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DETERMINATION OF ULTRASOUND WAVES ATTENUATION IN METALS

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ABSTRACT: A method is proposed, allowing assessing the influence of the grain size on the attenuation coefficient of ultrasound waves in metallic samples, by means of the maximum and minimum positive semi-waves within a transition process, caused by a rectangular signal waveform. Steel samples have been made and tempered at different temperatures for an hour. The generator of rectangular impulses has been set to the resonance frequency of both the piezo-transmitter and the piezo-receiver, and therefore the signal, measured by the oscilloscope, is big enough for direct processing. An averaged coefficient of compliance has been obtained, by means of which the diameter of the grains can be calculated for the corresponding sample.
Keywords: attenuation coefficient, ultrasound waves, resonance, piezo-transmitter, piezo-receiver, grain size

1. INTRODUCTION

Non-destructive metal tests (NDT) are a modern method of evaluating metal work-pieces. Certain physical and functional parameters are evaluated during this type of testing, which define the defectivity of the studied objects [1]. Defects in metals are due to deviation in structure, violation of continuity, and change in their physical and mechanical properties. The ultrasonic method of testing rigid bodies is one of the main non-destructive methods and therefore it is frequently used in practice. This method is based on the ability of ultrasound waves to propagate, refract, scatter and absorb in continuous elastic media, such as metals [2, 4, 5].

The pulse echo method and the through-transmission method occupy special place in ultrasonic NDT. The main shortcoming of the pulse echo method is that it is difficult to detect defects by means of itif they are located near the sensor. This problem is not observed with the through-transmission method, but the presence of a transmitter and a receiver severely limits its usein manual testing.

The amplitude of the ultrasound waves decreases when they propagate in rigid bodies, i.e., these waves attenuate. Their attenuation is defined by two phenomena – absorption and scattering – and is characterized by an attenuation coefficient, which increases at high frequencies. The attenuation coefficients of normal waves depend on the properties of the material, the grain size, the amount of carbides etc. [3, 5, 7].

The attenuation coefficient is defined in [2, 3, 5, 6, 7] by measuring the amplitudes of two successive positive semi-waves of the signal, going through the studied samples with various lengths. In [8] the attenuation of n(in number) semi-waves is studied as well, but the studied object is considered to be a mechanical system and differential equations are derived. A resonance method of non-destructive testing is presented in [9], in which anisotropic measurements are carried out for finding defective objects.

The aim of the present paper is to study the possibility to define the attenuation coefficient of ultrasound waves by means of the maximum and minimum positive semi-waves within a transition process, caused by a rectangular signal. After that an averaged coefficient of compliance is defined, by means of which and with the help of the attenuation coefficient the diameter of the grains for the corresponding sample can be calculated.

2. METHODOLOGY AND EQUIPMENT

2.1. Materials and thermal treatment

Four samples have been made of high carbon steel 70G(GOST) for the purpose, with dimensions ϕ25x10 mm, which have been tempered at 750°, 800°, 850° and 900°C for an hour. After that the samples have been grinded at R_a=0,32μm.

2.2. Experimental setting

Figure 1 presents the scheme of the low-frequency switch, while Figure 2 illustrates the experimental setting for defining the attenuation coefficient of the ultrasound waves in the studied samples.

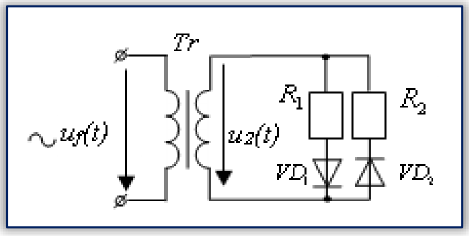

Figure 1.Scheme of the low-frequency switch

The action of the experimental installation is as it follows: phase voltage $u_f(t)$ with r.m.s. value 230 V is submitted to the lowering transformer, and then decreased to $u_2(t)$=8V. When there is a positive semi-wave of $u_2(t)$, current goes through the relay R_1(fig.1) and the contact К1 is switched for 10 ms(Figure 2). During this time the electric signal from the generator of rectangular impulses 3 is transmitted to the piezo-transmitter 5, which, by means of the magnet 6 is attached to the studied metal object (resonator) 7. The generator of rectangular impulses is set at the resonance frequency of the rigidly fixed piezo-ceramic plates 5 and 8.

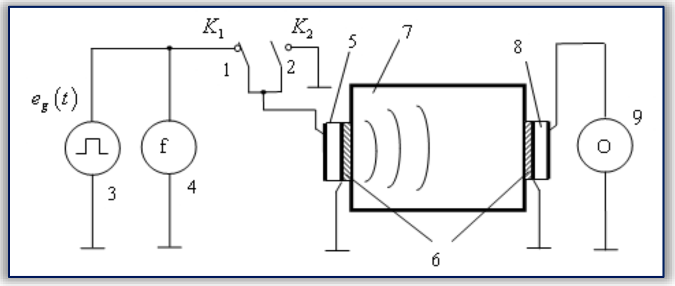

Figure2.Experimental installation

In the piezo-transmitter 5 the rectangular electrical signal $e_g(t)$ is converted due to the reverse piezo-effect, into acoustic oscillations with sinusoidal shape (Fig. 3). These acoustic oscillations propagate in the studied metal object and when they reach the piezo-receiver 8, they propagate in it, too. Then, due to the direct piezo-effect, they are converted again into an electrical signal and are registered by means of the digital oscilloscope 9.

When there is a negative semi-wave of the decreased phase voltage $u_2(t)$, current flows through the second relay R_2 and the contact $К_2$ is switched for 10 ms again. Then both electrodes of the piezo-transmitter are connected to the mass (i.e., the voltage between them becomes equal to zero) and the acoustic oscillations, created by the generator of rectangular impulses, quickly attenuate.

The following notations are used in Figure 2:

1, 2 - contacts of the relays;
3 - generator of rectangular impulses;
4 - frequency meter;
5 - piezo-transmitter
6 - magnets;
7 - studied metal object;
8 - piezo-receiver;
9 - oscilloscope.

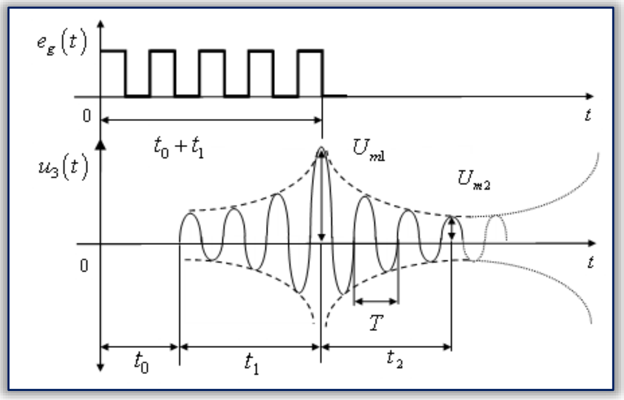

Figure3.Voltages on the screen of the oscilloscope

Thus the following image is observed on the screen of the digital oscilloscope (see Fig.3). The rectangular impulses, sent by the generator of rectangular impulses $e_g(t)$to the piezo-transmitter through the positive semi-wave are with duration t_0+t_1=10 ms. They are converted in the piezo-transmitter into sinusoidal acoustic waves, which for time t_0 reach the piezo-receiver.

There they are converted into increasing in amplitude sinusoidal electric voltage $u_3(t)$. This voltage begins to attenuate during the negative semi-wave. The change of the electric voltage $u_3(t)$ on the plates of the piezo-receiver is registered by the digital oscilloscope. In this particular case the transition process is important, i.e., the process after short-circuiting of the piezo-receiver $t=t_0+t_1$, after the moment when the phase voltage goes through its zero value. This transition process lasts for t_2, and the voltage in the piezo-receiver at its beginning has a maximum value U_{m1}. Because of the inertness of the system “piezo-transmitter – studied object – piezo-receiver”, the electric voltage $u_3(t)$ decreases after an exponential law for time t_2.

The amplitude of the voltage $u_3(t)$ at the end of the process of attenuation U_{mn} can be defined by the initial amplitude U_{m1} (Fig.3)

$$U_{mn} = U_{m1}\, e^{\alpha t_2} \tag{1}$$

After logarithms and certain transformations, for the full attenuation coefficient of the ultrasound waves α for time t_2 , it is obtained

$$\alpha = \frac{1}{t_2} \ln \frac{U_{mn}}{U_{m1}} \tag{2}$$

With the help of the number of periods n of the process of attenuation,

$$n = \frac{t_2}{T}\ , \tag{3}$$

the attenuation α_T between two neighboring positive amplitudes of the voltage (i.e., for a period T) is defined

$$\alpha_T = \frac{\alpha}{n} \tag{4}$$

3. EXPERIMENTAL RESULTS AND ANALYSIS

A coefficient of compliance k is introduced, which is obtained from the absolute value of the quotient of the average measured grain size $\bar{D}_{meas}$ and the full attenuation coefficient of the ultrasound waves α

$$k = \left| \frac{\bar{D}_{meas}}{\alpha} \right| \ . \tag{5}$$

The obtained results for the full attenuation coefficient α, as well as for the attenuation $\alpha_T$inone period, for both the measured $\bar{D}_{meas}$ and the calculated $\bar{D}_{calc}$ diameter of the grains, and for the coefficient of compliance k at a working (resonant) frequency of 200 kHz, are given in Table 1.

Table 1. Results for α, α_T, $\bar{D}_{meas}$, k and $\bar{D}_{calc}$.

№ of the sample	T, µs	t2 , ms	U_{m1}, mV	U_{mn} , mV	α , s-1	α_T , s-1	$\bar{D}_{meas}$, µm	k , µm.s	$\bar{D}_{calc}$, µm
1	4,4	10	50	12	-142,7	-0,0623	36,7	0,261	39,1
2	4,4	10	52	7,5	-195,8	-0,086	52,8	0,269	53,7
3	4,4	10	54	6	-219,7	-0,097	62,4	0,284	60,2
4	4,4	10	70	4	-286,3	-0,126	82,4	0,288	78,4

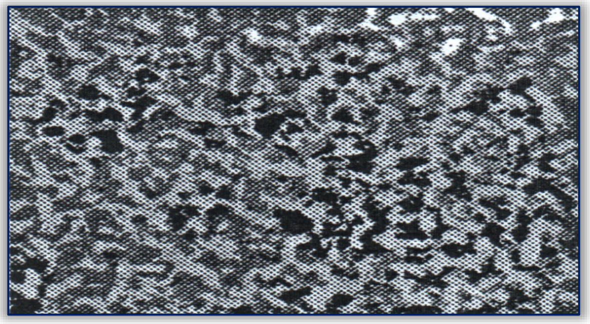

Figure4. Microstructure of steel70 G (950°C, 1 h)

The average grain size is defined in one surface by the Jeffries method. The biggest grain size (82,4µm) is observed at temperature 950°C (Fig. 4). From Table 1 it can be seen that the mode of thermal treatment considerably influences both the grain size and the attenuation coefficient.

The results in Table 1 show that together with the increasein the average grain size $\bar{D}_{meas}$, the attenuation coefficients of the ultrasound waves α, α_T also increase. This is explained by the fact that together with the grain size increase, the thickness of the inter-grain boundaries also increases. They have different acoustic resistance than that, of the grains. Thus conditions arise for increasing the acoustic losses at the expense of increasing the refraction of the ultrasound waves. This is due to the fact that the length of the ultrasound waves is considerably bigger (over 150 times) than the diameter of the grains.

If the introduced coefficient of compliance is averaged k_{av}=0,274 µm.s, an expression for defining the diameter of the grains is obtained with the help of the full attenuation coefficient α_i for the corresponding sample.

$$\bar{D}_{calc\ i} = k_{cp}.\alpha_i \ , \quad (6)$$

where i=1÷4 .

The maximum relative error between the measured $\bar{D}_{meas}$ and the calculated $\bar{D}_{calc}$ grain size in this case will be δ=4,98%.

4. CONCLUSIONS

A method is proposed in this paper, allowing evaluating the influence of the grain size in metals on the attenuation coefficient α of ultrasound waves by means of a simple analogue oscilloscope. It has been established that the highest frequency (resonant both for the piezo-transmitter and for the piezo-receiver) is 200 kHz, which allows easy processing of the output electric signal. An averaged coefficient of compliance k_{av}=0,274 μm.s has also been proposed, with the help of which and by means of the full attenuation coefficient the diameter of the grains for the corresponding sample $\bar{D}_{calc}$ can be calculated, and the maximum relative error will be δ=4,98%.

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