

1.3.45. MECHANISM OF DISCONTINUITY DETECTION IN PIPELINES BY ULTRASONIC GUIDED WAVES

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The paper deals with the features of detection of discontinuities in welded pipelines, interacting with low-frequency guided waves of the longitudinal and torsional modes during their propagation in the form of a circular wave over the pipe cross-section. Extended welded pipelines are characterized by presence of various discontinuities in them, associated with the change of the material density and/or cross-section of pipe walls on their joint line and/or along the pipe length. Such discontinuities are reflectors of ultrasonic guided waves, which propagate along the pipe through its cross-section.

All the reflectors in a pipeline can be divided into two types: symmetrical and asymmetrical. Symmetrical reflectors include welds, flanges, supports, branch-pipes, etc., the location of which on the pipeline is known from the technical documentation. Echo-signals from symmetrical reflectors are important markers to determine the location of asymmetrical reflectors. Asymmetrical reflectors include defective pipe sections, which are mostly due to damage in the pipe wall cross-section because of corrosion and erosion wear of the pipe wall, and are located along the path of the guided wave propagation. Corrosion damage of the pipe wall is oriented both along the pipe circumference, and along the pipe longitudinal axis. It can be located on the pipe inner and outer surfaces.

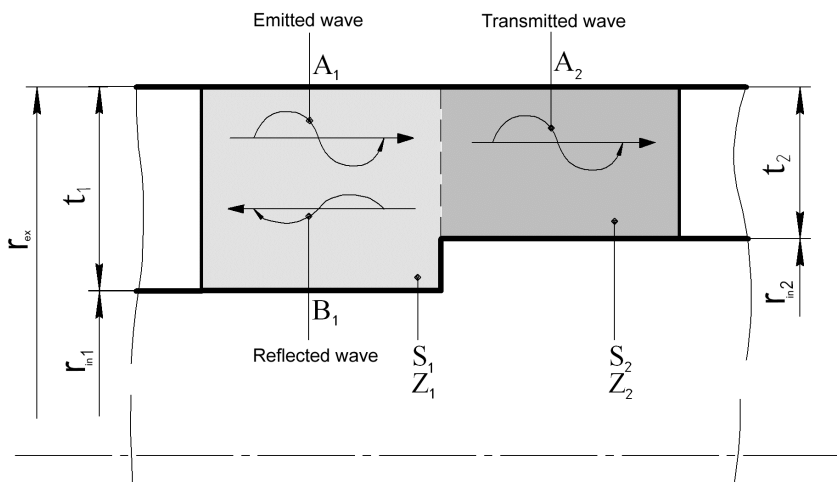
When studying the processes of interaction of guided wave elastic oscillations with pipeline discontinuities, it is necessary to take into account the parameters of its medium as an infinite waveguide. Such parameters of the pipeline as an acoustic system include specific acoustic impedance z_a and mechanical impedance Z [1].

Specific acoustic impedance z_a is an important parameter of the system with distributed constants and is the wave resistance of its medium, which is equal to $z_a = \rho C$, where ρ is the medium density, C is the sound velocity in this medium. This value is given per a unit of cross-sectional area in the path of elastic wave propagation. In the absence sound velocity dispersion, wave resistance is independent on wave shape, is a constant and characterizes the medium. As a guided wave propagates in the pipeline without attenuation, z_a is of an active nature. The meaning of the active nature of wave resistance consists in that at propagation of oscillation energy from the acoustic array transducers in each pipeline cross-section its medium absorbs the energy at the expense of further transmission of the same energy to the following pipeline section having the same resistance. Wave resistance is an important parameter of the pipeline medium, as it characterizes the reflecting properties of the medium and determines the conditions of sound reflection and passage on the boundary of the two media. If the wave resistances of the media are equal, the wave passes the boundary without reflection.

Mechanical index Z is the second in importance parameter of the medium of an extended pipeline, which is related to the wave resistance by the following dependence: $Z = Sz_a$, where S is the pipe cross-sectional area. In the pipe zones without defects the tested pipeline has finite mechanical impedance. Change of mechanical impedance is associated both with the change of the pipe cross-sectional area as a result of its corrosion damage and erosion wear, and with the change of wave resistance of the welded joint media and its cross-sectional area because of the presence of various discontinuities.

Mechanical impedance, essentially, shows the degree of resistance of pipeline medium to propagation of guided ultrasonic waves, which is what leads to appearance of reflected signals from discontinuities in the pipeline.

Mechanism of detection of discontinuities in welded pipelines is based on the principle of interaction of the falling and reflected ultrasonic wave, allowing for the change of the pipe cross-section as a result of the presence of various defects in the pipeline. Principle of reflection and passage of guided waves on the boundary of the change of pipe section is given in the Figure, which shows the general case of transition of one waveguide of section S_1 to another waveguide of section S_2 . When considering the guided wave in pipeline section with the pipe cross-sectional area S_1 the incident ultrasonic wave of amplitude A_1 meets with another pipeline in its path, the cross-sectional area of which is equal to S_2 . Here, the incident wave is converted into the reflected wave, amplitude B_1 of which depends on the degree of change of the pipe cross-section, and passing wave with amplitude A_2 , which propagates further along the pipe section.



If the reflected wave forms in the section of change of the pipe cross-sectional area, for instance, as a result of corrosion of the pipe wall, then mechanical index of the damaged and undamaged pipe sections will depend only on the degree of the change of the pipe cross-sectional area, as the wave resistances of these sections will be equal.

Then, the coefficients of reflection R and passage W for a guided wave of a longitudinal mode will be equal to:

$$R = \frac{S_2 - S_1}{S_1 + S_2}; \quad W = \frac{2S_2}{S_1 + S_2}.$$

On the boundary of the change of the pipe cross-section as a result of its corrosion damage the amplitudes of the reflected B_1 and passing A_2 waves will be given by the following expressions:

$$\hat{A}_1 = RA_1 = \frac{S_2 - S_1}{S_1 + S_2} A_1; \quad A_2 = WA_1 = \frac{2S_2}{S_1 + S_2} A_1.$$

The paper shows that only a small part of the sound wave energy is reflected back from the defect, while a considerable part of the sound wave energy passes further along the pipe section. So, even for relationships of pipe cross-section $S_2 = S_1 / 2$ only one ninth of the sound energy is reflected back.

Despite the fact that only an insignificant part of the sound wave energy is reflected from the defects, the amplitude of the reflected echo-signal is a parameter which is at the basis of the mechanism of detection of such defects as corrosion damage and erosion wear of the pipe wall. The height of the reflected echo-signals, essentially, corresponds to the degree of the change of the pipe cross-sectional area under the action of the defects, i.e. depends on the defect size. Correspondence of the reflected signal amplitude to the degree of the change of the pipe cross-sectional area because of the defect action is a fundamental technological feature of examination of the technical condition of extended pipelines by low-frequency ultrasonic guided waves.

References:

1. **Ultrasound.** Small encyclopedia. Ed.-in-chief I.P. Galyamin. – M.: “Sovetskaya encyclopedia”, 1979. – 400 p.