UTILIZATION OF NATURAL OSCILLATION FREQUENCIES "NOF" IN NON-DESTRUCTIVE TESTING OF PHYSICAL-MECHANICAL PROPERTIES OF MATERIALS AND PRODUCTS.

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The goal of the present report is to discuss a possibility of the usage of natural oscillation frequencies (NOF) of articles and especially prepared samples for evaluation of physicomechanical characteristics of different materials, primarily of nonmetallic materials with wide acoustic waves damping to which traditional methods of ultrasonic control cannot be applied or it is too hard to apply them. In the first place we imply articles from ceramic, polymeric and compositional materials, and also articles with surface making difficult to introduce ultrasonic oscillations, for example iron casting.

It is known that interrelation between NOF of articles and acoustic waves propagation velocity in material from which they are made generally can be presented as follows:

$$fi=Fi\cdot Cl, \qquad (1)$$

where fi - natural oscillation frequency appropriate to a certain mode of oscillation i;

Fi - form factor dependent on the form and the sizes of an article, mode of excited oscillations and Poison's ratio;

$Cl=\sqrt{E/\rho}$ – rod sound velocity (velocity of propagation of longitudinal elastic oscillations in indefinitely long thin rod); according to federal standard GOST 25961-83 and GOST P 52710-2007

E – Young's modulus;

ρ- density of an article material.

From the expression (1) follows that providing an equal form and dimension of articles frequency f*i* corresponding to a certain oscillation mode characterises a mentioned acoustic waves propagation velocity C_1. This value is an elastic constant of article material associated with Young's modulus, density, toughness, porosity, hardness and other material physicomechanical characteristics, and also with defects and material structural rupture.

On the other side providing equal values of velocity C_1 a frequency f*i* can vary because of form's coefficient F*i* change that in it's turn can be caused either by geometrical dimensions changing or by big defects. Thus anyhow change of the frequency f*i* of a certain oscillation mode causes either material physicomechanical characteristics changing or presence of defects. In this case deterioration of material physicomechanical characteristics (reduction of toughness, hardness, etc.) and any defects usually cause NOF value reduction.

From the formula (1) follows that we can divide influence by NOF values and geometry of the tested article for which is necessary to examine relation of natural oscillation frequencies of two different modes "i" and "k" that doesn't depend on velocity C_1 and is determined only by geometrical factors, including defects.

$$\frac{f_i}{f_k}=\frac{F_i}{F_k} \qquad (2)$$

Providing equal geometrical dimensions an expression (2) practically describes NOF spectrum changes if an article contains any defect.

For realisation of the method based on NOF measuring realisation it's necessary to work out special control methods that could provide an extraction from the NOF spectrum of certain modes of oscillations and exclude an influence on measuring results of form or dimensions of articles or samples.

For method realisation natural oscillations measuring devices (NOMD) that use a method of free oscillations exciting by a stroke as well as a forced oscillations method (resonant method) are applied. In practice the most popular in industry are NOMD by the following companies: "ZVUK",

LLC, Academic and Research Center “INTERPRIBOR” (Russia) and “J.W. LEMMENS N.V.” (Belgium).

The main application areas of the present method of control are:

- polishing tools control in all kinds of bonds, including crush-formed grinding wheels, cutting wheels of any diameter, and also small-sized tools with diameter less than 8 mm for definition of physicomechanical characteristics for which traditional hardness control methods cannot be used;
- refractory articles control;
- carbon articles control;
- control of cast iron blanks of different brands;
- control of articles made of high-strength ceramics and synthetic highly hard materials;
- control of natural oscillation frequencies of turbine buckets;
- determination of elastic constants (Young’s modulus, Poison’s ratio, etc.), articles of different forms and different materials.

Using acoustic control methods based on NOF of articles a working out of special control techniques considering an article form and dimension is required. In respect to the abrasive articles control in Russia such techniques are developed for the major part of standard size polishing tools in all kinds of bonds (ceramic, bakelite, vulcanite) and their usage is regulated by federal standard GOST P 52710 — 2007 “Abrasive tools. Acoustic method of hardness and sound indexes control based on acoustic waves propagation velocity (previously GOST 25961 — 83 “Abrasive tools. Acoustic method of control of physicomechanical characteristics”). According to the mentioned standards the use of devices like “Zvuk” or other devices with similar technical specifications for the NOF measuring is recommended

The specialized equipment developed by ZVUK, LLC, St. Petersburg, Russia — measuring instruments of natural oscillation such as "Zvuk", combines the requirement of simplicity and relative cheapness with sufficiently high accuracy of measuring of NOF and an opportunity to carry out analysis of NOF spectrum of both large-sized billets and articles, and articles of rather small sizes directly in conditions of their manufacture and operation.

Type “Zvuk” equipment includes the devices based both on a method of free oscillations, and on a method of forced oscillations (resonant method), as well as software required for calculation of elastic constants and the analysis of NOF spectrum in the course of test. In devices it is foreseen to receive final result of measuring in the following forms: NOF (f), sound velocity (Cl), Young’s modulus (E). It is possible as well to receive other physicomechanical characteristics of articles when introducing appropriate correlation dependences. For convenience of operation of devices in industrial conditions and conducting of sorting of articles it is foreseen as well to gain result as so-called sound indexes (SI) - gradation of sound velocity Cl with increment of 200 m/s. SI is designated by odd two-digit number multiplication of which by 100 gives average for the given gradation value of sound velocity Cl in m/s.

Method of free oscillations. Device “Zvuk - 203M” (fig. 1) realizing the patent of Russia № 2151385 is based on this method. Frequency range of the device from 22 Hz up to 17,4 kHz allows testing of articles in a wide range of the sizes, approximately from 20 - 50 centimeters up to several meters. As the receiver of oscillation a microphone built in the case of the device is used. There is as well possibility to connect an external microphone or the piezoelectric gauge. The basic difference from the known “Grindo - Sonic” device, that uses the same measuring method, is, that in the device there are band-pass filters with which help it is possible to allocate not only the basic tone, but also higher NOF of article. In devices connection to a computer that expands an opportunity of their use is foreseen.

Fig.1. Device “Zvuk - 203M”

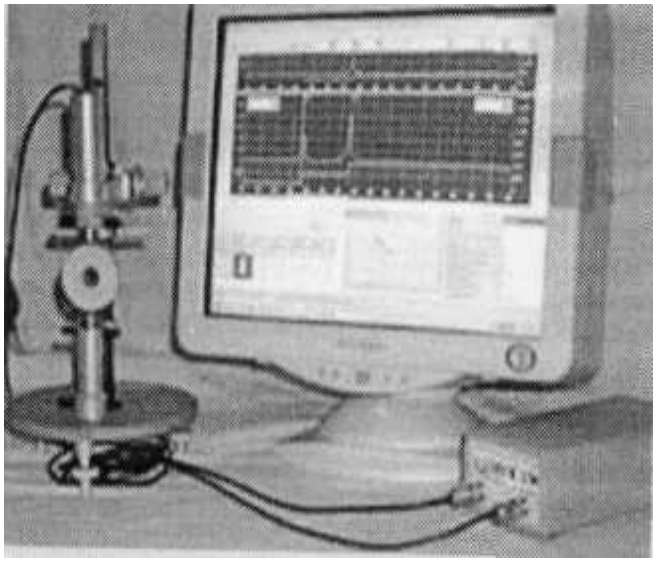

Fig. 2. Device “Zvuk - 130”

Resonant method. This method is put into life in “Zvuk - 130” device (fig. 2) and its previous updating “Zvuk - 110M”.

Frequency range of devices from 0,5 up to 500 kHz makes it possible to test small-sized articles with the sizes from 3 mm and even less, control of which as far as we know, is not made through acoustic method in world practice for the time being. The article that is under control is fixed in the measuring rack between two piezoelectric gauges supplied with dome-shaped nozzles for reduction of influence of recieving-emiting system on the article oscillation (the patent of Germany № 1648770 and the patent of the USA № 3499318). The electronic part of the device including the generator of variable frequency and the broadband amplifier, are designed as a separate block or the printed-circuit-board inserted in IBM compatible computer (in “Zvuk – 110M” device). Special software operates the work of devices. This software makes calculation of NOF expected spectrum of the controlled article and choice of measuring conditions for the definite standard sizes of articles of various forms and sizes. Results of the control are displayed the monitor in a graphic and digital kind (fig. 3).

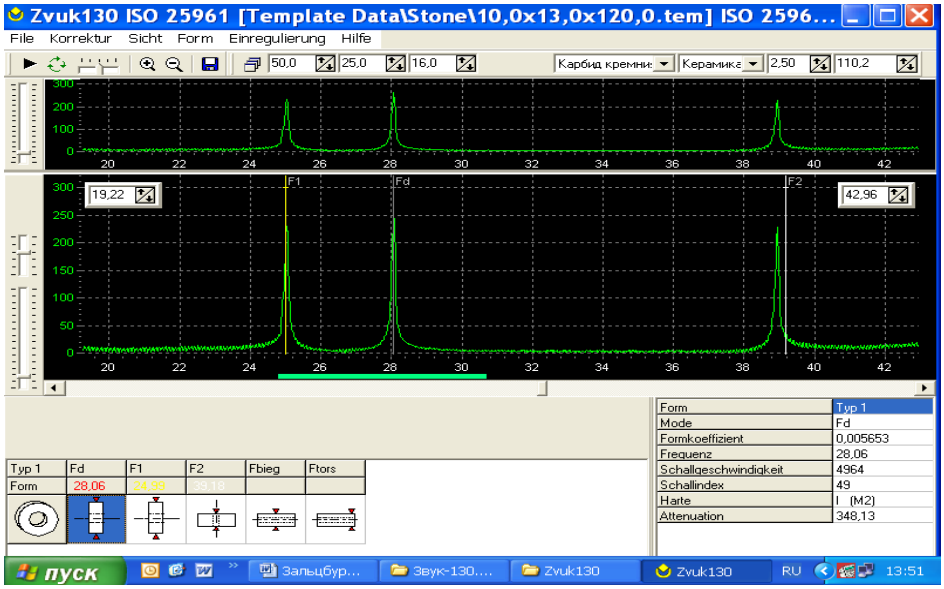

Fig.1

As for the present the given methods and devices have found wide enough use for control of various materials and articles.

APPLICATION OF "ZVUK" EQUIPMENT

Test of abrasive articles. Type "Zvuk" equipment is used for the control of physicomechanical characteristics (hardness) of abrasive articles of the widest range of sizes from 3 up to 1200 mm, allowing practically instantly to receive a final result of test.

Advantage of devices such as "Zvuk" in comparison with the device "Grindo Sonic" consists in the opportunity of test of the small-sized tool, cutting wheels, as well as simplicity and convenience in operation.

Test of refractory. For refractory articles there is a correlative dependence between the sound velocity Cl, measured by devices "Zvuk", and such parameters, as the open porosity, apparent density and strength.

Test of building materials. For construction articles correlation interdependence between Cl and strength characteristics of articles made of concrete, various kinds of brick, pavement tiles and etc. is established, that operatively allows to estimate variation of strength characteristics of the articles in one set.

Test of carbon products. "Zvuk" devices find application at the target test of physicomechanical properties of carbon articles: hearth-level blocks of baths of electrolyzers, electrographited electrodes used in the course of manufacture of aluminum and other metals.

Test of cast iron blanks. For cast iron parts there are correlation interdependences between sound velocity Cl and such important parameters as Brinnell hardness, strength characteristics, composition of spherical graphite. Application of a method of NOF measuring "Zvuk" devices has enabled on-the-fly to identify these parameters on blanks of rings of electric stoves, parts of power units: clutch plates, flywheels etc. prior to their machining.

Test of articles made of high-strength ceramics and synthetic highly hard materials. Correlation dependences between elastic characteristics (velocity Cl, Poison's ratio) and hardness, density, as well as operational parameters (wear resistance and strength characteristics) of articles are established. It is possible to test ceramic articles from materials on the basis of corundum, silicon carbide, boron carbide, cubic boron nitride etc. with various additives which are used for manufacturing cutting plates, wearproof parts, elements of organoceramic armour and coverings etc.

Test of elastic constants of materials. Type "Zvuk" devices have full metrological software and can be used for determination of elastic constants: Young's modulus, Poison's ratio and other parameters describing elastic characteristics of various materials. Devices also can be used for determination of elastic constants of ceramic articles according to the USA standard of ASTM C1259-94.

Defectoscopy of articles. The acoustic test based on NOF measuring, provides an integrated evaluation of all volume of an article. However, normally presence of defects and infringements in structures uniformity of an article results in downturn of NOF and appropriate Cl value, that is lower than some predetermined value, and in change of NOF spectrum, i.e. change of a ratio between NOF of different modes of oscillations. These circumstances in some cases make it possible to find out the specified infringements. Such work with positive results was carried out to detect occurrence of defects of structure of carbon articles at various stages of technological process of their manufacturing, as well as to detect various sort of defects in cast iron casts such as "cap of isolator". For some types graphitized carbon and ceramic articles the change of NOF values is revealed under repeated cyclic thermo-load, that shows an opportunity of use of results of the test for an estimation of article resource with the purpose of its duly withdrawal from operation and prevention of emergency situations.

At the present time control method based on NOF measuring is also applied for flaw detection of different kinds of casting, for articles used in railway transport (railway wheels and axes, pendant fitting of contact system, solebars of freight-car trucks), for control of wooden poles of electric power lines, etc.

REFERENCES

1. P. Cawley, Rapid Production Quality Control by Vibration Measurements// Materials Evaluation. – v. 45, may, 1987, p.543-548.

2. J.Kriegesmann, B.A.Glagovsky, I.B.Moskovenko, H.A.Schmid, Zerstörungsfreie Bestimmung der Härte an Schleif-und Honwerkzeugen// Industrie Diamanten Rundschau.- 1/93.- S. 58-61 (Germany).

3. A.F. Grebjonkin, W.A Krjukowskij, B.A. Glagovsky, W.A. Lyssanow, I.B. Moskovenko, Zerstorungsfreie akustische Materialprufung an Kohlenstoffanoden // Aluminium-66, Jahrgang.- 1990.- № 9.- S.854-857.

4. I.B. Moskovenko, L.Ya.Slavina, G.P. Zaitsev and N. Yu. Artsutanov, Determination of elastic constants of materials on specimens in the shape of square plates // Nondestr.Test.Eval.- 2001.-Vol. 17.-p.133-142.

5. Чернявец А.Н., Московенко И.Б., Коварская Е.З., Акустический неразрушающий метод контроля качества углеродных тиглей для плавки металла // Цветные металлы.-1997.- № 3.- С.77-79.