The use of magnetic flaw detection to control the offset of the edges of the welded joints of technological pipelines

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Abstract. The task was set of developing recommendations for identifying areas of displacement of the edges of the welded joints of abutting pipes, as well as identifying potentially dangerous sections of welded joints of technological pipelines by changing the normal component of the constant magnetic field. For research, 24 pipe fragments made of steel 20 with a length of 45 mm each were selected. The authors developed recommendations for identifying the presence and zone of displacement of the edges, as well as identifying potentially dangerous sections of welded joints of technological pipelines using the flux-gate control method. It is proposed to use the obtained maximum values of the normal component of the constant magnetic field for the objective detection of edge displacement zones and the determination of potentially hazardous areas. It was shown that the normal component of the constant magnetic field, is quite sensitive both to the displacement of the edges of the welded joints of the pipes and to the quality of the weld, its geometry, defectiveness and determines the above indicators with various characteristic values.

1. Introduction

At the enterprises of the oil refining and petrochemical industries, technological pipelines occupy one of the leading places in the metal consumption of the equipment of technological installations and are used to transport combustible, explosive, and fire hazardous and toxic substances. In the conditions under consideration, they are technical devices operating at hazardous production facilities, which are subject to increased requirements in terms of reliability, reliability and industrial safety throughout the life cycle stage [1-3].

One of the important components of the life cycle of a pipeline is its installation before operation, as well as repair after a certain time [4]. During installation and repair work related to welding, various defects of welded joints are formed, affecting the period of further work. One of the most significant aspects that determine the maximum service life of pipeline systems is the presence of a displacement of the edges of the abutting elements in the weld zone [5, 6]. The aforementioned defect has a negative effect on further operation under vibration loads acting on the pipeline. Moreover, the reduction in endurance directly depends on the amount of displacement of the edges [7, 8].

According to statistics, in all cases associated with welding on the pipeline, there is a displacement of the edges by at least 10% of the thickness of the joined elements.

Currently, the following non-destructive testing methods are used to identify the amount of edge displacement [9-12]:

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• visual and measuring;
• radiation;
• ultrasound.

However, the limited conditions for the applicability of these methods, as well as the rather sophisticated technology of the radiation and ultrasonic control methods, do not always allow them to be used and to qualitatively evaluate the technical condition of the object, and sometimes make their use inappropriate.

In this regard, an important and urgent task is to develop recommendations for determining the presence of edge displacement and identifying the displacement zone with non-destructive testing methods, with the aim of identifying potentially hazardous areas in a timely manner to ensure reliable operation of the equipment and the inadmissibility of premature failure in the weld zone [13, 14].

As the results of studies [1-4] show, one of the promising methods for identifying the “problem” zones of metal oil and gas equipment are electromagnetic control methods. In this regard, the authors proposed the use of the ferromagnetic control method, as one of the most informative. The flux-gate method of non-destructive testing is based on the detection by a flux-probe transducer of the magnetic field of the defect scattering on magnetized products and converting it into an electrical signal.

2. Experiment
For research, 24 pipe fragments made of steel 20 with a length of 45 mm each were selected. 12 pipe fragments with dimensions of 108–6 mm and 12 pipe fragments with dimensions of 219–6 mm. Fragments with the same structural dimensions were welded together by different types of welding with different displacements of the edges of the elements being welded, forming fragments of welded joints of technological pipelines (table 1).

The magnetic characteristics were measured using an F-205.30A magnetic flux-gate device, which is designed to detect defects in magnetized ferromagnetic parts, including welded structures, as well as to measure the components of the constant magnetic field strength ($H_n$, $H_0$) and the gradient of the constant magnetic field strength ($G$) on the surfaces of parts and in free space.

At the initial stage of measuring the magnetic characteristics, a mesh of 10 × 10 mm in size was deposited on each welded fragment.

The surface area of the fragment was measured at a length of 45 mm on each side of the weld. Each measurement zone is a square 10 × 10 mm in size. Three measurements were made in these squares, and the average value was taken as the final result. The normal component of the constant magnetic field $H_n$, A / m, was taken as the determining parameter. Measurements of the magnetic characteristics for each zone of the welded fragments were carried out counterclockwise from the reference point, which is the same for all measured zones.

Examples of typical graphs of changes in the normal component of the constant magnetic field $H_n$, as well as photographs of the places of the weld from the inside and outside, corresponding to the zones of peak and zero average values of the normal component of the constant magnetic field are shown in Figures 1-5.

According to the results of the measurements, it was found that the fluxgate control method is sensitive to the displacement of the edges of the welded joints of the pipelines and the weld joints. In the presence of edge displacement zones, the values of the normal component of the constant magnetic field $H_n$ are maximum in these zones, and they are also characterized by peak values in the places of damage on the inner and outer surfaces of the welded joint, and in areas of the maximum width and height of the weld. For sections of the minimum width and height of the weld, the minimum values of the normal component of the constant magnetic field $H_n$ are characteristic, and for areas of the "locks" of the weld, extended sections of zero values.

Based on the results obtained, recommendations were developed for identifying the zone of edge displacement, as well as for identifying potentially dangerous sections of welded joints of technological pipelines.
Figure 1. Distribution of the average value of the normal component of the constant magnetic field along the scan length of a welded joint fragment with dimensions of 108 × 6 mm with a 1 mm offset of the edges made by semi-automatic welding in zones 1-4 and the heat-affected zone of the left side of the welded joint fragment relative to the welded seam.

Figure 2. Photos of the weld seams from the inside and outside, corresponding zones of peak and zero average values of normal component of a constant magnetic field.

Figure 3. Distribution of the average value of the normal component of the constant magnetic field along the scan length of a welded joint fragment with dimensions of 108 × 6 mm with an offset of 1 mm edges performed by manual arc welding in zones 1-4.
Figure 4. Distribution of the average value of the normal component of the constant magnetic field along the scan length of a fragment of a welded joint with dimensions of 219 × 6 mm with an offset of the edges 1 mm, performed by semi-automatic welding, in zones 1-4.

Figure 5. Distribution of the average value of the normal component of the constant magnetic field along the scan length of a fragment of a welded joint with dimensions of 219 × 6 mm with an offset of the edges 1 mm, performed by manual electric arc welding, in zones 1-4.

The procedure for detecting the presence and zone of edge displacement, as well as identifying potentially dangerous sections of welded joints of technological pipelines using the flux-probe control method, should include the following points:

- installation (repair) of the process pipeline;
- scanning of butt welded joints with a flux-probe control method around the entire circumference of the weld in order to measure the normal component of the constant magnetic field Hn in the initial state;
identification of the presence of a displacement of the edges and the displacement zone, as well as the determination in which direction the displacement relative to the axis of the welded fragment occurred

determination of the permissible displacement of the edges of the joined elements by non-destructive testing methods in accordance with the standards established by the technical documentation (based on the results obtained, the object is either rejected or allowed for further operation);

entering into the pipeline passport the results of measurements of the normal component of the constant magnetic field \( H_n \) in the initial state;

operation of the pipeline for a certain period of time (the period of time is set depending on the degree of responsibility and operational parameters);

re-scanning of butt welded joints with a flux-probe control method around the entire circumference of the weld in order to measure the normal component of the constant magnetic field \( H_{n1} \) after a certain time has elapsed;

determination of the ratio of the normal component of the constant magnetic field \( H_{n \text{source}} \) in the initial state to the normal component of the constant magnetic field \( H_{n1} \) after a certain time \( H_{n \text{source}} / H_{n1} \);

identification of areas with a large change in the ratio \( H_{n\text{output}} / H_{n1} \);

a more detailed study of these areas using other non-destructive testing methods;

rejection or further exploitation, until the next re-scanning of butt welded joints with a flux-gate inspection method over the entire circumference of the weld in order to measure the normal component of the constant magnetic field \( H_{n1} \) after a certain time has elapsed.

3. Conclusion

The developed recommendations for identifying edge displacement zones, as well as for identifying potentially hazardous sections of welded joints of technological pipelines, must be applied after installation or repair of sections of the technological pipeline to better assess the technical condition and prevent accidents for technical reasons. The advantage of the above developed methodology is:

firstly, the sufficient simplicity of using the flux-gate monitoring method, and secondly, its sufficiently high information content, based on characteristic changes in the values of the normal component of the constant magnetic field \( H_n \):

- in the form of extrema - in the areas of displacement of the edges;
- peak values - in the zones of damage present, both from the outside and from the inside, as well as in places of maximum width and height of the weld;
- minimum values of the normal component of the constant magnetic field in the zones of the minimum width and height of the weld;
- extended sections of zero values of the normal component of the constant magnetic field in the zones of the "locks" of the welded joint.

This method allows, with minimal economic and time costs, to conduct a full scan of the weld from the outside and identify “problem” areas and zones that, during further operation, can manifest themselves on the negative side, being centers of destruction and premature failure of the process pipeline as a result of emergency situations.

References

[1] Bolotov S V, Belyagov A M and Vorobyov A O 2007 Bulletin of the Belarusian-Russian University 4 (17) 40–6

[2] Gorkunov E S, Povolotskaya A M, Tueva E A, Goruleva L S and Zadvorkin S M 2011 Defectoscopy 12 3–16
[3] Chirkova A G, Makhutov N A, Rubtsov A V, Naumkin E A and Andryu A B 2007 *Residual resource of oil and gas equipment* 2 38–46
[4] Chirkova A G, Makhutov N A, Rubtsov A V and Gaidukevich U P. 2007 *News of Universities. Oil and gas* 5 100–5
[5] Kulakov P A, Kutlubulatov A A and Afanasenko V G 2018 *SoCAR Proceedings Issue* 2 p 41–8
[6] Roxas, Cheryl Lyne C. Lejano, Bernardo A. 2019 International Journal of Geomate 16 (56) 79–84
[7] Khasanov RN, Valiev A S and Kuzeev I R 2018 *MATEC Web of Conferences* 224 04025
[8] Khasanov RN, Valiev A S and Kuzeev I R MATEC Web of Conferences IOP Conference Series: Materials Science and Engineering 327(4) 042012
[9] S G F Cordeiro and E D Leonel 2018 *Applied Mathematical Modelling* 63 415-44
[10] M Cozzani, A Azizi, S Eslami, A Pirhadirod and A Jamilian 2019 *International Orthodontics* 17(1) 45-52
[11] K Jee-Sang, Y J Jo, K S Yoo and B H Woo 2018 *Proceedings of the Annual International Conference on Architecture and Civil Engineering* 216379
[12] E Doncheva, B Medjo, M Rakin, S Sedmak and B Trajanoska 2018 *Procedia Structural Integrity* 13 483-8
[13] K Laha 2014 *Procedia Engineering* 86 195-202
[14] Y Liu, S Tsukamoto, T Shirane and F Abe 2013 *Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science* 44(10) 4626-33