IOP Conf. Series: Materials Science and Engineering **253** (2017) 012005 doi:10.1088/1757-899X/253/1/012005

Remote Acoustic Emission Monitoring of Metal Ware and Welded Joints

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Abstract. An unusual phenomenon was revealed in the metal-ultrasound interaction. Microwave sensor generates surface electric conductivity oscillations from exposure to elastic ultrasonic vibrations on regions of defects embracing micro-defects termed as “crack mouth.” They are known as the region of "acoustic activity,"method of Acoustic Emission (AE) method. It was established that the high phase-modulation coefficient of reflected field generates intentional Doppler radar signal with the following parameters: amplitude-1-5 nm, 6-30 dB adjusted to 70-180 mm. This phenomenon is termed as "Gorbunov effect," which is applied as a remote non-destructive testing method replacing ultrasonic flaw detection and acoustic emission methods.

Introduction

Until recently, it was supposed that acoustic emission becomes apparent as temporary short acoustic signal sequences, generated by electric coupling failures [1]. These failures result in emerging density variations, acoustic waves spreading throughout the metal in all directions at acoustic velocity. Registering these 0.1-25nm mechanical oscillations by contact-type piezoelectric sensors, oscillation onset location and hazard level of emerging defect were determined. The disadvantages of this method included: essential mechanical loading to obtain desired signals and required application of contact highly-sensitive piezoelectric sensors, involving the application of immersion liquid. Both disadvantages could be eliminated by applying ultra-high frequency radar. However, practical testing demonstrated that this radar has low-level degree of sensitiveness (1-5 micrometer). i.e. 3-4 times more than required.

Theory (Theoretical justification)

In numerous experimental investigations [2-4] the so-called "Gorbunov effect" which emerges with acoustic signals has been described. Pertinently, this effect is when emerging source of acoustic emission, related to as” active” (i.e. counting rate of acoustic impulses increase proportionally to i degree of breakage force), furthers an unusual change within the metal around the source of AE. In fact, even after the mechanical loading back period this region retains its unusual properties. If this region is subjected to elastic oscillations (low-power ultrasound waves of up to 5-10W/cm^2) one could observe synchronous changes of surface electric conductivity. Lateral spectral component of phase-modulated signal, reflected from investigated surface, exceeds the noise spectral power to more than 6-20 dB. In the case of no “active” region, lateral spectral component of phase-modulated signal is not higher than the noise level. Actual microwave sensor frequency is 33 ghz. This interaction effect, discovered in

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1985, is compatible with such well-known theories as failure process within metal objects[4] and metal ionization being of X-ray radiation source.

A characteristic feature of the "Gorbunov effect" is its time of occurrence. For example, if the "active" AE source time proceeds for a fraction of a millisecond and coincides with mechanical loading time, then the detection time for "Gorbunov effect" is from several minutes to ten hours after load release. Registering the "Gorbunov effect" by microwave sensor is possible at a significant distance (70-180 mm)from the object surface. Exposure zone is not associated with the "activity" zone but embraces the metal surface completely. In this case, no scanning is necessary as in previous AE diagnostic methods.

Experimental technique

Mechanistic potential of this new diagnostic method has not been completely described. Nevertheless, designed Doppler radar-based device (remote active defect indicator) has a wide application spectrum-investigating hazard metal defects, monitoring motor block and turning strength and expanding nondestructive testing method application. The steady loading could be excluded in the case of applying the acoustic emission (AE) method for testing. It was revealed that previously detected defects by AE method could be also identified by the "Gorbunov method," without applying additional mechanical loading. Super-high frequency crack (flaw) detector (DIAD-1) operates in combination with ultrasonic generator of the following parameters: frequency – 50 Kh; power outlet- $P= U_{out}^2/R_{tr}=(80^2/300)=21$ *W,* where U_{out} is generator ultrasound output voltage; R_{tr} – active resistance of piezoelectric transmitter of MA40E9-1 type. Ultrasonic transmitting unit area is 1см^2. Operating distance from super-high frequency sensor to examined sample is 90-120 mm with step 3.3 mm. Operating parameters of new device were compared to those investigated samples by ultrasonic crack detector. Two additional samples were tested on the X-ray unit (fig. 1 a, b). Photos of samples are presented in fig. 2 a-d. Desired signal level obtained through DIAD and fast Fourier transformation (FFT) program are depicted in fig. 3 a-d.

Figure 1a X-ray of object joint № 1-20. Defect of weld joint as a result of procedure violation (rapid water cooling); desired signal 14 dB. Crack under weld.

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Figure 1b X-ray of weld joint №1-24. Hollow aperture under weld. Desired signal 12dB.


Figure 2a.Weld joint, object №1-20 Desired


Figure 2b. Weld joint, object №1-24 Desired signal 12 dB.

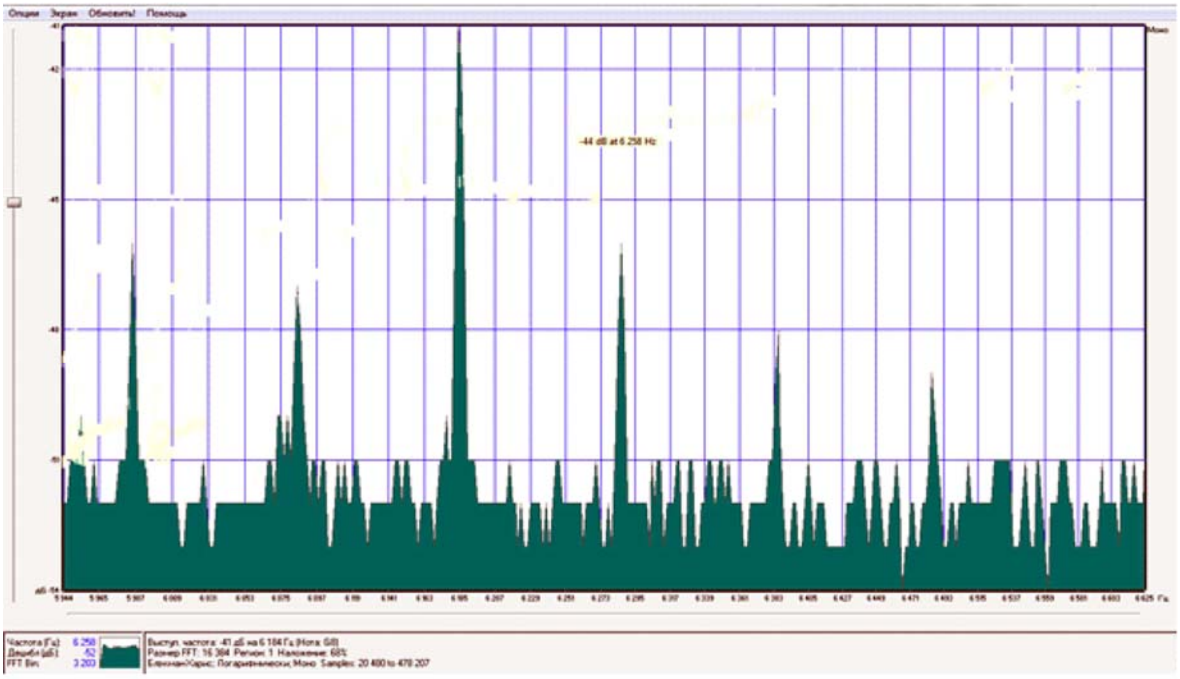

Figure 3a. Desired signal 14 dB. Object №1-20

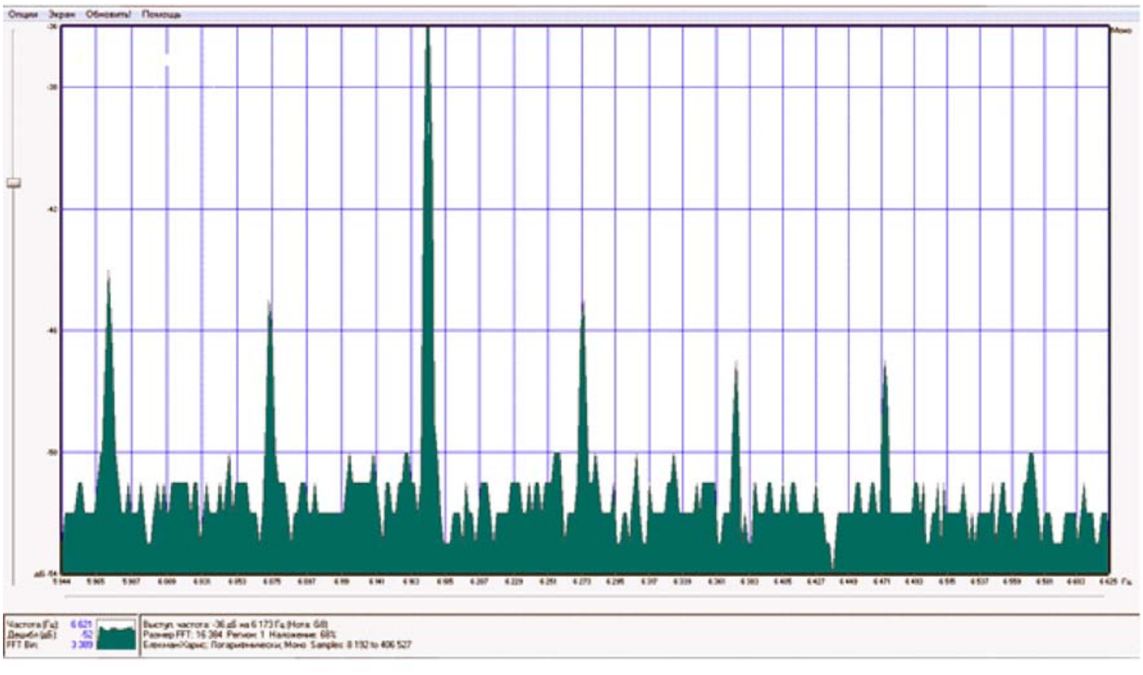

Figure 3b. Desired signal12 dB. Object №1-24

Brief explanation of acoustic-electronic interaction theory

Surface impedance is written on the basis of reflection coefficient ρ [5]

$$\rho = H_t(x)/H_t(0) = (1 - cZ/4\pi)/(1 + cZ/4\pi) \quad (1)$$

where, H_t - magnetic field vector; *c*- light velocity (3 10^8m/s); $Z(\omega,\sigma)$ –surface impedance (s/m);
$Z(\omega,\sigma) = (4\pi / c)\sqrt{\varepsilon}(\omega,\sigma), \varepsilon = \varepsilon_l + j4\pi\sigma / \omega$

where, $\varepsilon(\omega,\sigma)$ - complex dielectric constant; ε_l - real part; ω – cyclic frequency (rad/s); and σ - electrical conductance of metal (1/s)- arguments of surface impedance. The calculations showed surface conductance change (10%) resulting in significant reflection coefficient phase change (5%) and insignificant module change (0.025%). Likewise, the derived phase of reflection coefficient to conductivity(dφ/dσ) is less than zero. Increasing conductivity reveals decreasing reflection coefficient phase. At the same time calculations showed that mechanical surface oscillations result in inverse phase shift relationship. Reflection coefficient phase for surface is opposite to reflection phase of conductivity. Emerging elastic-surface-wave results in changing crystalline lattice density. Crystalline lattice density decreases maximum and increases minimum in S-waves. Thus, detecting surface elastic oscillations is characteristic of AE effect, and possibly, Doppler radar; in the case of emerging phase shift. Conditioned change of surface conductivity associated with mechanical oscillations is evidently observed and could be described as "Gorbunov effect."

Results and discussion

Described practical results of detecting concealed defects in metals by dynamic effect detector on microwave sounding-based proved the practical utility of this new non-destructive testing method. This new method embraced not only the ultrasonic diagnostic method and acoustic emission method, but also microwave sensor method for defect control. AE method requires significant mechanical loading and is incompatible with ultra- sound. Ultra-sonic zoning method does not interact with the microwave sounding method. Practically, all three methods successfully interact with each other demonstrating newly up-dated results. It should be noted that ultrasonic contact transmitters being substituted by ultrasonic laser generator of elastic oscillations are applied in diagnostics, which, in its turn, enhances this as a future non-contact method [6-10].

Conclusion

Above-described results in studying the new non-destructive testing method by applying Doppler radar showed that based on comparative control analysis results the welded joints are different from those in previous ultrasonic control methods (in this case, it is not necessary to compare experimental samples to reference samples without defects, but having complex geometrical shapes). AE method has numerous positive advantages – no additional mechanical loading and applicable with mobile units and / or units. The implementation of this method would decrease the diagnostic time, improve research reliability and simplify operations in auto-detection of fatigue effect in metal objects in-process. It should be highlighted that continuous control of welded joints after production is possible without complex ultrasonic equipment "X-raying."

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