Computer-digital technique for evaluating the geometry of the interface of the weld with the base metal

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Abstract. On the basis of the coordinate measuring machine CMM, there is a computer-digital technique for measuring the transition radius and the angle of conjugation of the metal with the base metal φ. It allows in automatic mode, with high accuracy and reliability, to determine the above parameters of welds, which are used in calculating stress factors and in assessing the fatigue strength of welded structures.

1. Introduction
Welded structures are widely used in various industries. The practice of their operation has shown that from 40 to 70% of accidents occur due to the occurrence of fatigue cracks in butt or fillet welds, in the places of welding of branch pipes and other, sometimes, insignificant elements [1-5].

Based on the data of the theory of elasticity, it has been established that the geometry of the welds has a great influence on the stress distribution in the zone of transition from the weld metal to the base metal [6-9]. The increase in stresses in the specified zone is estimated by the theoretical stress concentration factor Kt. It is used to calculate the cyclic strength of welded joints, to analyze the efficiency of using various technologies, to select the best design option for a structure [10-14].

The configuration of the transition zone from the weld to the base metal is not regulated by regulatory documents. At the same time, it is the approach angle and the radius of the joint between the weld and the base metal that have the most significant effect on the stress concentration than the overall dimensions of the welds.

The calculation of Kt is usually performed by the finite element method, while the node model should be as close as possible to the real product. The greatest difficulties and uncertainties arise when setting the value of the transition radius R and the angle of approach of the weld metal to the base metal φ.

Determining the R and φ values is a time-consuming process, especially on thick-walled structures. These data were obtained by cutting welded seams, making macro and microsections. Various techniques were used to reduce labor intensity and maintain the integrity of the structure [15]. So, for example, to assess the profile of the transition from the weld metal to the base metal, lead impressions were previously obtained, sometimes the weld configuration was obtained by pouring molds with Wood's alloy, or other methods were used. From the obtained prints, thin sections were made, photographed, magnified, and each researcher subjectively chose the base of measurement and, using templates, estimated the value of the radius and angle of approach of the weld metal to the base metal.
2. Purpose of work
To develop a computer-digital technique for measuring the transition radii $R$ and the angles of approach of the weld metal to the base metal $\varphi$, which makes it possible to standardize the measurement process and increase the reliability of the obtained values of the desired quantities.

To reduce the complexity of measuring the transition radii $R$ and angles of approach of the weld metal to the base metal $\varphi$, to eliminate the influence of the "human factor" on the measurement accuracy, at present, it is possible to use coordinate measuring machines (CMM). The CMM tracking system consists of an emitter and six laser interferometers with a displacement count of 0.05 microns. The laser interferometers are structurally separated from the actuators. This eliminates the direct effect of deformations and loads in the drives on the tracking system. The force developed by the measuring head in the current touch mode is 0.0003N. Measurement error $\pm 0.005$ mm. With point measurement of objects, the productivity reaches 8 t / s and up to 200 t / s for scanning. The CMM software organizes the collection of the entire array of X, Y, Z coordinates of measured points. Using CAD models and computer programs, the shape and dimensions of the object are obtained with maximum accuracy.

The method for determining the radius of transition and the angle of approach of the weld metal to the base metal will be demonstrated on the T-joint shown in Fig. 1, which was performed by mechanized welding in carbon dioxide.

![Figure 1. T-joint: $R$ is the radius of transition from the weld to the base metal, $\varphi$ is the angle of approach of the weld metal to the base metal, $K$ is the leg of the weld.](image)

The measurement technique requires a number of sequential operations:

1. The object to be measured (welded joint) is fixed on the coordinate table of the machine.
2. A probe is used to measure the object of research in order to set its base and working surfaces, to introduce them into the machine coordinate system and into the computer memory.
3. The probe is sequentially set at the end and start points of its movement, while the trajectory of the movement is entered into the control program of the computer.
4. The measurement step is set.
5. Measurements are being made.
6. The resulting array of points is collected, where the X, Y, Z coordinates of each point are given, as shown in the table.
7. The program for a given permissible error, using the equation of the circle, determines the minimum radius of conjugation of the weld metal with the base metal $R$, and, taking the first derivative, determines the angle of transition from the weld metal to the base metal $\varphi$.
8. The measurement results and statistical processing of the transition zone geometry are presented in the measurement protocol. An example of a measurement protocol in one section of a welded joint is shown in Fig. 2. Where on the axis of deviations the value 0 corresponds to the section radius.
Table 1. Coordinates of measurement points in one section of the weld.

| Serial No. of the measured point | X               | Y               | Z               |
|---------------------------------|-----------------|-----------------|-----------------|
| 1                               | 0.2208363304522329 | -2.645755916884198 | 1.921202384958576 |
| 2                               | 0.220809404837933 | -2.647499735834558 | 1.915730737419324 |
| 3                               | 0.2213560317865877 | -2.649538790422014 | 1.910817972570669 |
| 4                               | 0.2209464343464482 | -2.651473577588092 | 1.906311216023198 |
| 5                               | 0.2206068835654911 | -2.653518432348619 | 1.902116789821434 |
| 6                               | 0.22095232242487421 | -2.655359179504217 | 1.897203342263936 |

Figure 2. Protocol of measurements of the radius of transition from weld metal to base metal.

The developed computer-digital technique for measuring $R$ and $\phi$ makes it possible to standardize the process of obtaining these parameters. This creates conditions for calculating the cyclic strength of welded structures at the design stage and allows you to choose the most effective technology - the one that will ensure the smoothest conjugation of the weld metal with the base metal.

The developed computer-digital technique allows automatic measurements of $R$ and $\phi$ in different sections of welded joints. It fully automates the measurement process, many times (100 ... 1000 times) reduces the complexity of determining $R$ and $\phi$. Eliminates the influence of the "human factor" on the results obtained, while increasing the accuracy of measurements and the reliability of the results.

The proposed standardization of the measurement of $R$ and $\phi$ will allow combining the efforts of various researchers involved in the design and development of technologies for structures operating under fatigue or corrosion-fatigue loads. The developed method for determining $R$ and $\phi$ will allow, for example, to effectively solve the following problems:

- to improve the accuracy of calculating the fatigue life of welded joints;
- it is reasonable to choose a welding technology that provides the lowest stress concentration in the interface zone of the base and weld metal;
• to carry out control and testing of products during their manufacture from the standpoint of assessing the fatigue strength of welded joints;
• manage technological processes to ensure the required product quality.
• Other applications of the developed method for measuring $R$ and $\phi$ are also possible.

References
[1] Shahani A R, Shakeri I, Rans C D 2020 Effect of residual stress redistribution and weld reinforcement geometry on fatigue crack growth of butt welded joints International Journal of Fatigue, Vol 139
[2] Liu Y, Lemanski S, Zhang X 2018 Hamed Yazdani Nezhad, International Journal of Adhesion and Adhesives, Vol 87, 164-172 https://doi.org/10.1016/j.ijadhadh.2018.10.005
[3] Liu H, Yang S, Xie C, Zhang Q, Cao Y 2018 Journal of Alloys and Compounds, Vol 741, 188-196 https://doi.org/10.1016/j.jallcom.2017.12.374
[4] Lukyanov V, Assaulenko S 2014 Vestnik of DSTU, Vol 4, 186-193 https://doi.org/10.12737/6908
[5] Lyudmirsky Y, Assaulenko S 2018 Vol 3, 311-317 https://doi.org/10.1134/S2075113313060063
[6] da Silva A L L, Correia J A F O, de Jesus A M P, Lesiuk G, Fernandes A A, Calçada R, Berto F 2019 International Journal of Fatigue, Vol 123, 196-212 https://doi.org/10.1016/j.ijfatigue.2019.02.025
[7] Ladinek M, Niederwanger A, Lang R, Schmid J, Timmers R, Lener G 2018 Journal of Constructional Steel Research, Vol 148, 180-188
[8] Ilyin A V, Sadkin K E 2012 Determination of structural and technological stress concentration in welded joints when evaluating the fatigue strength of shell structures. -Questions of materials science, Vol 2 (70), pp 161-176
[9] Ilyin A, Sadkin K 2013 Inorganic Materials: Applied Research, Vol 4, 542–553 https://doi.org/10.1134/S2075113313060063
[10] Erofeev V, Grebenshchikova O, Sharafiev R, Trojanovskaya I 2020 Materialstoday: proceedings, available online https://doi.org/10.1016/j.matpr.2020.08.130
[11] Chang Y, Sun C, Qiu Y 2020 Thin-Walled Structures, Vol 151 https://doi.org/10.1016/j.tws.2020.106745
[12] Shen W, Qiu Y, Xu L 2019 Lifei Song, Ocean Engineering, Vol 184, 273-288 https://doi.org/10.1016/j.oceaneng.2019.05.019
[13] Cao Y, Meng Z, Zhang S, Tian H 2013 43, 195-205 https://doi.org/10.1016/j.apor.2013.09.006
[14] Lukyanov V, Assaulenko S 2015 Vestnik of DSTU, Vol 4, 31-36 https://doi.org/10.12737/16071
[15] Shron L, Bogutsky V, Yagyaev E 2018 Proceedings of the 4th International Conference on Industrial Engineering, 2461-2466 https://doi.org/10.1007/978-3-319-95630-5_266