THEORETICAL AND EXPERIMENTAL ULTRASONIC INVESTAGATION OF GENERAL CORROSION AND EROSION IN CONSTRUCTION

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ABSTRACT

The work is presented a model of propagation of longitudinal ultrasonic waves (UW) of surface corrosion. Modeling was conducted for cases of low and even highly developed general corrosion (GC)/erosion, which is presented in the model using periodic rough reflecting surfaces with different geometrical characteristics.

Experimental studies have been conducted on the comparative samples (CS) with periodic roughness on surfaces with ultrasonic thickness gauge by using longitudinal UW. The experimental dependencies are received of characteristics on back scattering information signals from the geometrical characteristics of roughness, suitable for use in ultrasound examination of GC.

KEY WORDS: acoustic geometry, diffusion reflection, phased array (PA)

1. Introduction

The most common type of corrosion is GC. It is characterized by failure of the entire metal surface in contact with corrosion protection. Roughnesses are formed on the metal surface covered with corrosion products of deposits, which are formed in the cavity. The roughness in the model is represented by its geometric features: height Rt (rms value σ) and pitch (regularity) Λ of their profile.

The reflection of UW of uneven surfaces corrosion is accompanied by scattering and interference of waves, leading to a weakening of the received information signal. Consequently, different depths of corrosion in different sections of the material (in the field of the ultrasound beam) reflected signal is strongly deformed. Reflected by the various sections UW travel different route to the receiver, as usual position of peak signal does not correspond to the smallest thickness of the object in the area of control. An information characteristic of the reflected ultrasonic signal depends on the geometrical characteristics of the roughness and acoustic characteristics of the environment [1, 2].

2. Models for representation of corrosion reflection

In the models of the reflection from the corroded uneven surface are using physical laws of propagation of UW, as radiation acoustics (acoustic geometry), diffusion (stochastic) nature of the distribution UW in materials and diffraction of reflector (corrosion damage) [1÷8]. Essential for modeling is the determination of boundary conditions for the validity of using models of the reflected UW from corroded surface.

The reflection of normal falling flat UW with wavelength λ toward corroded uneven surface with height Rt, depending on the values of Rt and λ is determined by different models. In fig.1a is presented reflection of UW with varying the wavelength λ of the uneven surface with equal uniform height roughness Rt, and the fig.1b the same value of λ and the value of the variable Rt [1].

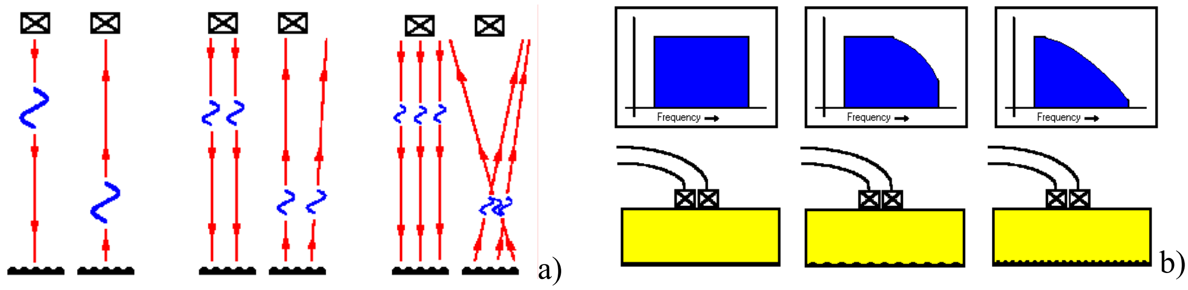


Fig.1. Scheme of the variance of the ultrasound pulse a) and its frequency spectrum b) in reflection from rough surface.

In [1] has shown that in method of reflection for value of Rt≥λ/4 the variance of the reflected information signal is significant. In those circumstances of reflection where the roughness are regular and evenly distributed at a specified angle of incidence of UW to the surface, are validity the law of reflection from the uneven surface by method using the acoustic geometry. Then the effect in any section of the roughness is determined by the law of the acoustic geometry, as the method proposed by Gmirin [5, 6].

From the analysis of the spectrum of reflected signal from unevenness (fig.1b) are observe an increase of the frequency dependence with decreasing height of roughness Rt. Frequency dependence is very effective for small values of Rt <<λ. In such case, the reflection from the uneven surface has a diffuse character and is accompanied by a slight reduction of the reflected signal information. The presentation of the reflection from unevenness with diffuse character is using the Rayleigh method [2÷4], and the reflection using the method of acoustic geometry-approach Gmirin [5].

2.1. Rayleigh metods

According to the method of Rayleigh roughness characteristics are representing with a high of unevenness and the distribution mode of the roughness. It is designed for sinusoidal and sufficiently smooth uneven surface (Rt≈Λ) with very small roughness height Rt, for which the phase difference φ≤1. For this case in any type of correlation function of the profile of surface roughness, coefficient of reflection R is frequency dependent and characterization of the roughness profile Λ has no effect at it.

The phase difference φ between two waves, resulting in an additional double pass of wave 1 at a distance σ, is given by the dependence [1, 3÷6]:

(2.1.1) $$\varphi_j = 2.\sigma.k_j.\sin(\alpha),$$

where σ is the rms value of roughness height Rt, $\kappa_i=2\pi/\lambda_i$ – wave number, $\lambda_i=C_j/f_0$ is wavelength of UW, α is the angle of incidence of UW toward base plane of the uneven surface.

The coefficient of reflection R and transmitted T in energy, according to the method of the Rayleigh is shown in the following form [1, 3÷5]:

(2.1.2) $$R = R_0.e^{-2.\sigma^2.k_1^2.\sin(\alpha)^2} \quad \text{and} \quad T = T_0.e^{-\frac{1}{2}.\sigma^2.(k_1-k_2)^2.\sin(\alpha)^2},$$

where k_1 and k_2 are wave numbers of longitudinal UW, in the first and the second media, R_0 and T_0 are, respectively, the coefficient of reflection and transmitted for a smooth surface with Ra≈0μm.

2.2. Gmirin metods

In fig. 2 is presented a schematic interference involved in the formation of a reflected impulse from surface triangular unevenness. Participation of this interference in the formation of the reflected signal increases with the height of the roughness Rt and their step Λ.

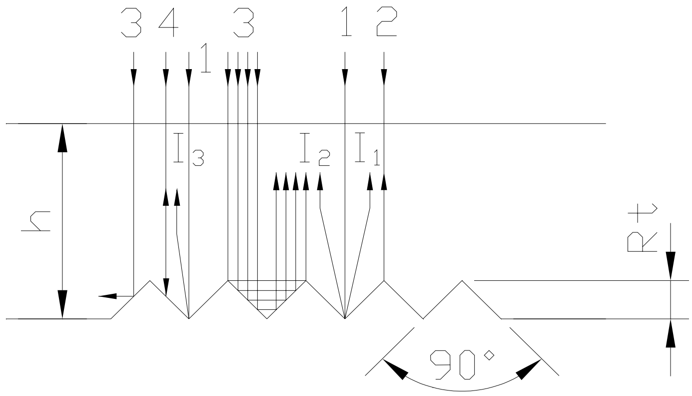


Fig.2. Scheme of reflected UW from bottom with unevenness.

In determining the size and shape of the amplitude of the interference pulse reflected from the unevenness is suggested, that a major part of its composition is formed from waves 1 and 2 presented in fig.2. Be taken for basic pulse 1 reflected from the top of the roughness, located on the line formed by the nominal thickness of the specimen. Two cases of interference Ii of ultrasonic pulses from a rough surface is consider in this work.

The first case is for interference I_1 of basic pulse 1 and pulse 2 reflected from the tops of the roughness with the smallest thickness in the model. In this case the phase difference φ is calculated by the relationship: $\varphi = 2.Rt.k.\sin(\alpha)$.

The wave 3 and 4, falling on an inclined surface are diffused. A significant part of wave 3 is reflected in the opposite direction and interferes with the wave 1. In the travelled path by wave 3 is render an account the distance between the roughnesses. This interference wave is denoted by I_2. Phase difference for interference of I_2 is written in the form: $\varphi = Rt.k.\sin(\alpha)$. Total interference of waves 1, 2 and 3 denote by $I=I_1+I_2$.

Modelling is used ultrasound pulse A (wave 1) from smooth surface, distributed in a continuous medium is used a bell shaped pulse. Interference between two ultrasonic waves reflected from different points of the surface roughness is presented with a phase difference φ. For reflected from a smooth bottom surface pulse $\varphi \approx 0$. Bell impulse A(x,t,φ) is given by the following expression [9]:

$$A(x,t,\varphi) = A_0.e^{i.((\omega_0.(t-\tau_0))+\varphi)-(\beta^2.((\omega_0.(t-\tau_0))+\varphi)^2)}, \quad (2.2.1)$$

where A_0 is the maximum amplitude of the transmitted pulse and it is assumed $A_0=1$, $\beta = \sqrt{\ln(2)}/\pi.n_0$ - coefficient of shape of impulse, $\tau_0=2.h/C$- time of arrival on reflected ultrasound impulse, C- velocity of distribution on UW in material. Interference $I_i=A_1(x,t,0)+A_i(x,t,\varphi_i)$ is presented as the sum of two impulses.

3. Numerical implementation of models for reflection from corroded surface

Numerical calculations are performed on reflected UW from corroded uneven surfaces by using two approaches to diffuse and mirror reflection. Used in this work reflectors simulating corrosion are regular triangular canal with different geometric characteristics.

3.1. Objects to modelling and experiment

For the purpose of the study are prepared CS from low-carbon steel with a series of landings, made on one of their surfaces, a width equal to the width of CS and length of 20mm. Over the landing are constructed triangular channels with different height and angle at the tip of their β=90°. The surface of CS without the presence of roughness is with roughness Rz≈4μm. The names, dimensions and the height of the unevenness of CS are given in table 1. On fig.3 is presented a CS3.

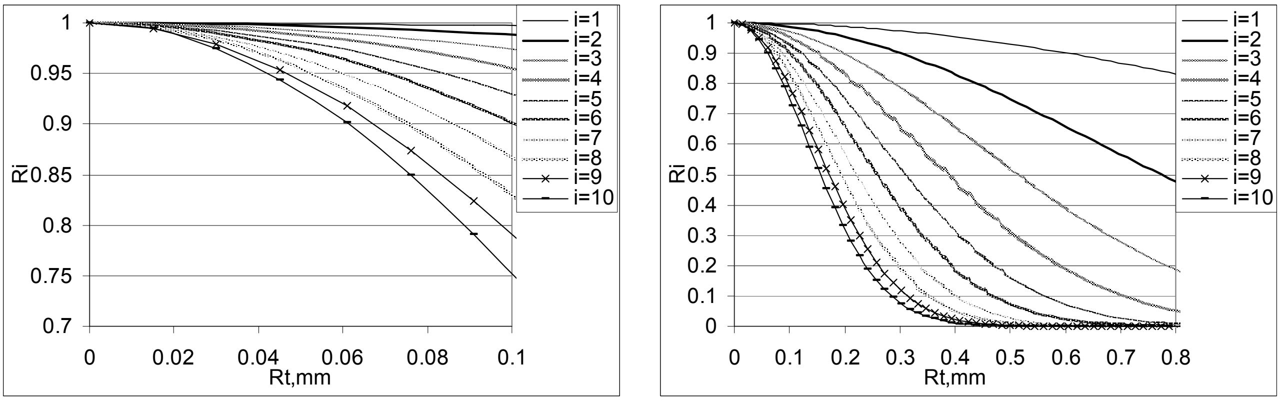
Table 1

names of CS	dimension [mm]	High of unevenness, Rt [mm]
CS1	100x24x25.5	from 0.1 to 0.4 through 0.05
CS3 (fig.3)	63x29.5x29.2	0.25, 0.5 and 1.5
CS4	104x22x35	from 0.1 to 0.8, through 0.1
CS5	104x22x40	from 0.1 to 0.8, through 0.1


Fig.3. CS3

3.2. Numerical results for diffusion reflection

On fig.4 is presented the coefficient of reflection Ri from uneven surface with diffuse characters by the method of Rayleigh, for CS5 from table 1 with Rt = 0÷0.8mm. The index value i, given in the upper right corner of the figure, determine at what frequency f in MHz is built relevant dependence. Dependencies are built for α=90° and β=90°. Bear on the abscissa variable roughness height Rt of 0mm to 0.1mm in fig.4a and 0mm to 0.8mm of fig.4b. Ordinate bear the size of the amplitude reflection coefficient Ri.



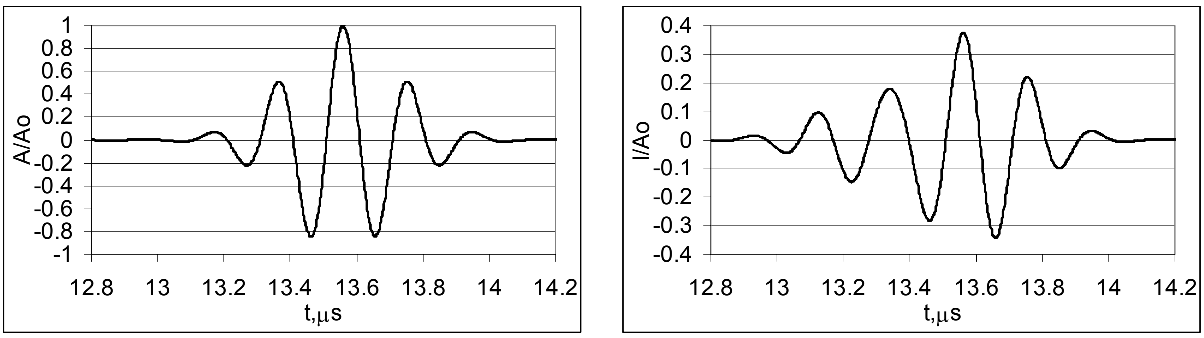
a) b)

Fig.4. Amplitude of coefficient R of a surface roughness.

The values Rt in fig.1a are for Rt<<λ (φ<1), which is in scope the dependence with diffuse nature of the Rayleigh.

3.3. Numerical results for reflection using of method acoustic geometry

Superposition of the issue in this work two cases of interference $I = I_1 + I_2$ is presented in fig.5b for CS5, Rt=0.7mm and α=90°. Acoustic pulse has parameters as follows: operating frequency f_0=5MHz, n_0=2 and C=5.9km/s. The reflected pulse A from smooth surface is presented in fig.5.



a) b)

Fig.5. Shape of signals reflected from a smooth a) and unevenness b) bottom surface

Changes in signal characteristics occur in the reduction of peak and change its location. Reducing the amplitude of the reflected pulse from the uneven surface is to $0.35.A/A_0$. Shift of the maximum signal is 0.01. The beginning of the signal at 10% of A/A_0 is shifted to smaller times with 0.24μs.

In fig.6 is presented the coefficient of reflection R from change of the height of the triangular roughness Rt for CS5. The first of the extremes seen in fig.6 is for Rt around λ/4 a second soon after when Rt≈λ/2.

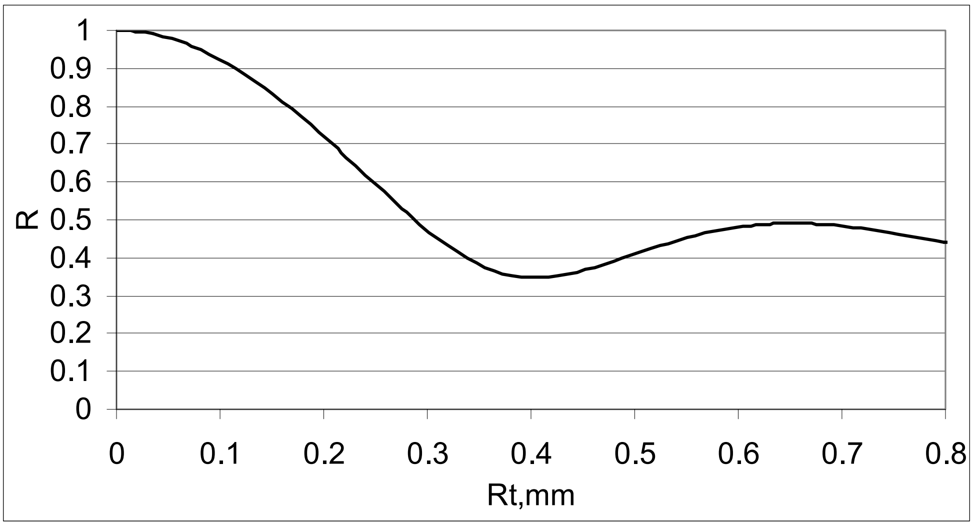


Fig.6. Coefficient of reflection R of the bottom triangular surface roughness.

3.4. Experiment

3.4.1. By using ultrasonic thickness gauge DMS2

Experimental ultrasound examinations were performed with ultrasound thickness gauge DMS2 and dual transducer (DT)- DA401 with an operating frequency f=5MHz and normal transducers (NT) K2K and K4K, respectively with f=2MHz and f=4MHz. For contact environment is using machine oil.

The studies include measuring and recording the amplitude of the first bottom signal. The scheme of the experimental investigation is presented in fig.7, where 1 is transducer, h - height of CS, Rt - roughness height.

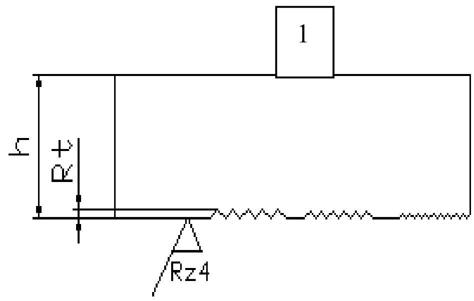


Fig.7. Scheme of ultrasonic experimental investigation

The attenuation of amplitude R of the first bottom signal for CS and NT with f=2MHz and 4MHz are presented, respectively, in fig.8a, fig.8b and for CS and DT with f=5MHz in fig.8c. On fig.8d are presented in a graph of experimental investigation using DT with f=5MHz and theoretical calculations using the method of Rayleigh and Gmirin for nominal frequency 5MHz.

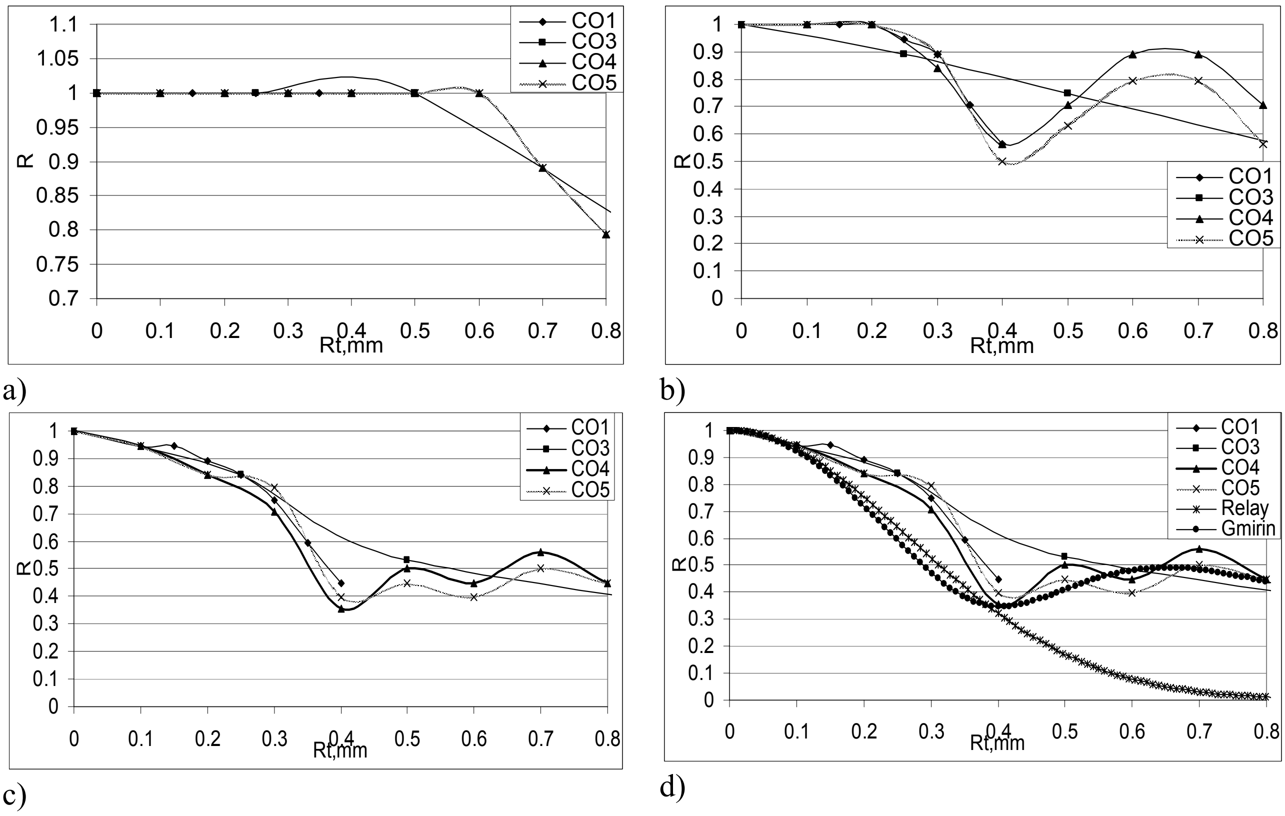


Fig.8. Loss of the information signal, depending of available at the bottom surface roughness with high Rt

On fig.8 is shown an increase sensitivity of the ultrasound system to the height Rt of the triangular roughness with increasing nominal frequency f of transducer. For example, the changes of amplitude using NT at 2MHz start from Rt$\approx$0.5mm (fig.8a), and for experimental work with NT at 4MHz differences in amplitude are observed in Rt$\approx$0.2mm (fig.8b). While results with DT at 5MHz on fig.8c shown that the amplitude is affected by lower heights roughness Rt of about 0.1mm.

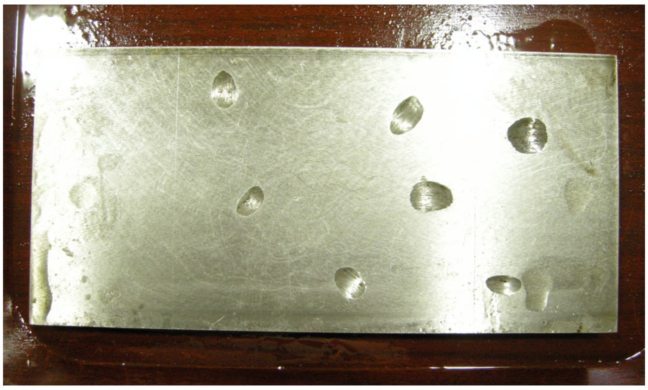
From fig.8d shows good coincidence of theoretical results with experiment for the operating frequency of 5MHz. Theoretical results using the Rayleigh's method are overlap with the switch to the experiment for Rt$\leq$0.1mm, which is corresponding to $\varphi<1$. Numerical results using the Gmirin's method is qualitatively consistent with the experiment for Rt$\geq\lambda/4$, where $\lambda/4\approx$0.3mm.

Using the experimental results on fig.8 is possible to evaluate the corrosion as a result of the amplitude of corroded surface is converted to the values of the amplitude of the reflected signal from the triangular channels.

3.4.2. By using OmniScanMX with phased array probe

Ultrasound examinations are performed with ultrasound equipment OmniScan MX with module for PA on CS PL22 with dimensions 260x120x18.9 provided on fig.9a. On one of the surfaces of CS PL22 is withdrawn metal by a 1mm depth with a grinding machine.

The used PA probe is 5L-128 of the operating frequency at 5MHz, with 128 elements. Measurements were conducted with longitudinal UW in the case of linear electronic scanning (LES) with an angle of incident wave in material 0°. The number of active elements group (virtual probe aperture VPA) is 32, the step of LES is trough one elements. The width of the active scanning axis is 73mm, and passive axis- equal to the length of the elements in PA probe. Focal laws are number 96. Electronic focus depth is 43mm, characterizing the work area of PA probe. Acoustic prism is used SI3 0L, made by OLYMPUS. For contact environment is used engine oil. Scheme of performed measurements is given in fig.9b. PA probe is placed on the smooth surface of CS and move it mechanically, as the scanning time is less than 10 seconds. The mechanical removal of PA probe on CS is recording with scanning encoder.

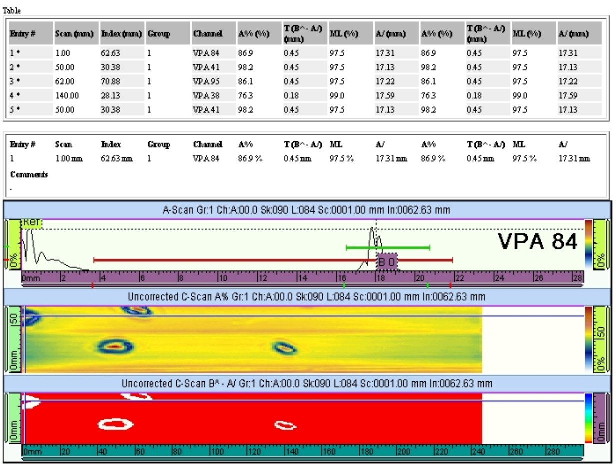


a)

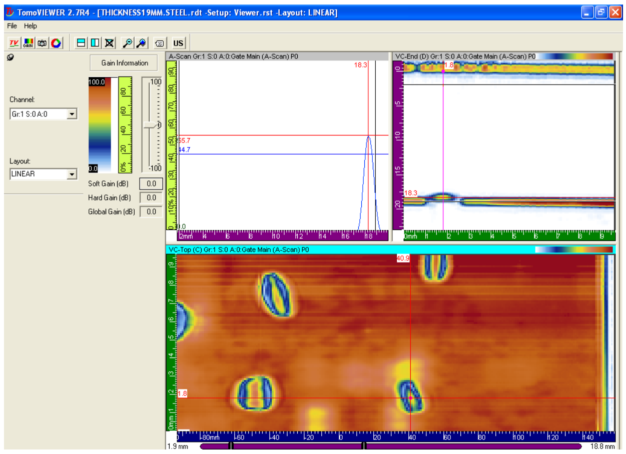
b)

Fig.9. Photo of experimental pattern a) and performed ultrasonic measurements b)

On fig.10a presents the results of ultrasound tests on CS PL22 using the standard sample (protocol) prepared by the software of the ultrasound equipment. Group of A-scan, B-scan and C-scan amplitude are presented on fig.10b using software TomoVIEWER 2.7R4. A-scan is presented of one of deprived sections of metal, as well and B-scan of the right in fig.10b for the same area.



a)



б)

Fig.10. Results from ultrasonic investigation on CS PL22 with ultrasonic equipment OmniScan MX and PA probe 5L-128

The relative size of sector with a difference in the thickness is determined by a weakening the signal amplitude with 50% of its maximum. These limits are determined by the amplitude C-scan, they are colored blue. On B-scan image presented above to the right of fig.10b, visually observed the missing material from bottom surface of the test specimen marked with red line, which is around 0.6mm.

Maximum signal reflected from the smooth surface of CS PL22 is 100% and the signal reflected from one of surface unevenness amplitude is 55%. Therefore, the reflected signal is diminished by 45% or by 0.45. Comparison of results of the amplitude of the test values with the amplitudes of the experiment fig.8c be seen that this amplitude corresponding to roughness height Rt=0.6mm. Such is the value of forfeited thickness for tested CS PL22.

Conclusion

In the work is probated method Gmirin and Rayleigh for describing the reflection of UW from the uneven surface. The results of numerical modeling and experimental investigation using ultrasonic thickness gauge and PA technology are received. CS is proposed to conduct investigation and comparative assessment of corrosion.

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