Quality and reliability improvement of “tube-tube plate” welded joints during welding by pulse pressure

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Abstract. The possibility of controlling the impact parameters for improving the quality and reliability of the welded joint of the tube-grid of the heat-exchange apparatus by adjusting the parameters of the discharge circuit of the electrotechnical-logical unit and the angle of cutting the opening of the tube grid is considered. A mathematical model is proposed and simulation is performed to estimate the impact parameters. The results of the simulation showed good agreement with the experimental ones, and the model can be used to calculate the optimum welding regime and improve the quality of the welded joint.

1. Introduction
The reliability of heat exchange equipment that operates at elevated pressures and temperatures, cyclic loads and the presence of corrosive media is largely determined by the quality of the fixed joint “tube-tube plate” that must have the necessary strength, leak tightness and corrosion resistance. For all types of heat exchanging equipment, connection of tubes to tube plates is mainly done by placing the tubes in the holes of a tube plate and fixing them in one of the known ways – flaring, soldering, welding or their combinations (welding-flaring, welding-soldering etc.).

Each of these ways of fastening has its own drawbacks [1-5]. The main disadvantage of fastening tubes in tube plates by the flaring method is the breaking of the connection density during transportation, installation and during operation. Failures, caused by this reason in the initial period, are 30%. Replacement of the rolling bender with the help of arc welding methods increases the reliability of tube-tube plate joints. However, with the presence of a gap between the tube and the tube plate, all the loads taken by the tube during operation, caused by a typical expansion of the tube, its vibration, are transmitted directly to the weld, which can cause its destruction. Therefore, in order to improve the quality of the fixed joint, improvement of the welding method is required. This method should be simple and provide high reliability of the joint.

One of the methods of obtaining fixed joints of the tube-tube plate that corresponds to these requirements is a welding method based on the use of pulsed pressure. Sources of pulsed pressure can be shock waves during detonation of explosives (explosion welding), pulsed magnetic field and an expanding plasma channel of an electric discharge in water. This makes it possible to achieve a high...
rate of deformation of the tube section [1-5], reaching 100-800 m/s. At this speed, the tube wall collides with the tube plate, and under certain conditions, welding is provided.

The aim of the work is to achieve control of the impact parameters for improving the quality and reliability of welding of the “tube-tube plate” fixed joints.

2. Materials and methods of research

In order to achieve the goal of achieving the control of the impact parameters, it is necessary to establish a functional relationship between the impact parameters \( (V_{\text{max}}, \gamma) \), parameters of the discharge circuit of the unit and the geometrical parameters of the edge preparation of the hole of the tube plate. Also one needs to develop an impact model of the surface of the tube and the surface of the tube plate during speed deformation of the tube to optimize the calculation of the impact parameters. Figure 1 shows a schematic diagram of a process for creation of the welding joint tube-tube plate with the use of pulse pressure from an expanding plasma channel of an electrical discharge.

![Figure 1. Welded joint with combined conical preparation.](image1)

![Figure 2. A welding process diagram of the welding joint tube-tube plate: a) preparation for making the joint; b) process of formation of a fixed joint; c) welding joint.](image2)

To determine the welding parameters, a research method based on the use of high-speed photographic registration in the time-lapse mode of the tube distribution process was developed [5]. The method was used in the investigation of welded joints in which a tube 28×4 mm in size is made of AD1 material and
a tube plate is made of material AMg5. The results of microhardness measurements are made with the help of PTM-3 perpendicular to the contact line of two materials in the zone with the maximum wave parameters.

3. Research results and discussion
Figure 3 shows the dependence of the change in technological parameters of impact, made of these materials, at different angles of edge preparation of the holes in the tube plate: $V_{\text{t}}$, $\gamma$, $\gamma$. Obtained dependences show that for all variants of edge preparation of the holes, an increase in the speed and the angle of impact is observed. In addition, there is an increase in the speed of the contact point at the beginning of the conjugation zone of the fixed joint. In this case, compounds with combined edge preparation had a more uniform distribution of the velocity of the point of contact and the angle of impact during the formation of conjugation. When developing the welding technology of the joint based on the use of pulsed pressure from the expanding plasma channel of the electric discharge, we determine the lower and upper boundaries of the existence of a tight metal joints. The lower boundary and the upper boundary for the investigated pairs AD1 + AMG5 were determined by the formulas from [4].

The results of calculating the upper boundary and the lower one are shown in figure 4. The current pulse generator (ETU with a charge voltage of 50 kV, a condenser capacitance of 18 $\mu$F) and industrial cartridges of caliber of 20 mm by [1] were used to carry out the experimental studies.

![Figure 3](image3.png)
![Figure 4](image4.png)

**Figure 3.** Dependence of technological parameters of welding on the angles of edge preparation of the hole of the tube plate: $V_{\text{t}}$ – velocity of wall tossing; $L_{\text{e}}$ is the length of the edge preparation.

**Figure 4.** Boundary conditions for the existence of a welded joints of metals.
From figure 4a it follows that the impact mode curve, obtained experimentally for \( \alpha = 3 \div 12^\circ \), has fallen into the shaded area, in which high quality of the welded joints is ensured. Fig. 4b shows the curves obtained by calculation using the model [2], where \( V_{sr1}(\gamma) \) is the velocity of the contact point without changing the cone angle of the tube plate, \( V_{sr2}(\gamma_1) \) is the velocity of the contact point with the change in the cone angle of the tube plate. For quality control of joints metallographic studies and tests for the transverse and longitudinal distribution of hardness of non-removable joints were made. When carrying out metallographic studies of fixed joints, it is established that there are characteristic zones, the location of which is shown in figure 5 and figure 6.

Figure 5. Macrosections of welded joints: a – with a conical edge preparation of the hole of the tube plate; b – with a combined edge preparation of the hole of the tube plate.

Figure 6. Microsections of the welded joint at 200 magnification: a – conical edge preparation; b – combined edge preparation.
In the presence of conical edge preparation, the holes of the tube plate of zones I and IV have gaps between the tube and the tube plate that, when measured on thin sections with the help of a microscope, are 0.1-0.4 mm. Zones II and III have surfaces with waves, the length and amplitude of which increase in the direction of motion from zone III to zone II. With the change in the angle of the cone, the position and extent of the undulating zone change. When welding a joint with a combined edge preparation of the hole of the tube plate, the presence of waves is noted in zone I-IV, the amplitude of which varies insignificantly over its entire length and exceeds 2-3 times the length of such section with conical edge preparation. This form of contact of the tube with the tube plate greatly increases the strength and tightness of the welded joint. The ones shown in figure 7, the results of measuring the hardness of welded joint materials show slight changes in their hardness along the contact line relative to the initial values. In the contact zone, there is considerable strengthening of metals on the outer surface of the tubes and the inner surface of the tube plate hole. This zone is thin in thickness. The metals of the main part of the tube and the tube plate retained their initial hardness.

![Figure 7. Longitudinal (a) and transverse (b) hardness distribution in a welded joint.](image)

4. Conclusion

It has been found that the use of a combined edge preparation of the holes in the welding of the tube-tube plate joint allows obtaining a more qualitative welded joint than for flat and angular edge preparation, which is confirmed by numerous tests on the hardness and breakdown of joints. Loading joints with a load causes stresses in the tube that are equal or higher than the yield point of aluminium. This leads to the appearance of corrugations or destruction in the cylindrical part of the tube. Subsequent hydraulic tests of fixed joints, obtained during the welding by the energy of conductor electric explosion, as well as cyclic loading with working pressure and temperature up to 250 °C, showed the needed strength and tightness of the welded joints obtained using this method.

References

[1] Kolmakov V P, Buzinaeva E M, Grechneva M V 2007 Sposoby vypolneniya soedineniya trubareshyotka teploobmennyyh apparatov (Irkutsk: IrGTU) pp 71-75
[2] Mazurovskij B Ya 1980 Elektrogidroimpul'snaya zapressovka trub v trubnyh reshyotkah teploobmennyyh apparatov (Kiev: Naukova dumka) p 172
[3] Gulyj G A 1977 Oborudovanie i tehniklicheskie processy s ispol'zovaniiem elektrogidravlicheskogo effekta (Moskow: Mashinostroenie) p 320
[4] Krivickij E V 1986 Dinamika elektrovzryva v zhiddosti (Kiev: Naukova dumka) p 208
[5] Kolmakov V P, Grechneva M V 2009 Sovremennye tehnologii. Sistmenyj analiz, Modelirovanie 3 (27) 45-50
[6] Balanovskiy A E 2017 Welding Int. 31 6 467-476
[7] Balanovskil A E 2016 High Temper. 54 5 627-631