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ULTRASOUND QUALITY CONTROL OF RIM HEAT TREATMENT IN THE WHEEL SPIDER CASTINGS OF A ROLLING

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Summary. The quantity of supersonic wave attenuation at frequency of 2.5 and 5 MHz on the samples of castings with ferrite - pearlite microstructure is defined in this paper. The dependence of amplitude quantity decreasing of heading echo in dB from a grain average dimension in a rim of a wheel spider casting of a rolling stock is calculated.

Key words: ultrasound control, heat treatment, echo method.

INTRODUCTION

Component wheels having a tyre and wheel spiders are widely spread in the locomotive building nowadays. It is because the locomotive wheels unlike the car ones perform one more additional function, the function of traction force transmission which leads to the increased wear of rolling wheels circle. Achieving the limit wear it is possible to change the tyre without changing a wheel spider. While making component wheels the steel casting wheel spiders are mainly used [Filonov 1996, State Standardization 11018 – 2000].

Shaped castings before heat treatment have coarse grained microstructure. In shaped casting we often have such a structure which is characterized by the plate form of ferrite sections which are located at an angle to each other, forming triangles. Steels with such microstructures possess low mechanical qualities. That’s why the wheel spider castings without heat treatment are not allowed to be used in further treatment and operation [State Standardization 4491-86].

The required [State Standardization 4491-86] steel mechanical qualities of wheel spider castings are received by heat treatment and in the result of which the steel structure is changed. Heat treatment consists of a number of processes accompanying with steel heating, endurance and cooling at definite modes. As a result of heat treatment the microstructure of steel is becoming fine and internal foundry stress is relieved. The steel microstructure after its final heat treatment must correspond to the samples.

In order to define the quality of performed heat treatment of wheel spider castings non-destructive ultrasound control method is used. This control is based on the phenomenon of amplitude attenuation of a supersonic wave when it interacts with steel. Interaction problems of supersonic wave in polycrystalline body are given in tables [Lifshits 1948, Merkulov 1956, Merkulov 1957, Kireev 2005].

According to [State Standardization 4491-86] the metal of wheel spiders must possess with a sonic test. Such a control is done by the ultrasound method. Ultrasound converter is installed on the rim and the hub of a wheel spider sample with satisfied microstructure. The quantity of heading echo-signal at the control level is installed on the flow detector screen. Supersonic wave comes from the converter to the opposite rim and hub surface, reflects and comes back to the converter. When the supersonic wave passes through the metal it is getting weak. We can say about the microstructure according to the attenuation quantity which means the quality of performed heat treatment. Till now there is not any information or data concerning the dependence of supersonic attenuation when the grain dimension becomes more than standard one.

THE RESEARCH OBJECT

The object: the manufacturing process of steel casting wheel spiders of the locomotives and electric motor coaches of electric and diesel trains of the railways with 1520 mm gauge.

The research subject: ultrasound control of heat treatment castings quality of wheel spider sets.

The research material: casting wheel spider sets. The spiders are molded and made of structural non-alloyed steel, quality 25 L; the chemical analysis and mechanical properties are given in tabl. 1, 2.

Fig. 1 shows satisfied fine and average grained ferrite – pearled microstructure.

Table 1. **Steel chemical properties 25 L**

Steel quality	Element fraction of total mass, %				
Symbolism according to State Standardization 977-88	Carbon	Silicon	Manganese	Phosphorus	Sulphur
				not more	
25 L	0.22 – 0.30	0.20 – 0.52	0.6 – 0.90	0.20	0.20

Table 2. **Steel mechanical properties 25L [3]**

Steel quality	σ_h	σ_t	δ	Ψ	KCU	
	N/mm^2		%		J/cm^2	
					$+20^0 C$	$-60^0 C$
	not less					
25L	470	265	20	30	49.0	24.5

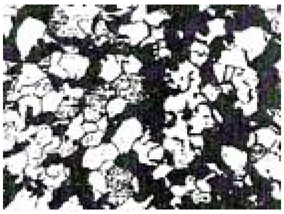

Fig. 1. Satisfied steel 25L microstructure after the heat treatment

The research method: metallographic method of microstructure defining, theoretical methods of supersonic wave propagation, ultrasound echo-method.

Equipment: ultrasonic flow detector UD 2-70, direct ultrasonic converters of 2.5 and 5 MHz, diameter of 12 mm, the samples of casting wheel spider with standard satisfied and raw unsatisfied microstructure.

The diagram of experiment carrying out. The microstructures of standard and raw samples are found after micro sections etching (pickling) made of named samples. The diagram of ultrasound control of wheel spider samples for sonic tests is given on fig. 2. If the grain dimension of controlled casting exceeds allowed one, the attenuation of supersonic wave will be greater and the height of the echo-signal on the flow detector screen will be lower than the control level. Such a wheel spider will be rejected and will be sent for the second heat treatment.

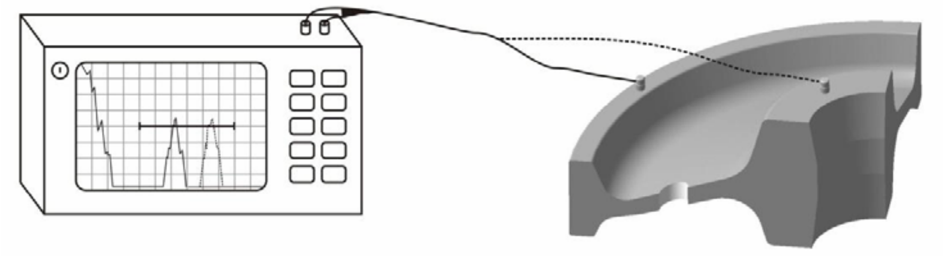

Fig. 2. The diagram of ultrasound control for sonic test of casting wheel spider sample

The aim of the present work is to define the dependence of amplitude quantity of heading echo-signal in dB of he average grain dimension at frequency of 2.5 and 5 MHz under ultrasound control for sonic test of the casting rim of the wheel spider.

To achieve the given aim it is necessary to solve such tasks as:

- to define the average grain dimension in standard heat treated and raw samples of steel 25L wheel spiders;
- to give proof of the formula for sound absorption coefficient in the researched steel;
- to lay down the analytical dependence of amplitude quantity change of the heading echo-signal according to the standard sample;

- to define experimentally amplitude decreasing of the heading echo-signal under ultrasound control of the wheel spider rim for sonic test using standard and raw samples at frequency 2.5 and 5 MHz;
- to calculate the dependence of relative amplitude quantity change of heading echo-signal in dB of the average grain dimension in the casting wheel spider rim of the rolling stock at frequency of 2.5 and 5 MHz.

THE RESEARCH RESULTS

Metallographic research has stated that the average grain dimension in a standard sample with a satisfied microstructure is equal to 0.04 mm and in a raw sample it is equal to 0.096 mm.

The average grain diameter and the wave length relationship gives great influence to the dispersion coefficient values in metals. As it is known the supersonic attenuation coefficient in metals depends on the relationship of the average diameter and the wave length.

The wave length is connected with the relationship of velocity propagation and oscillation frequency.

$$\lambda = \frac{C}{f}. \tag{1}$$

From here, the wave length and the supersonic wave length λ, is equal to λ= 2,36 mm at frequency 2.5 MHz and λ=1,18 mm frequency 5 MHz and the velocity is equal to $C = 5900$ m/s [Alyoshin 1991].

The attenuation coefficient consists of the dispersion and absorption coefficients [Alyoshin 1991].

$$\delta = \delta_d + \delta_a. \tag{2}$$

In the case of $\lambda \gg \overline{D}$ the dispersion coefficient δ_d is proportion to $f^4\overline{D}^3$, the absorption coefficient $\delta_a \approx f$ has preference value in the field of low frequencies. In this case, formula [Alyoshin 1991] defines the general attenuation:

$$\delta = Af + Bf^4\overline{D}^3, \tag{3}$$

where A, B are coefficients of proportionality.

The amplitude changing of the heading echo-signal in a distant zone of supersonic converter is subjected to the dependence:

$$A = K\frac{S_{p.el-t}}{2\lambda \cdot x}e^{-2x}A_0, \tag{4}$$

where:

x − is the thickness of the object control [mm],

K − is the coefficient of proportionality, connected with supersonic pass of a contact layer, and of the borders influence of object control,

λ − is the wave length [mm],

$S_{p.el-t}$ – is the square of a pieza element [mm^2],

δ – is the attenuation coefficient of supersonic oscillations,

A_0 – is an amplitude of an initial signal [Ermolov 1967].

It is not necessary to make amplitude A measurement in absolute units in this paper, but it is only enough to define its value according to any initial level which is symbolized by A_0. In this case, it is accepted to express the relative value $\frac{A}{A_0}$ in dB [Alyoshin 1991].

The value dB in the supersonic flow detector for echo-signal with amplitude A is defined from the expression:

$$N = 20\lg\frac{A}{A_{rs}}, \tag{5}$$

where A_{rs} – is a reference signal of flow detector UD 2-70 attenuation can be presented as:

$$N = 20\lg\left(K\frac{S_{p.el-t}}{2\lambda x}\cdot e^{-2\delta x}\right)\frac{A_0}{A_{rs}}. \tag{6}$$

ΔN - is amplitude change of the heading echo-signal in a controlled sample relatively to the standard one.

$$\Delta N = 20\lg\left(K\frac{S_{p.el-t}}{2\lambda x}e^{-2\delta x}\right)\frac{A_0}{A_{rs}} - 20\lg\left(K_s\frac{S_{p.el-t}}{2\lambda x}\cdot e^{-2\delta_s x}\right)\frac{A_0}{A_{rs}}. \tag{7}$$

Then

$$\Delta N = 20\left[\lg\left(\frac{K\frac{S_{p.el-t}}{2\lambda x}\cdot e^{-2\delta x}}{K_s\frac{S_{p.el-t}}{2\lambda x}\cdot e^{-2\delta_s x}}\right)\right] = 20\lg\left(\frac{e^{-2\delta x}}{e^{-2\delta x}}\right) = 20\lg e^{2x(\delta_s-\delta)}. \tag{8}$$

All researches have been done using the samples of the same thickness, one flow detector UD 2-70 with a pieza element of diameter d is equal to 12 mm has been used. The researches have been done at frequencies, f is equal to 2.5 MHz, and f – is equal to 5 MHz. The samples of steel 25L with an average grain diameter is equal to 0.44 mm (a standard sample) and with a diameter which is equal to 0.096 mm (a raw sample) have been used. The same technology of mechanical treatment of researched sample surfaces has been applied, and one contact liquid has been used. That's why the coefficients K and K_s are the same for both standard and researched samples.

$$\delta_s - \delta = \left(Af + Bf^4\overline{D}_s^3\right) - \left(Af + Bf^4\overline{D}^3\right) = Bf^4\left(\overline{D}_s^3 - \overline{D}^3\right). \tag{9}$$

Thus, we have such a formula as:

$$\Delta N = 20\lg e^{2xBf^4\left(\overline{D}_S^3 - \overline{D}^3\right)}. \tag{10}$$

Table 3 gives the results of experimental researches of amplitude attenuation of the heading echo-signal in standard and raw samples.

Table 3. **The results of experimental researches of amplitude attenuation of the heading echo-signal in standard and raw samples**

Frequency, MHz	$\overline{D}$, mm	N, dB	ΔN, dB
2.5	0.040	-23	-15
	0.096	-38	
5	0.040	-41	-22.5
	0.096	-63.5	

From here, we can find coefficient B, using the measured values ΔN, $\overline{D}$, $\overline{D_S}$ and given values f and x is equal to 105 mm according to the formula (10).

Minimum registered changing, the relative changing of supersonic wave amplitude in the casting sample relatively to the attenuation in the sample with standard microstructure while using the device UD 2-70 is equal to 0.5 dB. Let's define the value of the average grain diameter increasing according to the standard structure. This increasing leads to the supersonic attenuation rising by 0.5 dB.

From (10), we can find:

$$\overline{D} = \left(\frac{2xBf^4\overline{D}_S^3 - \ln 10^{\frac{\Delta N}{20}}}{2xBf^4} \right)^{1/3}. \tag{11}$$

$$\Delta\overline{D} = \overline{D} - \overline{D}_S. \tag{12}$$

The calculation results are given in table 4.

Fig. 3 and fig. 4 show that calculated dependence of amplitude value decreasing of the heading eco-signal in dB relatively to the standard sample of an average grain dimension in the rim casting of the wheel spider at frequency of 2.5 and relatively 5 MHz is produced by experimental final points and according to the formula (10) calculation.

Table 4. **Results of calculations**

	f, MHz	$\overline{D}$, mm	$\Delta\overline{D}$, mm
$\Delta N = 0{,}5$ dB	2.5	0.045	0.005
	5	0.044	0.004

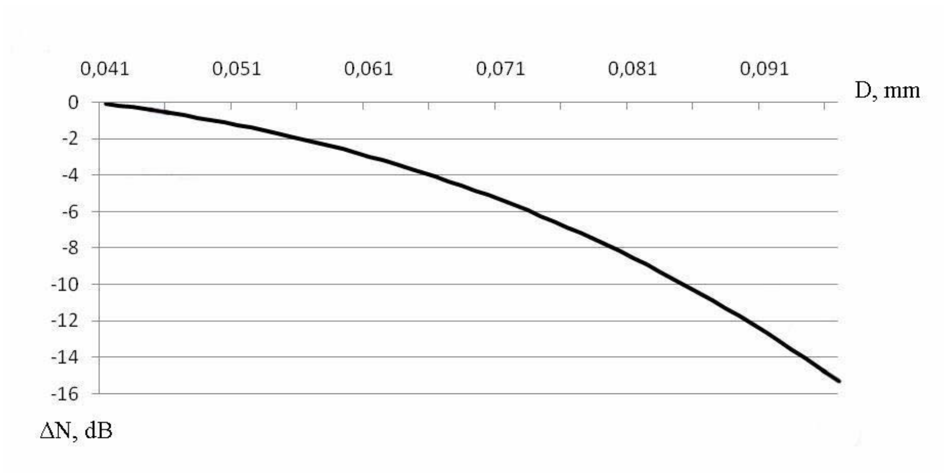

Fig. 3. The dependence of amplitude value decreasing of the heading echo-signal in dB relatively to the standard sample of the average grain dimension in the casting rim of the wheel spider at frequency of 2.5 MHz

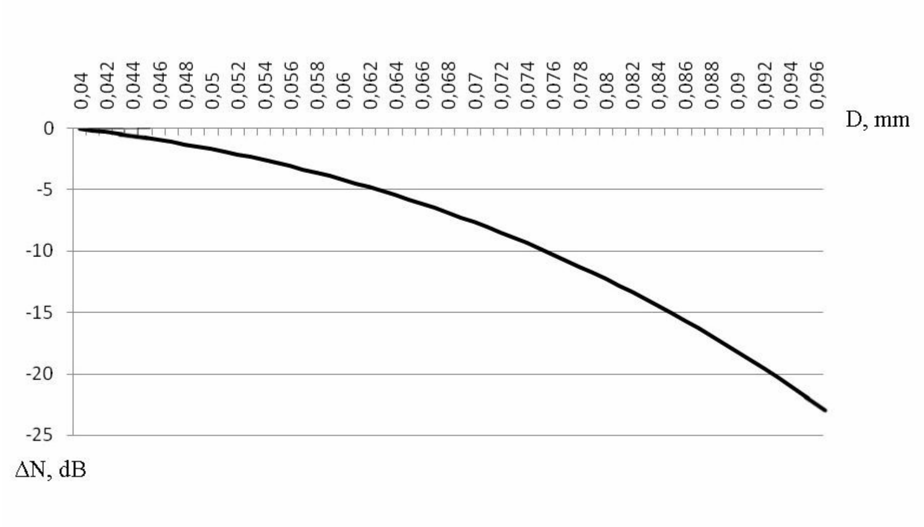

Fig. 4. The dependence of amplitude value decreasing of the heading echo-signal in dB relatively to the standard sample of the average grain dimension in the casting rim of the wheel spider at frequency of 5 MHz

CONCLUSION

1. The study of received microstructures has shown that the average grain dimension in the standard heat treatment steel 25L sample is equal to 0.040 mm, and in a raw one is equal to 0,096 mm.

2. It has been experimentally stated that under ultrasound control for sonic test the amplitude decreasing of the heading echo-signal on the samples of wheel spider rim is equal to: on the standard sample at frequency of 2.5 MHz the decreasing is 23 dB nd at frequency of 5 MHz it is 41 dB; on the raw sample at frequency of 2.5 MHz, it is 38 dB, and at frequency of 5 MHz it is 63.5 dB.

3. The calculation has shown that under ultrasound control for the sonic test the amplitude decreasing of the heading echo-signal sample by 0.5 dB will be if we increase the mean grain dimension by 0.005 mm at frequency of 2.5 MHz and by 0.004 mm at frequency of 5 MHz.

4. Received calculated dependence of the amplitude value decreasing of the heading echo-signal in dB of the mean grain dimension allows to define the values of amplitude value changing of the heading echo-signal for different at frequency of 2.5 and 5 MHz using the diagram.

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УЛЬТРАЗВУКОВОЙ КОНТРОЛЬ КАЧЕСТВА ТЕРМИЧЕСКОЙ ОБРАБОТКИ ОБОДА В ОТЛИВКАХ КОЛЕСНЫХ ЦЕНТРОВ ПОДВИЖНОГО СОСТАВА ЖЕЛЕЗНЫХ ДОРОГ

Савченко Р.Т, Колодяжный П.В., Волкова С.А.

Аннотация. В статье определена величина ослабления УЗ волны на частоте 2,5 и 5 МГц на образцах отливок с феррито - перлитной микроструктурой. Рассчитана зависимость уменьшения величины амплитуды донного эхо - сигнала в дБ от среднего размера зерна в ободе отливки колесного центра подвижного состава железных дорог.

Ключевые слова: ультразвуковой контроль, термическая обработка, эхо-метод.