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# Doppler Radar Detects Internal Metal Defects

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**Abstract:** *Two decades have passed since the discovery of a new phenomenon of the effect of ultrasound on the electronic gas of metals. It allowed metal defects to be indicated by Doppler radar sensors not only on the surface but also in the depth of the metal. Foreign authors involved in this task are faced with the problems of practical implementation. The sensitivity of Doppler radars was hundreds of times rougher (up to 1-2 microns) than was required for indicating acoustic emission signals (10-20 nanometers). The proposed versions of microwave sensors can only scan the metal surface to detect cracks on the surface (0.1 mm in size) hidden by paint or other dielectric coatings. Unlike the variants offered by foreign patents, for the first time the Doppler radar works together with an additional ultrasound source. Working models of devices based on this principle were tested together with a Doppler radar with a frequency of 33 kHz and an ultrasound generator with a frequency of 44 KHz. Research in this area was based on the hypothesis of Moscow professors Vasiliev B. V., Lyuboshits V. L. on "generation of additional surface conductivity by mechanical pressure on the electron gas region". The group of Tomsk Professor Gorbunov performed an experimental test of the hypothesis using ultrasound as a source of mechanical pressure. As you know, ultrasound was previously used only for embedding in the object under study and determining the amplitude of reflection from defects, the degree of screening of ultrasound by defects. In all these cases, the size of the defects should have been greater than a quarter of the ultrasound wave in the direction of the study. The new device allowed us to obtain results that differ sharply from the usual ultrasonic flaw detectors in reliability (up to 90%), from the previous versions of microwave sensors in the depth of detection of defects (from fractions of a millimeter to a depth of 5-6 meters), as well as in the size of detected defects (less than 1 cubic millimeter in volume). The results obtained require a review of the capabilities of the known active and passive ultrasonic flaw detectors.*

**Keywords:** *Active and passive ultrasonic methods, Doppler radar, metal flaw detection, interaction of ultrasound and electron gas.*

## Introduction

In the middle of the last century, there was a problem of replacing contact sensors used for ultrasonic monitoring of metals with remote sensors, comparable in their effect to Doppler radars. The practice of using contact sensors is faced with a high complexity of diagnostics of moving objects. These include railway wheels, shafts of generators and turbines of thermal power plants. There were difficulties in determining the defects of special products (zirconium tubes for Heat-Generating Elements (fuel Rods) of nuclear power plants). Restrictions on the use of contact ultrasonic sensors also applied to surfaces heated above 300 0, at which there is a loss of sensitivity of piezoelectric sensors. In addition, it soon became clear that the dynamic range of sensitive piezoceramic sensors (45-50 dB) is significantly lower than the dynamic range of the studied signals (90-120 dB). For this reason, sensor failures and loss of sensitivity often occur during critical tests. It was assumed that the interaction of the microwave field with the metal surface, with active and passive ultrasound diagnostics, can be easily detected. Moreover, the excitation of a metal surface by laser excitation of ultrasonic waves was no longer a difficult task. In the period 1970-1980, American ultrasound generators were produced by their military industry. For this reason, it was believed that the replacement of contact sensors with laser or microwave sensors is already in the near future. But it soon became clear that the sensitive laser sensor for surface deformations was very weak. A useful signal from ultrasound sources could only be detected on the surface with a laser at an amplitude of a few microns, while contact sensors could detect oscillation amplitudes of one nanometer. Later, this "trouble" was not overcome radically. Laser sensors could detect "movements" of a metal surface of 0.1 - 0.5 nanometers in size, but these movements extended only to artificial simulators, which are mirror-processed surfaces of very small sizes (10-20 microns). The practice of using laser "Speckles" of conventional surfaces has encountered a high level of complex processing, which does not allow us to study the spectrum of surface vibrations with a frequency of more than 100 Hertz.

As usual, at the beginning of complex research, many patents appeared in the open literature describing the possibilities of implementing microwave sensors that replace acousto-emissive contact sensors [1-3], but practical verification did not confirm this hope. The useful signal at the output of Doppler radars of different frequencies (from 10 to 40 GHz) was lower than the noise level even for temperatures close to absolute zero. An example of encouraging publications can be the work of the American researcher Gregory Smith [4], who not only describes the possibilities of implementing his invention, which completely repeats the Russian author's certificate published twenty years earlier [1], but also provides results that contradict known measurements of the parameters of acoustic emission of metals. However, both the first and second inventions proved untenable in practice. Nature does not allow direct recording of vibrations of a metal surface with an amplitude less than a few microns. For those elastic deformations in which the linearity of Hooke's law is preserved. Practice has shown that only for deformations of more than a micron, in which the linearity of Hooke's law is violated, it becomes possible to register vibrations of the microwave surface by radar.

## Researches

However, the long-term work of Russian researchers led by Professor V. I. Gorbunov has shown that direct measurement of acoustic emission parameters by Doppler radar is impossible. The reason is that the level of phase modulation of the microwave field reflected from the surface is close to zero [5]. Surface changes of an elastic wave consist of two components. The first is the natural amplitude of the vibrations. The second dependence of the metal density in this wave.The higher the vibration amplitude, the lower the density of the metal. Since the density of the metal is directly proportional to the density of the conduction particles (electrons), it turns out that the phase changes of the reflection coefficient consist of a positive phase change in the amplitude and a negative phase due to a decrease in the conductivity. To explain this property, consider the linear Hooke's law

$F=kX$

where F is the force of displacement of the particle on the surface, k is the coefficient of elasticity of the metal, X is the amplitude of displacement of the particle, indicates that it is impossible to detect changes in the phase of the reflection coefficient of the microwave field for small amplitudes of vibrations. The derivative of the phase in X ($d\varphi/dx$) consists of a pair of components whose sign is opposite. The derivative of the surface vibration amplitude $d\varphi/dxS$ is the opposite of the derivative of the metal density $d\varphi/dx\sigma$ ($d\varphi/dxS = - d\varphi/dx\sigma$). If the linearity of Hooke's law is violated (it is always more difficult to compress the metal than to break it), the equality of the previously mentioned derivatives is violated. It becomes possible to detect vibrations of the metal surface. This is what happens in practice. But we should not forget that the metal is destroyed when the amplitude of surface vibrations is more than a micron. Therefore, the practical use of the phase modulation effect to detect small vibrations of the metal surface of the microwave sensor is impossible.

It becomes clear why researchers of small changes (amplitudes) of surface vibrations (deformations) can not detect phase-modulated microwave signals reflected from the "vibrating" surface, which are successfully detected by contact sensors.

However, NATURE itself makes it possible to detect these ultra-small fluctuations (1-5 nanometers) using the Doppler radar. But on one condition. The fact is that the Russian scientists of their Kurchatov Institute-B. V. Vasiliev and L. V. luboshits their hypothesis, based on the virial theorem, suggested that the electronic gas of metals can generate an electric field when compressed, which changes the surface density of conducting particles (electrons) [6]. Members of the group of Professor V. I. Gorbunov we conducted successful practical tests of metal samples, using an ultrasonic generator as an external pressure source, measuring the level of the useful signal by the Doppler radar (variations in the phase of the reflection coefficient) under double mechanical and ultrasonic loading in the presence of hidden defects (microcracks obtained on the breaking machine). These tests confirmed the hypothesis of Moscow scientists from the Kurchatov Institute about the possibility of practical use of the effect of interaction of ultrasound with hidden metal defects. It is hidden defects that are generators of an additional electric field under" pressure " on them by ultrasound. The third phase component of the reflection coefficient $d\varphi/dxg\sigma$ is successfully indicated by the Doppler radar at the frequency of 30-40 GHz. This component is physically related to the surface conductivity wave. In turn, the surface conduction wave has a propagation speed close to the speed of light, so the wavelength is much longer than the wavelength of ultrasound. This property of the conduction wave , discovered experimentally, allows us to measure the useful signal on the entire surface of real metal objects. The size of a quarter of the wavelength of the surface conductivity of the frequency 50 KHz is about 1.5 Km. Obviously, any metal object (other than metal bridges) is hundreds of times smaller.

The obtained positive results confirmed the hypothesis of B. V. Vasiliev and V. L. Luboshits and allowed to create a new, unusual indicator of metal defects in the future. It is an indicator until it contains a meter of the phase delay between the beginning of the ultrasonic excitation signal and the beginning of the useful signal from the Doppler radar output. The new device (model of the device), working on the detected effect (interaction of ultrasound and conduction electrons), not only allowed to overcome the seemingly impossible obstacle ( the study of internal metal defects with a microwave sensor), but also to obtain new unusual results on the indication of defects.

## Test result

The tests continued for several years (2008-2020) and were accompanied by a gradual improvement in the sensitivity and usability of the device.

The final version of the device allows detecting hidden defects of metal objects with a volume of one micron [7] (cracks in the internal surfaces of high-pressure

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steam pipelines, chemical synthesizer reactors for liquid and solid polymerization of natural gas products, stratification of metal sheets (0.3-5 mm) made by rolling. Moreover, these defects can now be detected without additional mechanical loading, replacing the "external pressure" with a single low-power ultrasonic source (10-20 W/cm2). If earlier rolling defects of the type of bundles could be detected by a contact sensor of the frequency of 10-20 MHz, scanning the metal surface for 5-10 minutes, now such a marriage is indicated for 1-2 seconds without scanning the surface. The frequency of additional ultrasound is 40-50 KHz. Two orders of magnitude lower, therefore, two orders of magnitude less the degree of attenuation of ultrasound, two orders of magnitude longer the wavelength of ultrasound. This property of the new device, obtained as a result of experiments, significantly increases the operating range by reducing active losses. Scanning is excluded, and the time for displaying the defect is reduced. The depth of penetration of additional ultrasound (5-6 meters) allows you to use a new device for flaw detection of objects of large size and length.

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