On Use of Slots in Modelling Cracks in Ultrasonic Testing

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Abstract—The possibility of a rigorous theoretical solution of the three-dimensional problem of scattering of elastic waves at the tip of a vertical crack in a weld is analyzed. It is shown that in the general case of ultrasound scattering on a flat target, the three-dimensional problem can be reduced to a two-dimensional one. On this basis, for an arbitrary direction of sounding a crack in a weld, the dependence of the signal from the crack tip on the direction to the receiver was assessed. It is noted that the wave size of the crack tip is much smaller than the wave size of the end of the grooves that can be made to simulate defects in welded joints. As a result, it was found that the nature of the scattering of elastic waves by the tip of the crack differs from the nature of scattering on the grooves, including in cases where the opening of the grooves is minimal, based on the possibility of their manufacture. The results of an experimental verification of the obtained theoretical estimates on samples of steel and aluminum are presented. It is shown that at the ends of the grooves (in contrast to the crack tips), even with their minimal openings, conditions are created for the formation of a scattered field of the type of specular reflection from a volumetric cavity—a side-drilled hole.

Keywords: elastic wave scattering, three-dimensional problem, crack, defect model, groove as defect simulator

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1. INTRODUCTION

Traditional models of defects in the form of flat-bottomed holes and corner reflectors (“notches”) have been successfully used for many years to adjust parameters in the echo method of ultrasonic flaw detection [1]. However, they are not suitable for use in modern diffraction methods that are largely based on separate sounding schemes with ultrasonic transducers located on different sides of the weld. For these cases, according to foreign standards and Russian experience, cylindrical drillings and grooves of various orientations are used, for example, in [2, 3] and elsewhere. The question of the possibility of using drillings of various orientations is quite fully covered in [4] and others, while the question of the possibility of using grooves and restrictions on their parameters has received much less attention. Meanwhile, in the standards regulating the procedure for performing inspection by the time-diffraction TOFD method, the use of grooves with an opening of 2 mm or more tapered at an angle of 60° at the end of the groove is prescribed for tuning at frequencies of 5 MHz and higher. According to the publications of some authors who participated in the development of the TOFD method, the experimental data underlying such solutions were obtained on samples with grooves, the opening of which at the tapering point was approximately $2a = 0.4$ mm [5, 6]. Making grooves with smaller opening has been problematic in past years, and it was thought that such an opening is sufficient to simulate cracks that this method is primarily aimed at revealing. However, let us pay attention to the fact that at frequencies from 5 to 15 MHz, the longitudinal wave length $\lambda_L$ in steel or aluminum is approximately 0.4 to 1.2 mm, i.e., for a longitudinal wave the wave size $ka$ of this tapering ranges from 1 to 3 (hereinafter, $k$ is the wavenumber of a longitudinal wave). Consequently, the condition $ka \ll 1$, which is usually incorporated into computational models when simulating ultrasound scattering by crack tips, is not satisfied.

At present, the electroerosive method makes it possible to obtain grooves with an opening of about 0.14 mm. For example, Aleshin et al. [7] presented the photograph of a sample with such a groove, which clearly shows that the rounding of the end with a diameter of 0.12 to 0.14 mm is actually used as a “taper.”
The rounded shape of the end can also be seen in Fig. 1, which shows macrosections of several grooves with an opening of up to 2 mm made by the electroerosive method. In all cases, the “taper” of a groove looks like a rounding with a diameter equal to the width of the groove opening. At the same time, at frequencies from 5 to 15 MHz, for grooves with an opening of 0.14 mm the wave size $ka$ of such a rounding in steel or aluminum is approximately from 0.3 to 1. Thus, even for grooves with the smallest possible opening, the condition $ka \ll 1$ is still not satisfied. A similar condition for a transverse wave is all the more not satisfied, since the wavelength in this case is approximately 2 times less than that for a longitudinal wave.

Figure 2 shows a photograph on the same scale as in Fig. 1 (left photo) of a macrosection of a crack developing from lack of fusion in the welded seam of an aluminum blank. It can be seen that the crack opening at the tip does not exceed 0.01 mm. At frequencies from 5 to 15 MHz, this corresponds to wave sizes $ka \leq 0.05$; this is much smaller than for grooves. In this case, the difference in the shape of the groove end and the crack tip is also obvious.

Therefore, when tested at frequencies from 5 MHz, even a groove with an opening of 0.14 mm cannot be surely considered to be a simulator of developing cracks.

Therefore, the question arises: if we focus on the detection of cracks, then how legitimate is the use of the described grooves for setting the parameters of ultrasonic testing?

In this article, we will look at some of the details of this issue. Let us start with the theoretical results obtained in the study of the scattering of elastic waves by flat and bulk targets.

2. GENERAL APPROACH TO SOLVING 3D PROBLEM OF SCATTERING OF ELASTIC WAVES BY A PLANE CRACK

Let ultrasonic waves be scattered on a half-plane $x < 0$ and $y = 0$, simulating a vertical crack in butt welds. The edge of the “crack” lies along the $z$-axis, as depicted in Fig. 3.
Cracks in welds can be located both along or across the weld axis (θ₀ = 90° or 0° in Fig. 3) and at other angles. Therefore, as in [7], we consider the scattering of elastic waves when the target orientation varies in the range 0° ≤ θ₀ ≤ 90° leading to a three-dimensional problem of elastic wave scattering by a crack.

Note that rigorous solutions of the problem of elastic wave scattering by cracks are usually limited to two-dimensional models [8, 9]. In this article, we will not carry out a detailed consideration of the theory of scattering of elastic waves by cracks; we will dwell only on the most important points of solving the 3D problem that are essential for further presentation. In this case, we will adhere to the approach described in the general form in [10].

For the purposes of this article, several constraints can be introduced into the problem of elastic wave scattering. First, during ultrasonic testing by the time-diffraction TOFD method, the planes of ultrasound input into the metal for pulser P and receiver R are, as a rule, aligned. For this case, taking into account the possible rotation of the crack plane, the geometry of the problem is shown in Fig. 3. A more general scheme of the 3D case of the location of the pulser and receiver can be found in [7].

Second, we will assume that the incident wave is a plane harmonic wave with time dependence in the form \( \exp(-i\omega t) \). Next, let us define the crack plane using the unit vector of the y-axis \( \mathbf{n}_y = (0, 1, 0) \) and the plane of input (output) of ultrasound into the product by the normal \( \mathbf{n} = (0, -\cos \theta_0; \sin \theta_0) \). In this case, the angle \( \theta_0 \) varies within \( 0 \leq \theta_0 \leq \frac{\pi}{2} \), and the depth of the crack does not matter. It is only important that in order to sound the edge of the half-plane (or the upper overall point of a defect of limited dimensions such as disk, ellipse, strip, etc.), the beam is introduced at an acute angle \( \alpha \) to the surface of the tested product, i.e., \( 0 \leq \theta_0 \leq \frac{\pi}{2} \). It is this situation that is typical for detecting vertically oriented cracks in welds.

We consider an elastic medium with Lamé parameters \( \lambda \) and \( \mu \). The crack surface is considered free from stresses \( \sigma \), i.e., the boundary conditions on the crack surface are set in the form \( \sigma_{yy} = 0, \sigma_{xy} = 0, \) and \( \sigma_{yx} = 0 \).

Displacements in longitudinal and transverse waves (\( \mathbf{u}_L \) and \( \mathbf{u}_S \), respectively), are traditionally described using a scalar \( \psi \) and vector potentials,

\[
\mathbf{u}_L = \text{grad} \psi, \quad \mathbf{u}_S = \text{curl} \psi
\]

with an additional constraint \( \text{div} \psi = 0 \) [11]. However, in this case, the equations for the boundary conditions in the 3D problem become very cumbersome—they include mixed second derivatives of unknown potentials, with the potentials of longitudinal and transverse waves not separated. Typically, in 3D problems, such a path does not allow one to find scattered fields.

According to [12], due to the correct choice of expressions for the desired potentials of scattered waves, one can significantly simplify the equations for boundary conditions. This path was used in [10, 13]. It is based on the fact that for the 3D problem in the second equation in (1), the displacements in the transverse
wave are divided into components that are vertically and horizontally polarized relative to the crack plane (\(u_{SV}\) and \(u_{SH}\), respectively) that are sought in the form

\[
\mathbf{u}_S = u_{SV} + u_{SH}, \quad u_{SV} = \text{curl}[\nabla h, y^0], \quad u_{SH} = \text{curl}(\chi, y^0).
\]  

(2)

Here the functions \(h\) and \(\chi\) can be called the potentials of the corresponding displacement components. Now three unknown scalar functions \(f\), \(h\), and \(\chi\) satisfy the Helmholtz equations \(\Delta f + k^2 f = 0\), \(\Delta h + \alpha^2 h = 0\), \(\Delta \chi + \alpha^2 \chi = 0\), and, introducing the notation \(\Delta_2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2}\), it can be shown that the boundary conditions on the crack surface, i.e., for \(x < 0\) and \(y = 0\), take the form

\[
-\frac{1}{2\mu} \sigma_{yy} = \left(\frac{1}{2} \alpha^2 + \Delta_2\right) f + \frac{\partial}{\partial y} \Delta_2 h = 0,
\]  

(3)

\[
\frac{1}{2\mu} \sigma_{yy} = \frac{\partial}{\partial x}[\frac{\partial f}{\partial y} - \left(\frac{1}{2} \alpha^2 + \Delta_2\right) h] - \frac{1}{2\mu} \frac{\partial}{\partial y} \frac{\partial h}{\partial y} = 0,
\]  

(4)

\[
\frac{1}{2\mu} \sigma_{yy} = \frac{\partial}{\partial z}[\frac{\partial f}{\partial y} - \left(\frac{1}{2} \alpha^2 + \Delta_2\right) h] + \frac{1}{2\mu} \frac{\partial}{\partial y} \frac{\partial h}{\partial z} = 0.
\]  

(5)

This type of boundary conditions is much simpler than that used in classical works, for example, [11, 14]. Equations (4) and (5) can be considered as a system of two partial differential equations of the first order with respect to the variables \(x\) and \(z\) for the values of the functions \(\phi = \left[\frac{\partial f}{\partial y} - \left(\frac{1}{2} \alpha^2 + \Delta_2\right) h\right]\) and \(\frac{\partial \chi}{\partial y}\) on the crack surface \(x < 0\) and \(y = 0\). In this case, the potential \(\chi\) is not included in Eq. (3). Therefore, by calculating \(\frac{\partial \chi}{\partial y}\) from system (4), (5), we can find the potential of a transverse wave polarized in the crack plane.

Having calculated \(\phi\big|_{x<0,y=0}\) from Eqs. (4) and (5), we obtain, together with (3), a system of two second-order partial differential equations with respect to \(x\) and \(z\) for two unknown functions \(f\) and \(h\) with \(x < 0\) and \(y = 0\),

\[
\left(\frac{1}{2} \alpha^2 + \Delta_2\right) f + \frac{\partial}{\partial y} \Delta_2 h = 0,
\]  

(6)

\[
\frac{\partial}{\partial y} \left[\frac{\partial h}{\partial y} - \left(\frac{1}{2} \alpha^2 + \Delta_2\right) h\right] = \varphi.
\]  

(7)

The solution of this system gives the desired potentials of the scattered longitudinal and transverse waves vertically polarized with respect to the crack surface.

In fact, the described algorithm makes it possible to reduce the 3D problem of scattering of an elastic wave (longitudinal or transverse with any polarization) to a 2D problem and carry out the solution using the Wiener–Hopf method, similarly to how it was done in two-dimensional cases in [15] for the problems of scattering of acoustic and electromagnetic waves and in [8, 16], for elastic waves.

Let some of the following plane waves fall on a crack at an angle \(\theta_0\) to its axis:

\[
\chi_0(x, y, z) = \exp[i(\alpha r)] = \exp[i(\alpha r)] = \chi_{0i}(x, y) \exp[i\alpha c_0 z],
\]  

(8)

\[
h_0(x, y, z) = \exp[i(\alpha r)] = \exp[i(\alpha r)] = h_{0i}(x, y) \exp[i\alpha c_0 z],
\]  

(9)

\[
f_0(x, y, z) = \exp[i(k r)] = \exp[i(k r)] = f_{0i}(x, y) \exp[i\alpha c_0 z],
\]  

(10)

where

\[
\chi_{0i}(x, y) = \exp[i\alpha c_0 x + h_{0i} y],
\]  

(11)

\[
h_{0i}(x, y) = \exp[i\alpha c_0 x + h_{0i} y],
\]  

(12)

\[
f_{0i}(x, y) = \exp[i\alpha c_0 x + h_{0i} y].
\]  

(13)
Here, according to Fig. 3, in the case of incident transverse wave, we have
\begin{equation}
\begin{aligned}
a_0 &= -\cos \alpha, \\
b_0 &= -\sin \alpha \sin \vartheta_0, \\
c_0 &= -\sin \alpha \cos \vartheta_0
\end{aligned}
\end{equation}
or counterpart relations for the coefficients \(a_{0f}, b_{0f},\) and \(c_{0f}\) in the case of longitudinal incident wave.

Bearing in mind the equality of the phase velocities of the waves along the scattering surface, similarly to \([15, 17]\) it should be assumed that \(kc_{0f} = \omega c_0.\) Then relation (10) can be rewritten as follows: \(f_0(x, y, z) = f_{0f}(x, y) \exp\{i\omega c_0 z\}.\) Therefore, due to the chosen location of the coordinate axes and the half-plane simulating the crack, the dependence of the incident and scattered fields on the coordinate consists only in the presence of the factor \(\exp\{i\omega c_0 z\}\), and the scattered fields \(\chi_d(x, y, z), h_d(x, y, z), f_d(x, y, z)\) can be sought in the form
\begin{equation}
\chi_d(x, y, z) = \chi_{d1}(x, y) \exp\{i\omega c_0 z\},
\end{equation}
\begin{equation}
h_d(x, y, z) = h_{d1}(x, y) \exp\{i\omega c_0 z\},
\end{equation}
\begin{equation}
f_d(x, y, z) = f_{d1}(x, y) \exp\{i\omega c_0 z\},
\end{equation}
where the unknown functions with index 1 depend only on two coordinates \(x\) and \(y\) and satisfy the corresponding two-dimensional Helmholtz equations. Substituting expressions (8)–(17) into the boundary conditions (3)–(5) and cancelling out the common factor \(\exp\{i\omega c_0 z\}\) in each of the resulting equations, we reduce the 3D problem for the functions \(\chi_d, h_d,\) and \(f_d\) to a 2D problem for the functions \(\chi_{d1}, h_{d1},\) and \(f_{d1},\) the calculation algorithm for which is similar to the algorithm for solving Eqs. (3)–(5) described above.

Note that the desired fields must satisfy the radiation conditions at infinity, i.e., as \(|r| \rightarrow \infty,\) and the condition on the edge of the half-plane, i.e., as \(|r| \rightarrow 0.\) The use of the Wiener–Hopf method makes it possible to take these conditions into account.

Completing the analysis of the obtained solutions, including the calculation of diagrams for scattered fields, is a rather laborious task. It must be performed so that the results obtained can be fully used in ultrasonic testing. However, some practical conclusions can be drawn without resorting to performing calculations in full.

For example, it is obvious that when ultrasound is incident on a crack perpendicular to its edge—when \(\vartheta_0 = \frac{\pi}{2}\) in Fig. 3, i.e., \(c_0 = 0\) in (14)—the problem becomes two-dimensional. In this case, \(\chi_0 = 0\) in the incident wave, i.e., the crack is sounded by a longitudinal wave with a potential \(f_0\) of the form (10) or a transverse wave with a potential \(h_0\) of the form (9). The solution of such a problem is quite fully described, for example, in \([8, 16]\) based on the rigorous theory of elastic wave scattering or in \([18]\) based on the geometric theory of diffraction. In those and other works, it is shown how scattered signals are formed on a crack, including their components scattered according to the laws of geometric acoustics from the flat surface of the crack, and how the signals diffracted directly by the crack edge are formed. In particular, the transformation of the wave type, the formation of lateral waves, as well as the formation of a Rayleigh wave radiated by the edge of the crack along its surface are described.

Using the above-described algorithm for solving Eqs. (3)–(5) and taking into account (6) and (7), it can be shown that in the 3D case, when \(0 \leq \vartheta_0 \leq \frac{\pi}{2},\) similar signals are formed on the edge of the crack with the only difference that, according to (15)–(17), all parameters of the scattered body waves and the Rayleigh wave propagating from the edge of the crack depend on the variable \(\exp\{i\omega c_0 z\}\). In this case, similar to Eq. (2.20) in \([15],\) the amplitude of the signal diffracted by the edge of the crack and received according to the scheme of Fig. 3 changes proportionally to the quantity
\begin{equation}
A_d \sim A = \frac{|\omega - \omega \cos \vartheta_0|^\frac{1}{2} \sin \vartheta_0}{(1 - \sin^2 \alpha \cos^2 \vartheta_0)^\frac{1}{2}}.
\end{equation}

It should be noted that, strictly speaking, a relation of the type (18) was obtained in \([15]\) under the condition \(\vartheta_0 \neq 0.\) However, for practical purposes, one can always assume that the angle \(\vartheta_0\) is small enough to consider it close to zero but still finite. Then the form of expression (18) shows that when an elastic wave of any type is scattered, the amplitude of the scattered waves decreases simultaneously with a decrease
in the angle $\theta_0$ from 90° towards 0°, i.e., when we pass from sounding the crack perpendicular to its edge to sounding the crack along its surface (see Fig. 3).

This assessment was made for the scattering of plane waves taking into account the constraints imposed at the beginning of this section. However, it remains valid in the case of an incident beam of limited dimensions, since such a beam can be expanded into a spatial spectrum in terms of plane waves, and the conclusion drawn will be valid for each component of this spectrum.

3. ON THE 3D PROBLEM OF SCATTERING OF ELASTIC WAVES BY A SIDE-DRILLED HOLE (SDH)

If the target for ultrasound scattering is the upper cylindrical part of the grooves shown in Fig. 1, then the signal received according to the scheme in Fig. 3 can be calculated in the same way as for specular reflection from a cylindrical cavity, when the wave is incident obliquely to the SDH axis, i.e., again, the 3D problem of elastic wave scattering takes place. In this case, as the angle $\theta_0$ decreases from 90° towards 0°, the surface area of the rounded end of the groove that falls within the radiation pattern of the pulser and receiver increases, because in this case, the rays propagate closer and closer to the direction of the cylinder axis, and instead of scattering by a compact defect with diameter $2a$, we pass to scattering by an extended defect with width $2a$. According to [1, 19], in the first approximation, it can be assumed that the dependence of the amplitude $A_{\text{refl}}$ of the specularly reflected signal on the angle $\theta_0$ and the reflector diameter $2a$ has the form

$$A_{\text{refl}} \sim \left( \frac{ka \cos \alpha}{1 - \sin^2 \alpha \sin^2 \theta_0} \right)^{1/2}.$$ (19)

For example, for a groove with an opening of 0.14 mm in steel or aluminum at a frequency of 5 MHz, an input angle $\alpha = 60^\circ$, and $\theta_0$ changing from 90° to 0°, this corresponds to an increase in the amplitude within 3 dB.

4. ANALYSIS AND EXPERIMENTAL VERIFICATION OF THE RESULTS

When the “pulser—receiver” pair is rotated in the range of angles $\theta_0$ from 90° to 0° according to the diagram in Fig. 3, the amplitude of the signal from the crack tip should decrease. In contrast to this, according to Sec. 3, upon reflection from a three-dimensional cylindrical surface (for example, from the rounded end of the groove) with a similar change in the input–output direction, the signal amplitude of the received signal should increase slightly.

However, it should be noted that relations (18) and (19) were obtained under practical constraints. Let us dwell on this issue in more detail.

When considering scattering by a crack, it was assumed that it starts at a fixed point $x = 0$, $y = 0$, its surface is stress-free and imitated by a smooth and flat surface of the half-plane $x < 0$, $y = 0$. In fact, operational cracks in welds can have a rough surface. The direction of their propagation and the coordinates of the tip can change in accordance with the orientation and relative position of the crystallites in the weld. Moreover, the crack does not develop “instantly” from a point, as in the diagram in Fig. 3. In fact, the “tip” of the crack is a section up to 0.5–1 mm long, where the crack surfaces are pulled together so tightly that ultrasound partially penetrates through their impedance boundary. Taking into account the previously given estimates, at the used frequencies the length of such a section can be up to 1 wavelength of ultrasound, and this can significantly affect the parameters of scattered signals.

Relation (19) was also obtained for the scattering of ultrasound by a smooth surface in the high-frequency case. It was experimentally verified in [19] on drillings with a wave size $ka \gg 7$. However, in our case, as indicated above, the wave size of the rounding at the end of the groove with an opening of 0.14 mm is close to unity.

Therefore, relations (18) and (19) can only be considered as an estimate of the possible change in the signal amplitude when sounding a real crack or groove from different directions.

To test dependences (18) and (19), a series of experiments was carried out on the ends of grooves in steel samples (see Fig. 1) and on the tip of a crack in a weld connecting aluminum blanks (see Fig. 2).

The amplitudes of the signals scattered by the rounding of the grooves or by the tip of the crack were measured according to the scheme used in [7]. A fragment of this scheme and the amplitude of the signal...
in Fig. 4 for entry angles $\alpha = 57^\circ$ and $65^\circ$. In Fig. 4, the dots indicate the measurement results, and the solid curves indicate their polynomial approximation. It can be seen that this amplitude is practically constant at small angles $\theta_0$ and changes insignificantly within 1–2 dB during rotations through angle greater than $60^\circ$; this generally corresponds to the estimate by formula (19).

Note that the coordinates of the groove end are set by the conditions for its manufacture by the electroerosive method. In contrast, the coordinates of the crack in the weld are initially unknown. Therefore, to analyze the signals scattered by the crack tip, the coordinates of this tip were preliminarily determined by the TOFD scheme at frequency 10 MHz by a pair of transducers 3 mm in diameter with an input angle of $60^\circ$. This angle is chosen as characteristic in practical applications of the TOFD method. On the other hand, this angle is intermediate in comparison with the angles of $57^\circ$ and $65^\circ$ that were used in [7] for scattering by grooves; this makes it easier to compare the results with each other.

Figure 5a shows the scanning scheme for the weld along its axis when searching for the crack tip, and the resulting TOFD crack pattern is shown in Fig. 5b. The numbers mark the zones of location of the following signals: (1) side wave signal; (2) signal due to the supposed crack tip; and (3) bottom signal. As stated above, the crack tip does not look like a strictly straight line. Therefore, it was expedient to measure the amplitudes of diffracted signals with the rotation of the pulser–receiver pair at the points where the signals from the crack tip look most clearly on the TOFD screen. As such points, we selected the sections of the crack tip with the coordinates $z = -20, -40, -50, -60, -90$ mm, marked with white lines in Fig. 5b.

Further, the “pulser-receiver” pair was centered over the crack tip at the indicated 5 points and rotated according to the scheme in Fig. 4a through $360^\circ$ with simultaneous measurement of the amplitude of the signal received from the tip. In this case, as in [7], the orientations $\theta_0 = 0^\circ$ and $180^\circ$ correspond to the location of the pulser and receiver as in Fig. 4a, i.e., perpendicular to the crack tip. Accordingly, with $\theta_0 = 90^\circ$ and $270^\circ$ the crack is sounded along its surface. In this case, the rotation of the transducers by $360^\circ$ can be considered as consisting of four sections $0^\circ—90^\circ, 180^\circ—90^\circ, 180^\circ—270^\circ$, and $360^\circ—270^\circ$, in each of them the conditions for scattering of ultrasound by the edge are similar. In this case, it is possible
to average the results over these areas and consider the scattering of ultrasound in the range of sample rotation angles from 0° (beam incidence perpendicular to the edge) to 90° (beam incidence on the edge along the crack surface). Thus, it is possible to partially reduce the measurement error that occurs due to the instability of the acoustic contact, possible anisotropy of materials, inaccuracy in the alignment of the transducers, etc. The results of measurements at the indicated points, taking into account the averaging at each point over the four sections, are shown in Fig. 6. Here, as in Fig. 4b, the dots indicate the measurement results, and the solid curves indicate their polynomial approximation.

Figure 6 shows that the amplitude of the signal from the crack tip changes somewhat from point to point; this is apparently due to local changes in the shape of the crack at its tip. However, in general, there is a tendency to a decrease in the amplitude of this signal by 4–9 dB when the “pulser–receiver” pair turns from the sounding direction perpendicular to the crack plane to the direction “along” the crack. This result qualitatively coincides with the estimate by formula (18). It is opposite to the estimate obtained for sounding rounded groove surfaces according to formula (19) and the results of the groove sounding experiment.

CONCLUSIONS

1. Based on a theoretical estimate of the amplitude of ultrasonic waves scattered by the tip of a vertical crack in a weld, it is shown that when the pulser–receiver pair is rotated in the range of angles ϕ₀ from 90° to 0° (according to the diagram in Fig. 3), the signal amplitude due to the crack tip decreases. In contrast to this, when reflected from the rounded end of a groove made by the electroerosive method, the amplitude of the received signal increases slightly with a similar change in the input–output direction. These qualitative differences in the nature of the scattering of ultrasound by these targets have been confirmed experimentally.

2. The surface of the groove made by the electroerosive method with an opening of 0.14 mm is rounded near the tip. When ultrasound is scattered on such a surface according to the scheme used in the TOFD method to detect the upper tip of a crack in a weld, this creates conditions for the formation of a scattered field of the type of specular reflection from a volumetric cavity—a side-drilled hole. Thus, even with
a minimum opening of fractions of a millimeter, grooves that can be manufactured by electroerosion do not correspond to cracks in welds in their dissipative characteristics.

3. When designing reference samples and measures for setting ultrasonic testing parameters, it is advisable to choose sample sizes large enough so that it is possible to provide a wide range of angles (approximately at least 45° to 90°) between the input–output plane of the “pulser–receiver” and the side surface of the groove simulating a crack. In this case, it will be possible to provide the best conditions for simulating both longitudinal and transverse cracks in welds.

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