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Measurement of Acoustic Emission Signals Using Doppler Radar

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Abstract: Specialist nondestructive testing (NDT) know the method of acoustic emission. One of its advantages is high reliability of obtained results. Shows the sources of emissions do not doubt the presence of identified dangerous areas. The disadvantages of this method are the need for prior mechanical loading and the use of contact piezoelectric transducers. These limitations can be eliminated by applying the "Gorbunov"effect, discovered by the authors. Its essence is the abnormal interaction of the elastic waves of ultrasound with electron gas.

Keywords: Ultrasound, MW Sensor, “Gorbunov” Effect

1. Introduction

Acoustic-Emission method operates with the concepts associated with the detection of elastic surface oscillations having amplitude of 0.1-5 nanometers. The existence of these oscillations does not exceed a few milliseconds, is always associated with a pre-stress object of research. The time of occurrence of the desired signal is not defined. Registration requires the use of piezoelectric sensors high sensitivity (30-36 kV/mm). Disadvantages of contact sensors create significant obstacles testing of moving parts of machines (wheels of railway cars and locomotives), heated objects (steam lines) (Curie point not higher than 300-400°C), the fragility of the sensors, collapsing (losing sensitivity), with significant operating signals (90-100 dB) that exceed the dynamic range of the sensors themselves (40-50 дБ0. Repeated attempts to replace contact sensors microwave failed for many researchers [1], [2]. The fact, that the amplitude of mechanical vibrations of surface is always accompanied by fluctuations of the density of the metal. In turn, fluctuations in density lead to changes in the electric surface conductivity σ. As will be shown, both these phenomena have almost equal coefficients of reflection ρ for microwave radiation. But implemented opposite signs. As a result, the registration of the vibrations of metal surface to microwave radiation, it becomes extremely difficult not only because of the small size, but also because of the mutual compensation of the phase of the reflection coefficients of the surface and surface conductivity.

This tension, however, was overcome through the use of "Gorbunov effect" [3], [4]. Practically implemented a new variant of the AE method. Instead of contact sensors use microwave sensor the oscillations of the surface conduction. Instead of mechanical loading is used an additional source of elastic vibrations. The test results exceeded all expectations. It turned out that at the moment of occurrence of AE signals from the active regions, elastic waves interact with the electron gas within the composition of these areas. Formed wave surface conductivity, easy registered microwave sensor. In addition, such a process does not need any additional source of mechanical loading. The “Gorbunov” effect is observed for any metal objects ever experienced the effect of generation of acoustic signals. Metal object "remembers" how it "tortured" over a long period of time.

2. The Method of Using Bessel Functions

Consider the operation of microwave phase meter, registered the vibrations of metal surface small amplitude. For this we use the known transformation, cylindrical Bessel functions of the first kind [5]. Formula single-tone modulation can be converted to the form

$$u\ (t)=U_{\beta}\cos\ (\beta\text{-}\sin\ (\Omega t))\ \cos\ (w_{o}t)\text{-}U_{\beta}\sin\ (\beta\text{-}\sin(\Omega t))\ \sin\ (w_{o}t). \quad (1)$$

where U_β–the spectrum component the amplitude of of the order β, Ω-the modulating oscillation frequency, w_0-the frequency modulated oscillations, β-modulation index.

At low value of the modulation index $\beta <<1$ significant amplitude values only has the fundamental harmonic so that the approximate equality:

$$\cos(\beta\sin(\Omega t)) \approx 1,\ \sin(\beta\sin(\Omega t))\ (\sin(\omega_0 t) \approx \beta\sin(\omega_0 t).$$

When they are used in (1), we get:

$$u(t)=U_\beta\cos(\omega_0)+(\beta U_\beta/2)\cos[(\omega_0+\Omega)t]+(-\beta U_\beta/2)\cos[(\omega_0-\Omega)t]. \quad (2)$$

A pair of lateral components $(\beta U_\beta/2)\cos[(\omega_0+\Omega)t]$ are of equal amplitude and differ in phase by π/2. The carrier amplitude U_β much more of the amplitude components of the side $\beta U_\beta/2$, when $\beta<<1$. The calculated ratio of carrier amplitude to the amplitude of one of the components side:

$$U_\beta/\ \beta U_\beta/2)=2/\beta.$$

3. Communication with the Reflection Coefficients

Since each component carrier is less than $\beta/2$ times should be taken that the detection of this component is possible, provided that its electric power exceeds the spectral noise by 3 dB. The level of power spectral density radio signal associated with the working strip with temperature by the relation coming from the power spectral density, which is determined by the formula Nyquist [6]:

noise spectral power=$4kT\Delta f$

where k — Boltzmann constant (1,38 10^{-23} J/K), Δf-frequency band (Hz), within which the measured voltage fluctuation, T-the object's temperature in Kelvin degrees.

The ratio of the minimum power of the lateral component of the phase modulated signal to the power carrier is calculated as $20\log 2/\beta$. The power density is multiplied by the Kelvin degrees $P(\Delta f, T)=kT\Delta f=-174$ *dB/W* (1/Hz),или-*144 dB/mW* (1/Hz) for a temperature of 300 degrees Kelvin, band *1 Hz*. The ratio of the minimum power of the lateral component of the power carrier is calculated as $20\log 2/\beta$. Given the condition of the minimum relative power *mW* (-*144 dB/mW+3 dB=-141 dB/mW* you can always specify that the power of the carrier must not exceed-141 dB relative to the level of the lateral component. Given the physical representation of the modulation index $(1/(\lambda/4)/a_{max})=(1/(\pi/2)/\Delta\varphi),=\beta,$ where a_{max} mechanical vibrations amplitude, $\Delta\varphi$ the phase of the reflection coefficient:

$$P_{max}=-141+20\log(2a_{max}/(\lambda/4))=-141+20\log(8f\,a_{max}/C) \quad (3)$$

Plot $P_{max}=F(a_{max}, f)$ where a_{max}–the amplitude of the vibrations of the metal reflector (0,5-25 10^{-6}mm), f–the frequency of irradiation of microwave oscillations (10^9–100 10^9 Hz), C-the speed of light (3 10^{11} мм/c). Schedule (Fig. 1) shows that the observation of the lateral component of the phase modulated carrier signal of 10 GHz is possible for the amplitude of mechanical vibrations of more than 0.5 nanometers (the noise factor of the receiver-6-7 dB, bandwidth 100 Hz). However, even for amplitude of 5 nanometers (the excess of signal above the noise level of 24-26 dB) useful signal is not observed.

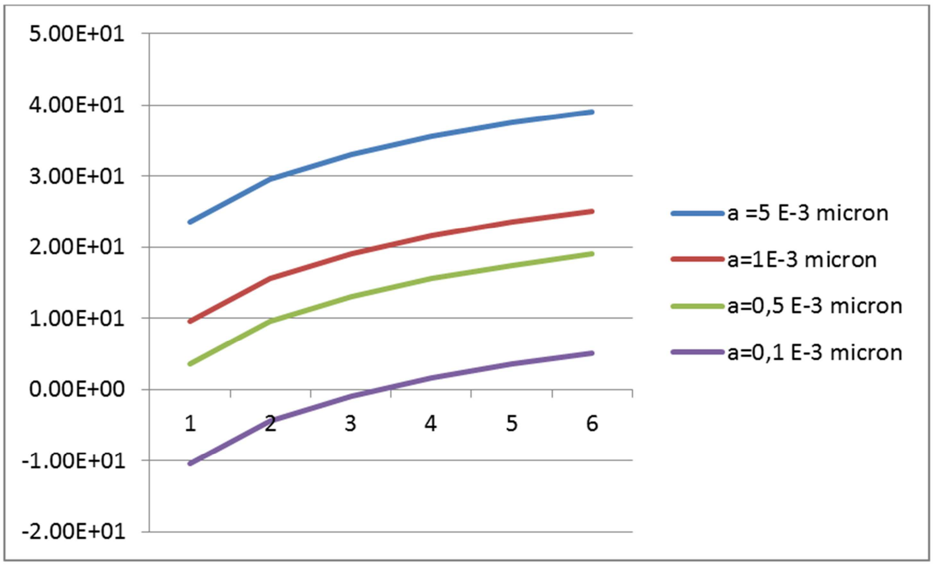

Fig. 1. *X-axis-frequency in the tens of GHz, the Y-axis exceeding the lateral component of the signal above the noise (dB) carrier at a power of 1 mW.*

Calculate the reflection coefficient of the surface electrical conductivity ρ, depending on changes in the conductivity σ.

Known recording of the surface impedance using the reflection coefficient [7]

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

where H_t the magnetic field vector, c-the speed of light (3 10^8 м/c), $Z(\omega,\sigma)$ –impedance surface (c/м),

$Z(\omega,\sigma)=(4\pi/c)\sqrt{\varepsilon}(\omega,\sigma), \varepsilon=\varepsilon_l+j4\pi\sigma/\omega$ where $\varepsilon(\omega,\sigma)$ -complex dielectric permittivity, ε_l -the real part, ω –circular frequency (rad/s) and σ -the electrical conductivity of the metal (1/s)-the arguments of the surface impedance. The calculation showed that a slight change in the conductivity of the surface leads to a significant change of the phase of the reflection coefficient. In addition, the increase of conductivity leads to the appearance of positive values of phase shift and Vice versa. The decrease in conductivity indicates the negative value of the phase shift of the reflection coefficient.

$$(1/(\lambda/4)/a_{max})=\beta_a,\ (1/(\pi/2)/(-d\varphi),=-\beta_\sigma. \quad (5)$$

The emergence of surface elastic waves leads to a change in the density of the crystal lattice. The density of the crystal lattice is reduced maximum and increased minimum transverse waves.

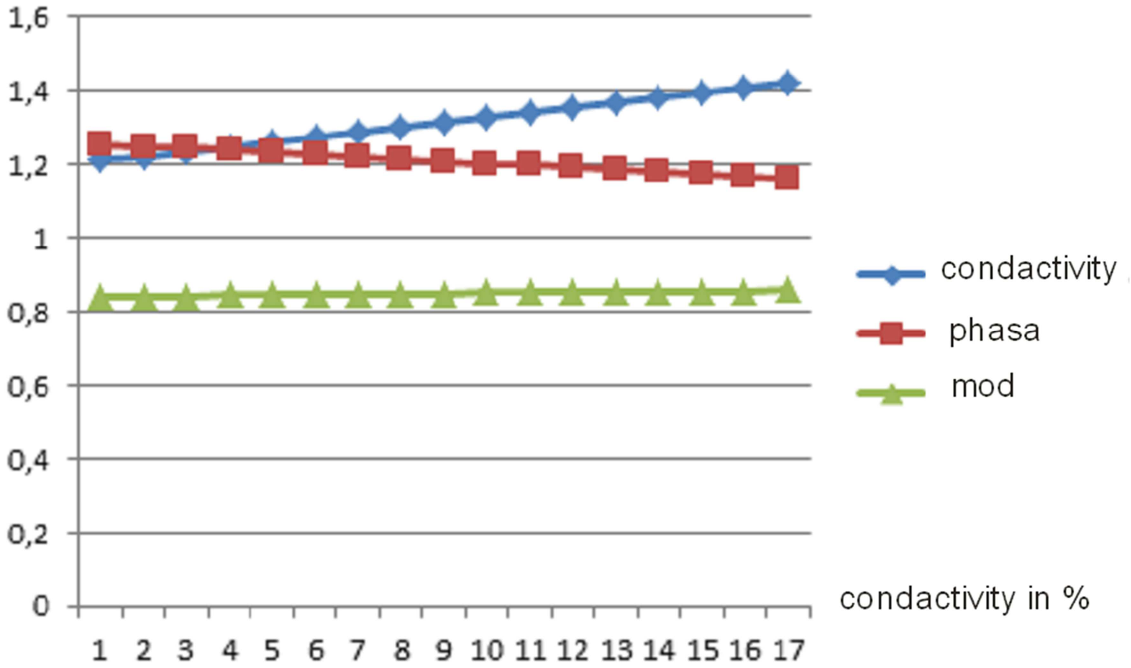

Fig. 2. *Diagram of functional dependence of module and phase of the reflection coefficient ρ when changing the conductivity σ (om2^11 до 2,34^11 1/s, to 14%) for f=33 GHz, ε_l=1. Phase changed to 1,25/1,16=1,077 (to 7,7%).*

4. The Results of the Experiment

The experimental results obtained in the test metal objects, the active defects, have demonstrated the useful signal by *20-25 dB* signal/noise. It became possible due to the implementation of an additional component of the modulation index β_G (modulation index "Gorbunov" effect) associated with a change of the surface conductivity. Referring to the information of Fig. 1, given the ideality of the receiving channel (the noise level is 7-10 dB, the bandwidth of the measurement 1000Hz (30dB)), it can be argued that the virtual amplitude of this type of conductivity is greater than 5 nm for a frequency of 33 GHz. In this case, it is possible to register waves of the surface conductivity.

5. Conclusion

Studies show that the practical registration of the oscillations of the metal surface of the microwave sensor is impossible. The magnitude and phase of the reflection coefficient of microwave radiation from the metal does not change when the surface has a transverse elastic vibrations. The reason is the fact that together with the mechanical displacement varies the density of the metal The reduction in the density of the crystal lattice characteristic of high waves, leads to a reduction in the density of the electron gas, the decrease in surface conductivity. Increasing the density of the crystal lattice in the minimum oscillations leads to increased surface conductivity. As a result of mechanical surface oscillations are in antiphase with oscillations of the density of the electron gas (negative slope of the phase characteristic of reflection coefficient Fig. 2). Obviously in case of equality of the amplitudes of these processes (5) it is impossible to observe the total fluctuations by analyzing the reflected microwave signal. They cancel each other out.

The "Gorbunov" effect of changes in surface conductivity simultaneously over the entire surface, so it is possible to observe even minor fluctuations in conductivity, the virtual amplitude is more than *5* nanometers.

Experimental results obtained using a set of instruments "Remote Indicator of Active Defects" [8-10], demonstrate the efficiency of the new direction of non-destructive testing. The authors hope to continue the description of experimental studies. Theoretical justification of the calculation of the amount of defects according to the results of practical measurements.

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