external inertial forces created during the rotation of unbalanced masses.

To generate vibrations, an unbalanced body is usually used, with the rotation of which a centrifugal force occurs:

$$F = m_d \omega^2 r$$

Where: $m_d$ – unbalance mass; $\omega$ - unbalance angular velocity; $r$ – unbalance eccentricity.

A model of a system with one degree of freedom of translational displacement is shown in figure 2.

![Figure 2. Dynamic model of a system with one degree of freedom of translational movement.](image)

The differential equation of motion of the system shown in figure 2 has the form:

$$(m + m_d) x + bx + cx = F \cos \omega t,$$

Where: $m_d$ – mass of the oscillating system; $x$, $x$ and $x$ - acceleration, speed and movement of the system, respectively; $b$ - coefficient of viscous resistance; $c$ coefficient of stiffness of elastic connections; $F$ - the driving force of the vibrator.

The simulation results showed that with a lower hopper stiffness up to 0.5 kN/m and an operating time up to 100, the vibration amplitude was from 0.07 to 0.36 mm. Accelerations in the vertical plane ranged from 0.9 to 4.6 m/s², in the horizontal plane they ranged from 0.7 to 3.2 m/s². An increase in the system runtime from 100 s to 300 s led to completely different readings. Thus, with a system operation duration of 200 s, the vibration amplitude was 0.4 - 0.7 mm. In the vertical plane, the acceleration of the system varied from 2.86 to 4.56 m/s². Despite the increase in the operating time of vibration to 300 s, the vibration amplitude practically did not change; accelerations did not increase much: in the vertical plane up to 3.62 - 6.33 m/s², in the horizontal plane up to 0.5 - 0.9 m/s².

As a result of the analysis of empirical data, it became clear that at the maximum unbalance, the amplitude of oscillations of the bunker walls will be maximum both in the empty and in the loaded state, that is, with the maximum driving force $P_{\text{exc.}} = 8.0 \text{kN}$. At the same time, non-working walls (end walls, racks, frames, etc.) have an insignificant vibration amplitude: 0.3, 0.6 mm. The working walls of the hopper have an amplitude of oscillations: 2.6, 2.2 and 2.0 mm in the loaded state and in the unloaded state - 2.7; 2.9 and 3.1 mm.

Bunker racks at $P_{\text{exc.}} = 8.0 \text{kN}$ have vibrations only in the upper part of the hopper.
Figure 3. Dependence of the amplitude of vibrations of the walls of the bunker on the frequency of vibrations of the vibration exciter.

The vibration amplitude of the hopper walls is described by the equation:

\[ A = -0.001f^2 + 0.13f + 0.43 \]

Where: \( f \) - vibration frequency.

The amplitude decreases towards the middle of the wall with the smallest unbalance, and the corners of the hopper vibrate more strongly, which allows the mixture to be compacted around the frame perimeter and thereby equalizes the density of the entire product. The use of a vibrating unit with an industrial frequency of 50 Hz makes it possible to start the oscillation amplitude of the hopper walls up to 3.2 mm.

4. Discussion
The obtained analytical dependences of vibration accelerations and vibration amplitude of the hopper ensure the constructive safety of quality control of the welded joint by the value of vibration accelerations, in accordance with regulatory requirements with vibration time up to 200 s.

According to the specified conditions for ensuring the stability of periodic movements, it becomes possible to adjust the vibration. To achieve a positive effect, the following parameters should be determined: the amplitude and frequency of vibrations of the tested product, the type and parameters of the excitation system of the required vibrations. The dynamic state of the equipment is characterized by the degree of influence of the oscillatory process depending on the vibration time. With a longer vibration of up to 300 s, the amplitude fluctuations did not decrease much; the acceleration, on the contrary, increased: in the vertical plane to 6.33 m/s\(^2\), in the horizontal plane to 0.9 m/s\(^2\). A rational level of vibration acceleration is provided when the wall stiffness of the hopper is 100 kN/m;

5. Conclusion
The variability of the amplitude of vibrations of the walls of the bunker is linear depending on the action of the driving force of the vibrating device and nonlinearly on the frequency of vibration of the vibrating device. In the range of vibration frequency of 40 - 50 Hz, the greatest amplitude of vibrations of the walls of the bunker of the vibroforming installation is formed.
During the use of a vibration unit with an industrial frequency of 50 Hz, it allows to obtain a swing range of the hopper walls up to 3.2 mm. The theoretical studies of the vibration molding process have been confirmed. The range of vibration amplitude of the bunker walls is not more than 24%.

The permissible values are obtained with the correct choice of the following: the amplitude and frequency of oscillations of the working body, the type and parameters of the oscillation excitation system.

References
[1] Emelyanov R T and Gorobets A A 2002 Measurement of residual stresses Abstracts. Report and conference materials p 101
[2] Lashchenko G K and Demchenko Yu V 2008 Energy-saving technologies of post-welding processing of metal structures p 168
[3] Sagalevich V M, Mezentseva S A and Nasyrov G X 1995 Study of reduction of residual stresses in welded structures of beam type by vibration treatment Welding production 15
[4] Shukhostanov V K, Galyash A A and Ilyichev A A 1993 Vibration machining of large welded structures made of titanium alloys Automatic welding 39
[5] Wang X 2016 ALCOA STARprobe – update in further development for measuring cryolite properties Light Metals p 397
[6] Knorr K 2012 Present progress in fast XRD analysis applying the Rietveld method for 128 bath control The 19th International Symposium and Exhibition of ICSOBA
[7] Feret F R 2012 Phase Quantification of Alumina Using Rietveld-XRD Analysis F R Feret The 19th International Symposium and Exhibition of ICSOBA 402
[8] Yakimov I S, Zaloga A N and Solovev L A 2012 Method of evolutionary structure-sensitive quantitative X-ray phase analysis of multiphase polycrystalline materials Materials 343
[9] Stein H 1982 Schweisen der Holme fur eine 50–MN–Blech–formpresse Blech–Rohre–Profile p 359
[10] Sedek P and Rawicz F 1980 Wplyw drgan na stabilizacje wymiarowa Konstrukcji spawanych Przegląd spawalnicwta p 7
[11] Zarrabian P, Kalantar M and Ghasemi S S 2014 Fabrication and Characterization of Nickel Ferrite Based Inert Anodes for Aluminum Electrolysis Journal of materials engineering and performance 1656