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TECHNOLOGY OF THE FABRICATION OF ROLLED JOINTS WITH INCREASED VIBRATION RESISTANCE

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The development of constructions of heat-transfer apparatus, connected with an increase in the parameters of the working media, has brought about an increase in the requirements imposed on the quality and reliability of rolled joints between tubes and tube grids, including on their vibration resistance. For the selection of means for increasing the vibration resistance, investigations were made of the fatigue strength of rolled joints with regular bending loads.

Three variants of samples of the rolled joints of tubes with a size of 18 × 2 mm with tube grids with a thickness of 50 mm were fabricated for the experiments. The yield point of the material of the tubes was 420 MPa, and of the material of the grid 680 MPa. Samples of the first and second variants were made by the usual technology, using only a roller instrument; here, in the first variant, the tubes were rolled over the whole thickness of the tube grid, including at the inner edge of the opening (with a clearance at the edge), while in samples of the second variant the rolling band started in the tube grid at a distance of 2-3 mm from its edge (rolling with a clearance at the edge).

In samples of the third variant, the tubes were fastened as follows. Before rolling, to exclude twisting of the tubes, they were fastened (clamped) by a special holding mandrel (Fig. 1) at the inner edges of the openings of the tube grid. The principle of the action of the clamping mandrel is as follows. The mandrel is inserted into the tube 5 up to the stop of the ring 3 in the tube grid 4. A special device is used to force the mandrel 1 through the clamp 2. The spherical parts of the mandrel, moving forward, deform the tube up to the appearance of contact stresses at several localized sections around the periphery, which are the clamping zones. After fastening of the tube, it is rolled in the tube grid beyond the clamping zone.

The results of the tests showed that, with preliminary clamping, the absence of torsional stresses in the rolled tube leads to a 75% increase in the limit of the wear resistance of rolled joints in comparison with rolled tubes with a clearance at the edge, and by 42% in comparison with rolling without a clearance at the edge.

In addition, the elimination of torsional stresses simplified the assembly of pieces of apparatus and raises the reliability of their work. As is shown by experience in the fabrication and operation of apparatus

TABLE 1

No. of model	Fastening of tube at edge of opening	Number of open tubes
1	With clearance	9
2,3	Without clearance	2
4,5	With fastening	0

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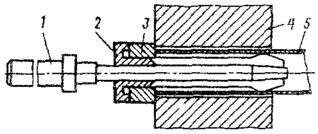

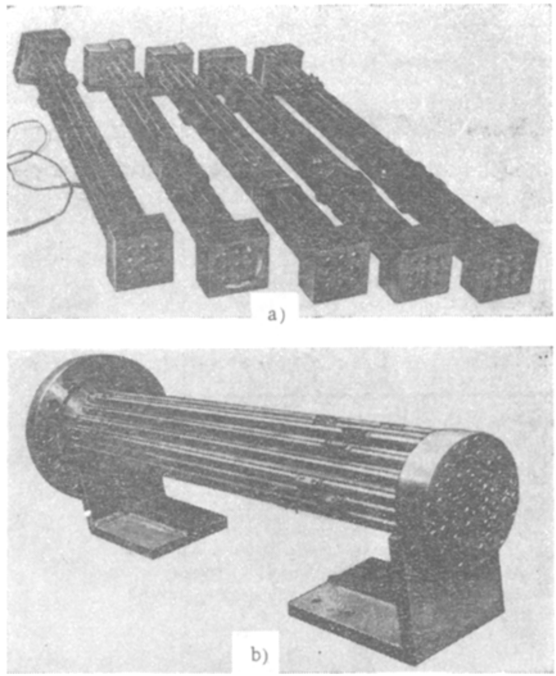

Fig. 1 Fig. 2

Fig. 1. Clamping of tube by holding mandrel.

Fig. 2. Tube models: a) nine-tube; b) 50-tube.

with floating tube grids, twisting of the tubes with rolling brings about a rotation of the tube grids with respect to one another. In the tubes, in particular in the peripheral tubes, there arise residual bending stresses, decreasing the tensile strength of the tubes. With large angles of the twisting, there may even be jamming of the floating tube grid.

A preliminary evaluation of the vibration resistance of rolled joints (without verification of their seal) was made from the results of tests of simplified models of tube bundles in a vibration test stand (Fig. 2a). Such a model is a bundle of nine tubes with a dimension of 18 × 2 mm, both ends of which are fastened in the tube grids in a determined manner. The distance between the internal planes of the tube grids is 1000 mm. Five models with different variants of the technology used in making the rolled joints were fabricated (see Table 1).

In model No. 1, the rolled joints in both tube grids were made by rolling with the formation of a clearance at the inner edges of the openings. This model was used as a reference standard, with whose vibration resistance that of the other models was compared. In models Nos. 2 and 3, the rolled joints were made with a clearance, and, in models Nos. 4 and 5, by rolling with clamping.

Before the vibration tests of the simplified models, to each tube, with the exception of that located at the center of the bundle, there were attached two PKV-10-100 resistance strain-gauges, spaced over one quarter of the length of the circumference of a circle. After this, for all the control tubes, the frequencies of their vibrations were measured and the tubes were tuned to the minimal value of the measured frequencies. For the models investigated this value was 93 Hz. The frequencies were tuned using a concentrated load, which was moved over the length of the tubes and was fastened in a determined cross section of the latter.

After mounting of the tuned models in the vibration test stand, during the course of the tests, the values of the stresses in the tubes were fixed with strain-gauge pickups, and the amplitudes of the vibrations were determined in their mean cross section. The stresses were measured using a dial-type instrument, forming part of a universal measuring device UM-131 (East Germany), and the amplitudes of the vibrations of the tubes were determined visually, using a linear scale. For the best observation and for a more exact measurement of the amplitudes, at the center of a tube there was installed a metal ball with a diameter of 1 mm.

Comparative tests of nine tube models were carried out in two stages. First, all the models were tested simultaneously in a VUS 500/200 single-component test stand, with vibration of the table, which assured that bending stresses equal to 20-25 MPa would be set up in the tubes. Under these circumstances, the frequency of the vibrations of the table of the vibration test stand was 77.5 Hz, and the amplitude 0.2 mm. The amplitudes of the vibrations of the tubes at the middle of their length at the start of the tests were approximately identical for all the tubes, and were equal to 2-2.5 mm. After a 6-h test in one tube of model No. 1, in which the rolling was carried out with clearance at the inner edges of the openings in the grid, there was a sharp increase in the amplitude of its vibrations (up to 8 mm), which attested to the appearance of cracks in it. However, in spite of this, the tests were continued. After 15 h of vibration tests, the amplitude of the vibrations of a defective tube became practically equal to zero, which constituted evidence of a break in the tube. The tests of the models were continued for a period of 25 h. In this case, the amplitude of the vibrations of the remaining tubes of model No. 1, increased somewhat, while for all the tubes of the other models no changes were observed.

After the tests in the stand, the natural frequencies of the vibrations of the tubes were verified. It was found that in model No. 1, except for one (broken) tube, the deviations of the vibrations of all the remaining tubes from the original frequency were up to 40%. In other models, no changes in the frequencies were observed.

However, for comparison of the investigated variants of the rolling of the tubes, the vibration tests were continued under more severe conditions, with the aim of achieving breakdown of the tubes also in the remaining models. Additional tests of the models were made for a period of 20 h and with a frequency of the vibrations of the table of the vibration test stand equal to 90 Hz and an overload of 3.5 g. Since the natural frequency of the vibrations of the tubes was equal to 93 Hz, the chosen conditions of the tests were close to resonance. The maximal amplitudes of the vibrations of the tubes was 7-8 mm. Examination of the models after the tests showed that joints made by rolling with clamping have a higher vibration resistance than joints made by the usual technology (see Table 1).

A final evaluation of the technology of the rolling of tubes with clamping was made on the basis of tests of the vibration resistance (strength and seal) of two multitube model (see Fig. 2b), in one of which the rolling of the tubes was carried out by the usual technology, and in the other with clamping. Each model consisted of 50 tubes measuring 18 × 2 mm, fastened in two tube grids of different diameter. The distance between the inner planes of the tube bundles was 1300 mm. The ends of the tubes, in the length of a section of the rolling were cleaned by polishing with emery cloth. The openings in both tube grids were made by drilling and reaming, with assurance of an initial diametral gap equal to 0.2-0.3 mm. The edges of the openings were blunted on both sides.

After rolling, the seal of the rolled joints was monitored in a special test chamber, inside which a tube bundle of the investigated model was put, using compressed air, pure water, and an aqueous solution of a luminophore. First, compressed air with a pressure of 0.15 MPa was fed into the chamber, and the outer surface of the tube grid, along with the joints, was wetted with a soap solution. Then, after venting-off of the air pressure, the chamber was filled with pure water, and the water pressure was gradually raised to 10 MPa, with holding every 1 MPa.

A final check of the joints was made with an aqueous solution of a luminophore. To a chamber half filled with pure water, there was added a powder of sodium fluorescein in the proportion of 1 g powder for 10 liters of water. The chamber was then completely filled with water, and the pressure of the water was gradually raised to 10 MPa. After holding for a period of 30 min, the pressure was increased to 14 MPa. After wetting of the joints, they were examined visually using an ultraviolet lamp. No leaks were found in any of the above tests.

Before the vibration testing of the models, in 13 control tubes, arranged over the inner contour of a bundle, strain-gauge resistance pickups were attached with an adhesive. These were used to tune the tubes to the natural frequencies, equal to 57.1 Hz. With a frequency of the vibrations of the table of the vibration test stand equal to 45 Hz, and an overload of 5.7 g, the stresses arising in the tubes were equal to 22-25 MPa. The vibration of one of the control tubes in a model with rolling of the tubes with clamping took place with a bending stress of 49 MPa. Models with 50 tubes were tested for a period of 13 h. During the tests, the amplitude of the vibrations of the tubes was monitored every 2 h.

To check the seal of the rolled joints and the integrity of the tubes, after the vibration tests, hydraulic tests of the models were carried out. To this end, the models were mounted in a chamber, which was filled with an aqueous solution of a luminophore. Density tests were made with a gradual increase in the pressure, at first up to 10 MPa with holding for 30 min, and then up to 14 MPa with holding for 10 min. In a model, in which the rolling of the tubes was carried out using the usual technology, with hydraulic tests, carried out after 6 h of vibration tests, cracks were observed in ten tubes along sections located at the inner edges of the openings of the tube grid. In a model with rolling of the tubes with clamping, over the whole range of pressures, there was no penetration of the testing medium into the tubes, or of any luminescent luminophore into the rolled joints.

Tests of 50-tube models showed the high reliability of rolling with clamping, which allows a considerable increase in the vibration resistance of rolled joints in present-day constructions of heat-transfer apparatus.