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EXPERIMENTAL STUDY OF THE PROCESS OF WELDING OF PIPE BILLS UNDER VIBRATION IMPACT

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Abstract. *The article proposes an effective way to reduce the residual stresses arising in the welded seams of pipes, based on the use of vibration in the welding process. The experimental study was divided into the following stages: welding of longitudinal preformed pipe blanks using vibration action; fixing the value of residual stresses in the weld and the heat-affected zone of the samples obtained during the experiment; the processing of the data obtained during the experiment. Measurements were carried out in the cross-section of the samples, which made it possible to obtain data on the residual stresses contained in the weld, near-seam zone, and the base metal of the pipe. The tendency of changes in residual stresses at various frequencies of vibration, as well as in its absence, has been investigated, which made it possible to estimate, in percentage terms, the efficiency of removing residual stresses depending on the frequency of vibration.*

Key words: *Vibration processing, welded seam, near-weld zone, residual stresses, pipe billet, vibration frequency.*

1. Introduction

Currently, great importance is attached to the technical aspects of obtaining high-quality pipe production. A significant role in this issue is assigned to the production of welded pipes with improved strength characteristics, which is achieved by reducing the residual stresses arising in the process of applying a weld.

Each of the known methods for reducing residual stresses has a more or less limited area of rational application, therefore, it becomes necessary to both improve existing and search for fundamentally new methods of post-weld treatment of joints in order to remove residual stresses, as well as harden, stabilize geometry, and change the structural state.

2. Direct problem

To date, reliable information has been obtained on the positive effect of vibration on the refinement of the crystal structure, reduction or complete elimination of the transcrystallization zone due to the growth of equiaxed crystals, decrease in zonal and dendritic heterogeneity, and increase in the mechanical and special properties of metals and alloys [**1**, **2**].

Production experience in obtaining welded joints made of steels of various modifications has shown that the use of vibration treatment in the process flow after welding provides a decrease in residual stresses up to 50% [**3**, **4**].

Thus, it becomes necessary to conduct experimental studies aimed at removing residual stresses by means of vibration directly during welding.

3. Analysis of publications on the topic of research

Known scientific works [**5-7**], which provide the results of studies of the wave theory of plastic deformation. The works consider the possibility of the practical application of vibration waves to stimulate the plastic flow of solid crystalline bodies. However, vibration in these works is used during cold deformation of workpieces, while the pipe production process involves heating the edges of the workpiece either to a liquid component (fusion welding) or to a temperature corresponding to the technological process (pressure welding).

Also, according to well-known studies [**8**], vibration treatment of welded specimens made of low-carbon steel in modes that ensure the flow of elastic-plastic deformations allows one to reduce stresses of the first kind, measured by the tensothermal method, by 50 - 60%, and heat treatment by 70% or more. ... The stresses of the second kind in the fusion zone, determined by the X-ray method, after vibration treatment are reduced by 45%, and after heat treatment - by 65%.

However, in these studies, vibration treatment was used after the final crystallization of the weld metal and the formation of total residual stresses, while in [**9-16**], the positive effect of vibration on the molten metal during crystallization was proved.

This creates real prerequisites for the use of vibration during the crystallization of the weld in the production of longitudinal seam pipes and requires a series of experiments to confirm this assumption.

4. Purpose of the study

The purpose of this study is to identify patterns of change in the level of residual stresses when welding pipe blanks using the vibration of various frequencies.

5. Presentation of the main material

Experimental studies of the influence of vibration on the value of residual stresses were carried out in the laboratory of the Department of Technological Design of the National Metallurgical Academy of Ukraine. The measurement of residual stresses in the samples by the metal magnetic memory method was carried out at the Pridneprovsk center for non-destructive testing and technical diagnostics.

The experiment was carried out:

- welding of longitudinal preformed pipe blanks using vibration action;
- fixing the value of residual stresses in the weld and the heat-affected zone of the samples obtained during the experiment;
- processing of the data obtained during the experiment.

The initial billet was obtained at the enterprise of LLC "DMZ KOMINMET", molding was carried out in the electric-pipe shop No. 2 using the TPESA 20-114 pipe-profile electric welding unit. As an initial billet for the experiment, a formed pipe billet without applying a weld seam was chosen, produced according to TU 14-236-15-93 "Electric-welded steel pipes for domestic needs". The main characteristics of the blank for the experiment are presented in Table 1.

Table 1.

Characteristics of the original stock

Parameter	*Value*
Outer diameter, mm	89
Wall thickness, mm	4
Steel grade	3PS (GOST)
Heat number	1010610

Chemical composition of 3PS steel:
Carbon - 0.14-0.22%;
Silicon - 0.05-0.15%;
Copper - up to 0.3%;
Manganese - 0.4-0.65%;
Nickel - up to 0.3%;
Nitrogen - up to 0.008%;
Phosphorus - 0.04%;
Chromium - up to 0.3%;
Sulfur - up to 0.05%;
Arsenic - 0.08%.

Billets made of 3PS steel can be welded using almost all modern methods: manual arc welding, electroslag welding, and contact-spot welding, submerged arc welding, and gas shielding, while the alloy does not lose its positive properties. If the thickness of the steel is more than 36 mm, it is recommended to subject the metal to heating and heat treatment.

Due to its prevalence and maximum proximity to the industrial conditions of pipe production, the inverter welding method was chosen for the experiment on welding samples. During the experiment, a Powercraft PWI-245 welding machine was used.

In the process of welding, electrodes of the MONOLIT RC brand with a diameter of 4 mm were used, designed for manual arc welding with direct or alternating current. These electrodes are used when welding ordinary and critical structures made of low-carbon steel grades and are used in all spatial positions (except for vertical from top to bottom for electrodes with a diameter of 5.0 mm).

Tables 2 and 3 show the chemical composition and mechanical properties of the weld metal, respectively.

Table 2.

Chemical composition of the deposited metal, %

Mn	Si	C	P	S
0,40-0,65	0,15-0,40	≤0,11	≤0,035	≤0,030

Table. 3.

Mechanical properties of the weld metal

Temporary resistance, H/mm^2	Relative extension, %	Impact strength, Дж/см^2
≥ 450	≥ 22	≥ 78

On the basis of calculations, a vibrating table was developed and constructed for the experimental processing of pipe billet samples according to the above theoretical studies. By constructing mathematical models, the optimal location of the vibration unit relative to the vibration table was found and a rational choice of vibration supports was made. Figure 1 shows all components of the vibrating table assembly.

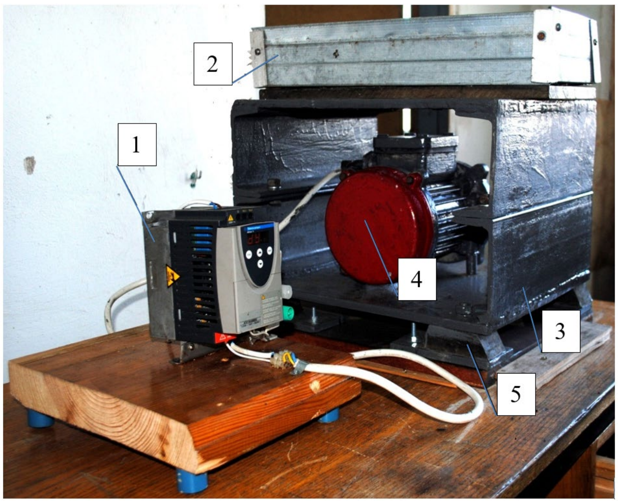


Fig. 1. Vibrating table: *1 - frequency converter; 2 - vibrating table working surface; 3 - vibration table frame; 4 - engine; 5 - vibration mounts*

The vibrating table uses a platform electromechanical vibrator model EV - 1000, which is designed to create periodic oscillations. The principle of operation of this device is based on the conversion of the supplied electrical energy into the energy of mechanical vibrations - vibration.

The workpiece, obtained at LLC "DMZ KOMINMET", was divided into samples of the same length of 150 mm, which were subsequently welded under the influence of vibration. The distribution of samples according to vibration frequency is shown in Table 4.

Table 4.

Distribution of samples according to vibration frequency

Номер образца	1	2	3	4	5	6	7	8	9	10
Частота вибрации, Гц	0	10	25	50	75	100	125	150	175	200

The duration of the vibration effect was determined by the time of solidification of the metal in the welded pool of the processed pipe billet.

To obtain the most complete information on residual stresses, measurements were carried out in the cross-section of the samples with a ИКН-1М-4 device. The measurement was carried out with a fixed speed of the sensor movement. Thus, the study area included both the weld and the heat-affected zones on both sides of the axis of the weld, and the base metal of the pipe. Figure 2 shows a schematic diagram of making measurements.

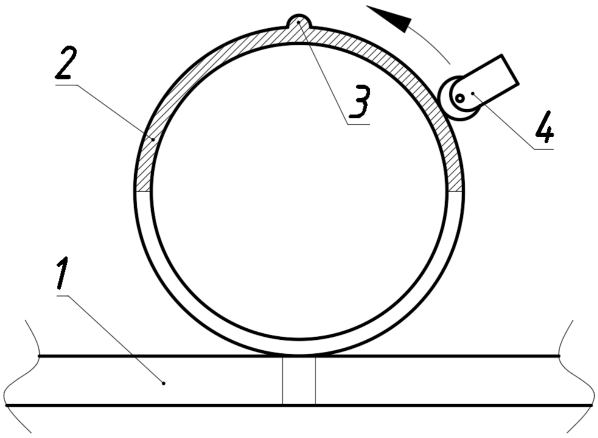


Fig. 2. Schematic diagram of making measurements:
1 - vibrating table; 2 - research area; 3 - weld bead; 4 - sensor.

The samples were measured with a sensor with two flux-gate transducers. When setting up the software, before taking measurements, the corrective parameters of the workpiece were introduced, presented in Table 5.

Table 5.

Corrective parameters of ИКН -1М-4 settings

Parameter	Value, mm
The thickness of the metal of the test sample – S	4
Weld width – b	15

The analysis of the obtained results was carried out with the help of the software "Program for processing control results by the Magnetic Memory Method", produced by the "Energodiagnostika" company.

With the help of the analysis module built into the program, the obtained data were processed and the average K_{av} values were derived - the weighted average value of the intensity of the change in the stray magnetic field H_p.

6. Research results

The quality of welded joints with such a control method is evaluated by the nature of the distribution of the stray magnetic field H_p and by the values of the magnetic intensity factor of the change in this field along the length for each measurement channel and between the channels.

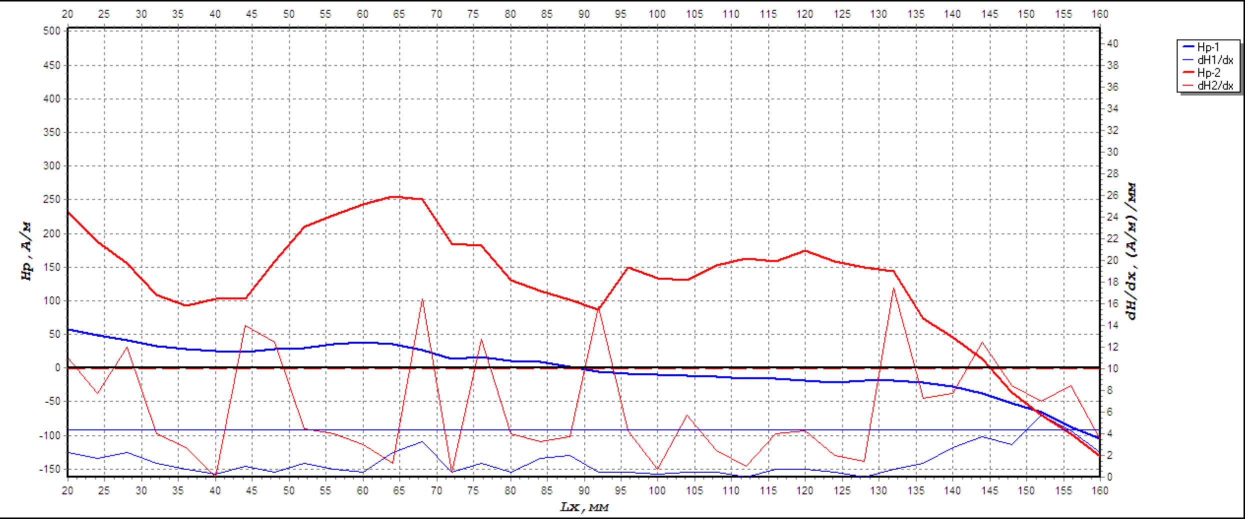
In this experiment, the ratio of the average values of residual stresses K_{av} was analyzed in comparison with the analogous parameter of the first sample welded without vibration. The K_{av} value is a key parameter of this experiment, characterizing the average value of the residual stresses.

Tables 6 and 7 present data cards of residual stress measurements for samples 1 and 4. Sample 1 was welded without the use of vibration, and sample 4 with the use of vibration at a frequency of 50 Hz.

According to the guidelines for the technical diagnostics of vessels and devices using the magnetic memory method (MMM), the most prone to the development of damage are the areas of the welded seam, where the maximum intensity factors K_{max} of the heteropolar distribution of the H_p field between adjacent measurement channels and / or the maximum value of the intensity factor are recorded dH/dx changes in the H_p field on any of the measurement channels.

Table 6.

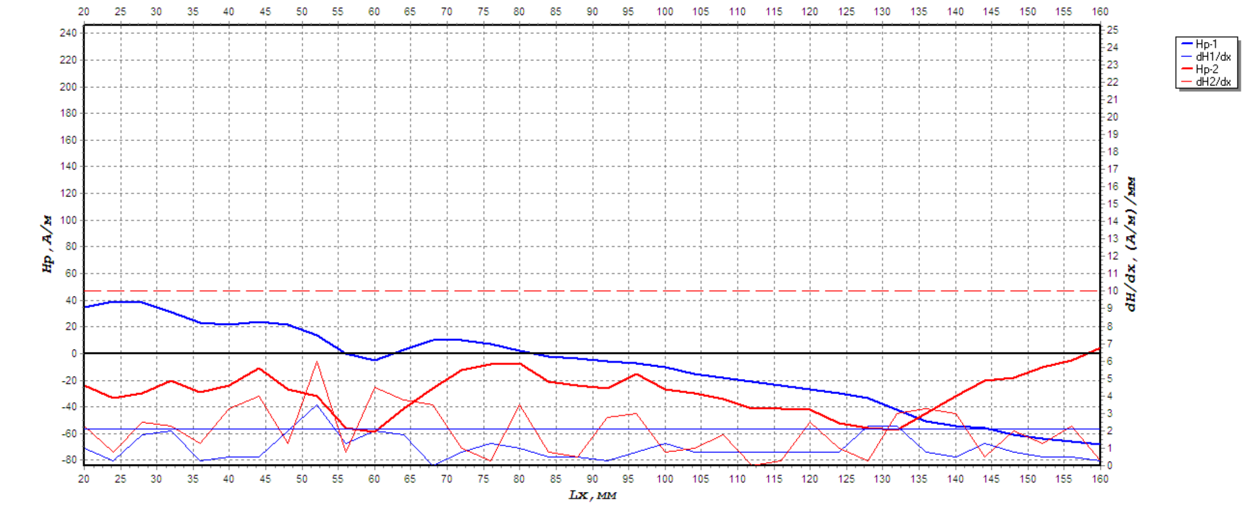
Data card for sample 1.



Vibration frequency, Hz	Extreme values of Hp		Kmax	K_{av}
	max	min		
0	255	-132	22,01	10,307

Table 7.

Data card for sample 4.



Vibration frequency, Hz	Extreme values of H_p		Kmax	K_{av}
	max	min		
50	39	-68	6,738	2,947

Since the magnitude of residual stresses can be influenced by various factors, such as non-metallic inclusions and defects in the weld, the nature of the distribution of stresses in the cross-section in the graphs may not describe the complete distribution pattern, but it gives a clear understanding of the average residual stresses in the entire sample.

Analyzing the tendency of the residual stresses, traced over the entire measurement range, it is possible to construct a graph describing the regularities of the change in the level of residual stresses described by the K_{av} parameter when welding pipe blanks using vibration of various frequencies (Fig. 3).

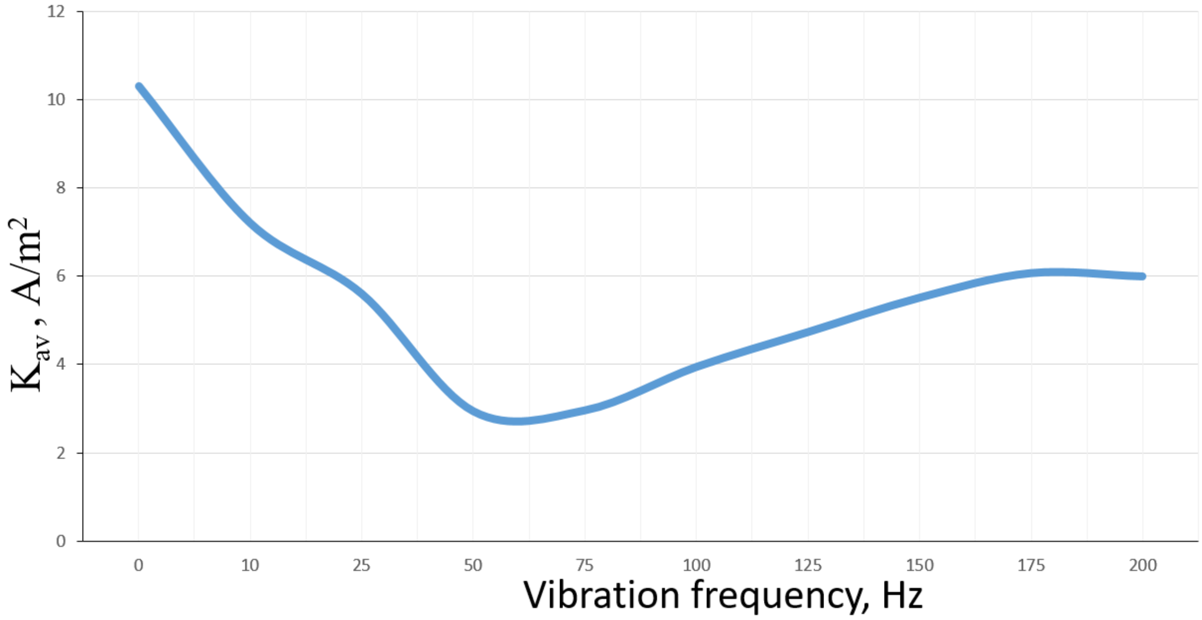


Fig. 3. Dependence of the level of residual stresses on the vibration frequency applied during the welding process

As can be seen from Figure 1, without the use of vibration, the pipe specimen has a very high residual stress level - 10.307 A/m^2, that is, it is considered to contain the full volume of residual stresses physically realized within the framework of this experiment (100%). The values of all subsequent samples that underwent the procedure for relieving residual stresses by applying vibration during welding were compared with sample 1 and the values of relieving residual stresses at a specific vibration frequency were recorded as a percentage.

Sample 2 was subjected to vibration of 10 Hz during welding, while a positive effect of vibration is traced - the residual stresses of the sample decreased by 30.11%. With an increase in the vibration frequency to 25 Hz in sample 3, you can see a more intense removal of residual stresses – 45.63%.

The most successful results were achieved when using a vibration frequency of 50 Hz on sample 4 - removal of residual stresses of 71.41%, and when using a vibration frequency of 75 Hz on sample 5 - removal of residual stresses 71.20%.

A further increase in the vibration frequency demonstrates a decrease in the efficiency of removing residual stresses in the range from 61.67% at 100 Hz in sample 6 to 41.78% at 200 Hz in sample 10. Presumably, this is due to the dissipation of the vibration force directed to the objects of study. The vibration frequency at the time is too high to be perceived by the weld metal. The total volume of the values obtained during the experiment is presented in Table 8.

Table 8.

Values obtained during the experiment.

Sample number	Value K_{av}, A/m^2	Vibration frequency, Hz	Residual stress reduction level, %
1	10,307	0	-
2	7,204	10	30,11%
3	5,604	25	45,63%
4	2,947	50	71,41%
5	2,968	75	71,20%
6	3,951	100	61,67%
7	4,74	125	54,01%
8	5,518	150	46,46%
9	6,075	175	41,06%
10	6,001	200	41,78%

7. Conclusions

1. Conducted analytical studies of the effect of vibration on the residual stresses of the weld have shown the need for research aimed at reducing the residual stresses directly in the welding process.

2. As a result of the study of the welding process on preformed pipe billets with the use of vibration exposure, the regularity of the intensity of the removal of residual stresses relative to the vibration frequency was established.

3. Analyzing the data obtained for a given standard size of pipes and steel grade, the optimal vibration frequency was established, at which the most intensive removal of residual stresses, equal to 50 Hz, occurs.

References

1. Moroz LS. *Mechanics and Physics of Deformations and Fracture of Materials*. Leningrad: Mashinostroenie, 1984, p. 223.

2. Gorenko VG, Rusakov PV. Static and dynamic methods of reducing the level of residual stresses and stabilizing the size of olives. In : *Improving the reliability and durability of cast parts: collection of scientific works of the Academy of Sciences of the Ukrainian SSR Institute of Casting Problems*, 1987, pp. 23-39.

3. Mayboroda VP, Kravchuk AS, Kholin NN. *Rapid deformation of structural materials*. M .: Mechanical Engineering, 1986, p. 264.

4. Zuev LB. On the formation of plasticity autowaves during deformation. *Metallofizika i newest technologies* 1994; 16: 31-36.

5. Balakin VF, Kuznetsov EV, Didyk RP. Physical foundations and practical application of the wave theory of plastic deformation. *Theory and practice of metallurgy* 2006; 3: 39-50.

6. Kuznetsov EV, Conditions of vibroplastic resonance occurrence in metals . *Forging and stamping production. Material processing by pressure* 2002; 2: 6-9.

7. Morozenko VN, Didyk RP, Kuznetsov EV, Balakin VF. The regularity of plastic behavior of viscoelastic and viscoplastic media under conditions of their

developed vibroplastic deformation. *Scientific discoveries (collection of brief descriptions of scientific discoveries, scientific ideas, scientific hypotheses*) 2001, pp. 56 - 58.

8. Skakovskiy VD. *Development of technology for vibration treatment of frame-type welded structures.* For a job. learned Degree, K.: Publishing house E.O. Patona IES, 1987.

9. Mezhidov VKh., Askhabov KhI., Eldarkhanov AS. and et al. *Vibration influence on crystallization of organic ingot. Influence of external influences on liquid and crystallizing metal*. For a job. learned Degree, Kiev: IPL of the Academy of Sciences of the Ukrainian SSR, 1983.

10. Taranov ED., Nuradinov AS., Kondratyuk SE. et al. Crystallization and structure formation of steel ingots under vibration impact. *Casting processes*,1998; 3-4: 84-90.

11. Balakin YuA., Gladkov MI. Energy intensity of external influence on solidifying metal from the standpoint of thermodynamics. Izv. universities. *Black metallurgy*, 2001; 6: 44-46.

12. Gladkov MI, Balakin YuA, Goncharevich IF. Thermodynamic analysis of the conditions of nucleation and growth of crystals during vibration treatment of metal. *Izv. universities. Black. Metallurgy* 1989; 9: 27-29.

13. Efimov VA., Eldarkhanov AS. *Technologies of modern metallurgy*. M.: New technologies, 2004, p. 784.

14. Servetnik VM, Solyanikov BG, Nosov VA. Improvement of the quality of steel ShKh15 by vibro-processing of ingots. *Steel* 1987; 4: 48-49.

15. Eldarkhanov AS. *Application of physical methods of modeling to study the effect of vibration on the solidification of alloys*. Dis. Dr. tech. sciences, Kiev, Ukraine ,1996.

16. Balakin YuA., Gladkov MI. Calculation of the parameters of vibration treatment of crystallizing metals. *Izv. universities. Black. Metallurgy* 2003; 9: 56-60.