The Study of Possibility of Stress-Corrosion Cracks Group Resolution by Eddy-Current Flaw Detector

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Abstract. The question on the possibilities of spatial resolution for a group of stress-corrosion cracks in the body of a steel pipe under eddy current control was considered. Using a VD-12NFP eddy current flaw detector, stress-corrosion cracks on specimens with artificial defects were investigated. Specimens were made according to the results of statistical studies of linear dimensions and the location of stress-corrosion cracks of operational origin in a section of the main gas pipeline. In the course of the research, it was revealed that it is possible to achieve sufficient spatial resolution for a group of stress-corrosion cracks in the pipe body using signals from a detachable eddy current probe (ECT) of the transformer type, which is part of the eddy current flaw detector. For this, the diameter of the probe core should not exceed the interval between adjacent defects in the group of cracks. The signal half width of the detachable eddy current probe installed above the defect is an informative parameter for the eddy current probe signals. It depends on the number of defects in the stress-corrosion crack group.

1. Introduction
One of the most important tasks of modern technical diagnostics is the creation of conditions for ensuring the safe operation of pipeline systems. Due to the enormous length of pipeline networks, it is not possible to overhaul and reconstruct all obsolete steel pipelines. Therefore, the most appropriate and effective alternative in this situation is the selective repair and reconstruction of individual sections based on the obtained diagnostic information [1-5].

The analysis of the statistics of accidents on main gas pipelines (MG) in Russia shows that the most common cause of failures of gas pipelines is external corrosion, including stress-corrosion cracks [6-10]. These defects, as a rule, develop on the outer surface of the steel pipeline, they are numerous, and their depth reaches 10% of the pipe wall, which is why internal in-line flaw detectors poorly detect them [11–15]. The most reliable and valid diagnostic information about the technical condition of a steel pipeline is obtained when defects are being detected with the use of external flaw detectors [16-20].

Since stress-corrosion cracks on the pipe surface are arranged in groups, for a correct assessment of their linear dimensions, their spatial separation (resolution) from the group is required. This paper is devoted to the spatial resolution capability study for eddy current testing of a group of stress-corrosion cracks in the body of a steel pipe.
2. Main part
Based on the results of statistical studies for a group of natural (operational) stress-corrosion cracks in a section of the main gas pipeline, specimens with artificial defects (ADSs) were made from structural steel 09G2S using the milling method. The layout of the specimen with artificial defects and its appearance are shown in Figures 1 and 2, respectively.

Figure 1. The layout of the specimen with artificial cracks.

Figure 2. The appearance of the specimens fabricated with artificial cracks.

To study stress-corrosion cracks in the fabricated specimens, a VD-12NFP flaw detector with detachable eddy current probes (ECTs) of the transformer type was used. The width of a VD-12NFP’s control strip varies from 2 mm to 4 mm, depending on the type of eddy current probe used: the ferrite core diameter for the eddy current probe No.1 is \( D = 1.8 \) mm, and for the eddy current probe No.2 \( D = 3.5 \) mm.

The method of procedure is as follows:
- The test specimen is placed on the base of the experimental installation (if necessary, wooden blocks should be laid to reduce the gap between the eddy current probe and the specimen) so that the first single crack should be near to the micrometer device, as shown in Figure 3;
- An eddy current probe, with which the studies will be performed, is inserted into a special hole in such a way as to be on the defect-free area and to the left of the crack under study;
- The VD-12NFP values are reset;
- The movement of the eddy current probe above the surface of the specimen under study is performed using a micrometric device. After each complete revolution, the output signal values (voltage, \( U \), in mV) are recorded;
- Based on the data obtained, the dependences of the output signal (voltage \( U \), in mV) on the coordinate (\( x \), mm) where the eddy current probe is located are built. The coordinates are read from the left edge of the crack (a group of cracks), and the coordinate of the probe location on the defect-free area is taken as the zero value.
As a result of the study of stress-corrosion cracks using the VD-12NFP device, the dependencies of the output signal distribution over the artificial cracks of the specimen using eddy-current probes No.2 and No.1 were obtained. They are presented in Figures 4 and 5.

Analyzing the signal distribution for the eddy current probe No.2 over the artificial cracks of the specimen (Figure 4), it was concluded that the measured signal couldn’t be used to achieve the desired spatial resolution for the group of cracks in the pipe body within the interval $dx \leq 3$ mm. The reason is that in these signals there are no local maxima corresponding to the signals of individual defects (Figures 4, b and 4, c). For a group of cracks located at intervals of $dx = 5$ mm $> D = 3.5$ mm, local maxima associated with the location of defects in the pipe body appear in the signal measured by the eddy current probe No. 2 (Figure 4, d).

**Figure 3.** The external view of the experimental installation.

**Figure 4.** Signal distributions over cracks using eddy current probe No.2.
Analyzing the distribution of the signals from the eddy-current probe No. 1 over the artificial cracks of the specimen (Figure 5), it was concluded that the measured signal couldn’t be used for achievement of spatial resolution for a group of cracks located in the pipe body with the interval \( dx \leq 2 \) mm. The reason is that there are no local maxima in these signals corresponding to the signals of individual defects (Figure 5, b). For a group of cracks located at intervals of \( dx = 3 \) mm and \( dx = 5 \) mm at \( D = 1.8 \) mm, local maxima appear in the signal measured by the eddy-current probe No. 1 and associated with the location of defects in the pipe body (Figures 5, c, and 5, d).

Thus, it was concluded that using a detachable eddy current transformer-type probe, one can determine the resolution for a group of cracks in the pipe body if the interval between them exceeds the core diameter, that is, under the condition \( dx > D \). It was also concluded that the parameters of the detachable eddy current probes (diameter of the ferrite core \( D \)) of the existing eddy current flaw detectors (such as VD-12NFP) do not allow a reliable spatial resolution to determine for a group of cracks in the pipe body located with an interval \( dx \) less than 2 mm. In this case, the signal of the eddy current probe from a group of cracks in the pipe body is identical to the signal of the eddy current probe from a single crack of greater depth.

Analysis of the signals from the eddy current probe located above the crack group for which no spatial resolution was obtained shows that there is an informative parameter for them depending on the number of defects in the group. This parameter is the half width of the signal from a detachable eddy current probe of transformer type (the half width of the signal \( x_{1/2} \) set at the half maximum of the signal). Figure 6 shows a graph for the magnitude of the half-width of a signal obtained from a detachable eddy-current probe versus the size of the interval between groups of defects in a specimen having artificial cracks. This graph is derived from the graphs shown in Figures 4 and 5. In Figure 6, the interval value \( dx = 0 \) corresponds to the half-width of an individual crack. It can be seen that even in the absence of spatial resolution (inseparability) for a group of cracks the half width of the signal from the detachable eddy current probe located above the defect group is more than 40% greater than the half width of the signal of the detachable eddy current probe of a single crack.
The signal half width of the eddy current probe \( z = x_{1/2} \) located above the group of \( n \) cracks with a constant interval \( dx \) is determined by the formula:

\[
z = z_1 + dx(n - 1)
\]

(1)

Where \( z_1 \) is the half width of the signal from the detachable eddy current probe located over a single crack.

Figure 7 shows the dependence of the half-width of the signal experimentally obtained from the eddy-current probe over a group of cracks in the pipe body of a specimen with artificial cracks, on the width of the group of cracks.

The figures show that the experimental curve and the curve constructed by the theoretical formula (1) coincide with the error.

Therefore, the informative parameter, namely, the half-width of the signal from the detachable eddy current probe located above the defect provides the potential to reliably detect a group of cracks in the pipe body from the measured signal of this probe and their separation based on the measured signal of the eddy current probe located above a single crack.

3. Conclusions
1. Achievement of the desired spatial resolution in relation to a group of stress-corrosion cracks in the pipe body according to a signal of a transformer-type detachable eddy current probe included in the eddy current flaw detector is possible provided that the diameter of the probe core does not exceed the interval between adjacent defects in the crack group \( dx > D \).

2. The parameters of the detachable eddy current probes (diameter of the ferrite core \( D \)) of the existing typical eddy current flaw detectors (such as VD-12NFP, etc.) do not allow the spatial resolution to achieve for a group of cracks in the pipe body spaced at intervals which are no more than 2 mm.

3. The half width of a signal from the detachable eddy current probe located over a group of stress-corrosion cracks in the pipe body of a steel gas pipeline linearly depends on the number of defects in the group of the stress-corrosion cracks and the interval between adjacent defects in the group.

In case of unreachability of the spatial resolution for a group of cracks, the half width of the signal from the detachable eddy current probe located over the stress-corrosion crack group is more than 40% greater than the half width of the signal from the probe located over a single crack.

4. References
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