The assessment of the individual resource of the welded joint during repairs of the technological pipeline

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Abstract. The relevance of research is due to the necessity to develop recommendations for assessing the "individual" resource of welded joints of technological pipelines using non-destructive testing methods for the timely detection of welds with the smallest resource to ensure reliable operation of equipment and the inadmissibility of premature failure in the weld zone. The task is to develop recommendations for determining "individual" resource of welded joints of technological pipelines with a different level of edge displacement and imperfection by introducing correction factors into the modified Coffin-Manson equation based on the mechanical characteristics of the yield strength and strength, determined as a result of static tensile testing of samples of various sections of welded joints with maximum acoustic and magnetic signals according to the results of flux-probe and ultrasonic non-destructive testing.

For research, 6 pipe fragments were selected made of steel 20 with dimensions of 159×7 mm and a length of 45 mm each. Fragments were welded together by different types of welding with different displacements of the edges of the welded elements. The authors developed recommendations for assessing the "individual resource" of welded joints of technological pipelines. It is shown that the introduction of correction factors depending on the amount of offset of the edges of the welded joint allows to increase the accuracy of the predicted durability of individual welds by 4% for manual and 11% for semi-automatic welding, respectively.

1. Introduction
During operation, process pipelines invariably undergo a gradual accumulation of damage from the effects of internal pressure, temperature, process medium, etc. When performing non-destructive testing in the process of assessing the residual life, sections of the pipeline with discovered unacceptable defects must be repaired.

During repair using welding in butt welded joints of the pipeline, various defects may be formed, the admissibility standards of which are given in the current regulatory and technical documentation.

The resulting defects in welded joints adversely affect the life of the pipeline, reducing their reliability and safety [1-3].

One of the common defects in the geometry of a welded joint is a displacement of the edges of the joined elements [4-5]. The aforementioned defect helps to reduce the life of the device when exposed to vibrational loads. Moreover, the reduction in endurance directly depends on the amount of displacement of the edges.
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 [6-8].

To determine the defectiveness of a welded joint, a rich arsenal of non-destructive testing methods is currently being used, the use of which is laid down in methods for assessing the technical condition of technological pipelines [9-12].

But the existing methods for predicting the life of pipeline systems do not take into account the fact that each welded joint has an individuality, which depends on the geometric dimensions of the welded joint, the presence of defectiveness, the type of defect, allow you to reject the weld only by the parameter of “admissibility” of defects and do not give a qualitative assessment of further term of safe operation of welded joints.

In this regard, an important and urgent task is to develop recommendations for assessing the “individual” resource of welded joints of technological pipelines using non-destructive testing methods, in order to timely identify welds with the smallest resource to ensure reliable operation of the equipment and the inadmissibility of premature failure in the weld zone [13-15].

2. Experiment
For research, six pipe fragments made of steel 20 with dimensions of 159×7 mm were selected.

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.

In order to assess the quality of welded joints, visual-measuring and radiographic control methods were used. During the inspection, various defects of the welded joints that were formed due to a violation of the welding technology, as well as the presence of a displacement of the edges of the joined elements, were identified.

Information about fragments of welded joints are presented in table 1.

Table 1. Information about fragments of welded joints.

| Fragment designation | Fragment dimensions, mm | Type of welding                      | Displacement of the weld edges, mm |
|----------------------|-------------------------|-------------------------------------|-----------------------------------|
| 3-0                  |                         |                                     | 0                                 |
| 3-1                  |                         | Manual arc welding                  | 1                                 |
| 3-2                  | 159×7                   |                                     | 2                                 |
| 4-0                  |                         |                                     | 0                                 |
| 4-1                  |                         | Semiautomatic welding               | 1                                 |
| 4-2                  |                         |                                     | 2                                 |

To measure the magnetic characteristics, the F-205.30A magnetic-flux-probe device was used, 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_t) and the gradient of the constant magnetic field strength (G) on the surfaces of parts and in free space.

To evaluate the value of the acoustic signal during ultrasonic testing, an A1212 MASTER ultrasonic flaw detector was used.

At the initial stage of measuring the magnetic characteristics, a mesh of 10 × 10 mm in size was deposited on each welded fragment. An example of a fragment with a grid is shown in figure 1.
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, the same for all measured zones.

An example of a typical graph of changes in the normal component of the constant magnetic field $H_n$ is presented in figure 2.

To determine the magnitude of the acoustic signal, the adjacent zone of the weld of pipe fragments was cleaned on both sides from the weld to the required roughness. After that, the sounding of the welded joint of each fragment was performed with a comparison of the results obtained when determining the normal component of the constant magnetic field $H_n$.

An example of ultrasonic testing of welded joints with different levels of edge displacement and imperfection, as well as evaluating the magnitude of the acoustic signal, is shown in figure 3.
After measurements of the magnetic characteristics and the acoustic signal were identified areas of welds with maximum parameters. Subsequently, these sections were cut out and samples were made from them for mechanical static tensile testing. Mechanical tests of specimens with a welded seam for static tension were carried out on a servo-hydraulic installation INSTRON 8801.

The results of mechanical tests are presented in the histogram (figure 4) as averaged values of the tensile strength and yield strength for a group of samples cut from welded joints with different edge displacements and performed by manual electric arc and semi-automatic types of welding.

The calculation of the permissible number of loading cycles to failure \( [N] \) for samples cut from welded joints with different edge displacements and performed by manual electric arc and semi-automatic types of welding was performed according to the formula:

\[
N = \frac{1}{n_N} \left[ \frac{A}{\sigma_A - \frac{B}{n_\sigma}} \cdot C_t \right]^2
\]

where \( \sigma_A \) is the stress amplitude, MPa; in the calculations we take \( \sigma_A = 0.9\sigma_T \);
\( n_N = 10 \) - safety factor by the number of cycles;
\( n_\sigma = 2 \) - safety factor for stresses;
\( A = 0.6105 \) - characteristic of the material, MPa;
\( B = 0.4R_{m/1} \) - material characteristic, MPa;
\( R_{m/1} \) is the temporary resistance of the material, MPa;
\( C_t = 0.99 \) - correction coefficient of temperature, °C

The calculation results are presented in table 2.

The values of the permissible number of loading cycles to failure \( [N] \), presented in table 2, allow one to determine correction factors for calculating the durability of fragments of welded joints made...
by manual arc and semi-automatic types of welding with different values of edge displacement, according to the formula:

\[ K = \frac{N}{N_{cm}} \]

where \( N \) is the number of permissible number of loading cycles to failure without edge displacement;
\( N_{cm} \) - the permissible number of loading cycles to failure with different values of the displacement of the edges.

**Table 2.** The results of calculating the permissible number of loading cycles to failure \([N]\) for samples cut from welded joints with different values of the displacement of the edges and performed manual arc and semi-automatic types of welding

| Fragment designation | \([N]\), cycles |
|----------------------|----------------|
| 3-0                  | 31312          |
| 3-1                  | 28366          |
| 3-2                  | 27348          |
| 4-0                  | 30368          |
| 4-1                  | 29289          |
| 4-2                  | 27808          |

Values of correction factors for calculating the durability of welded joints with offset edges calculated according to the above formula are presented in table 3.

**Table 3.** The values of the durability coefficient of fragments of welded joints with different values of the displacement of the edges.

| Fragment designation | Fragment dimensions, mm | Type of welding      | Value of edge displacement, mm | The value of the coefficient of durability |
|----------------------|-------------------------|----------------------|-------------------------------|------------------------------------------|
| 3-0                  |                         |                      | 0                             |                                          |
| 3-1                  |                         | Manual arc welding   | 1                             | 0.905                                    |
| 3-2                  | 159×7                   |                      | 2                             | 0.964                                    |
| 4-0                  |                         |                      | 0                             |                                          |
| 4-1                  |                         | Semiautomatic welding| 1                             | 0.964                                    |
| 4-2                  |                         |                      | 2                             | 0.949                                    |

Based on the results obtained, recommendations were developed for assessing the "individual resource" of welded joints of technological pipelines.

The procedure for predicting the "individual" resource of a welded joint of a process pipeline should include the following items:

- scanning of butt welded joints with flux-gate and ultrasonic control methods around the entire circumference of the weld;
• identification of the presence of displacement of the edges and the displacement zone, as well as the level of defectiveness of the welded joint of the fragment;
• determination of the permissible displacement of the edges of the joined elements by non-destructive testing methods in accordance with the standards established by technical documentation (based on the results obtained, the object is either rejected or allowed for further operation);
• determination by the nomogram of the correction factor of the welded joint for the corresponding types of welding and the amount of displacement of the edges:
• input into the modified Coffin-Manson equation of the correction factor and the calculation of the durability of the welded joint:
• identification of sections of the welded joint with the least durability.

3. Conclusion
The developed recommendations for assessing the resource of welded joints of technological pipelines, taking into account the misalignment of the elements to be joined, must be applied after repair work to better assess the technical condition and prevent emergency situations associated with depressurization and destruction of the technical device. The advantage of the above developed method is to increase the accuracy of the predicted durability of individual welds by 4% for manual and 11% for semi-automatic welding, respectively, taking into account the input of correction factors into the modified Coffin-Manson equation, depending on the magnitude of the offset of the edges of the weld.

The calculation of the durability of the welded joint depending on the level of edge displacement and imperfection is based on the obtained values of the normal component of the constant magnetic field $H_n$ during flux-gate monitoring and the acoustic signal during ultrasonic testing, which are characterized by extrema in the zones of edge displacement and the defects present, both with external and from the inside.

This method allows to determine the durability of the most unfavorable sections of the welded joint with low values of the tensile strength $\sigma_B$ and the yield strength $\sigma_T$ of the weld metal, identified by the results of flux-probe and ultrasonic testing methods and to predict the “individual” resource of the welded joint based on the use of nomograms to determine the correction factor welded joint for the corresponding types of welding and the magnitude of the displacement of the edges and the subsequent input of this coefficient in mod Coffin-Manson fixed equation.

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