

## **Nondestructive Control of Physico-Mechanical Properties and Quality of Carbon Materials and Products Used in the Production of Aluminum**

**Elena Kovarskaya<sup>1</sup> and Igor Moskovenko<sup>2</sup>**

1. Deputy General Director,

2. General Director

«ZVUK», Saint Petersburg, Russia

Corresponding author: info@ndtest.ru

### **Abstract**

The report reflects the modern world level in the field of non-destructive quality control of various kinds of materials and products, primarily carbon, used in the production of aluminum and shows the possibility of using modern methods of acoustic control for quality control. The possibility and expediency of using acoustic methods, based on measuring the natural vibration frequencies of products for the evaluation of the physico-mechanical properties of carbon materials, whose quality largely determines the life expectancy of the cell and its main technical and economic indicators. The effect of porosity is shown both on the performance of carbon products and on the results of their acoustic control, which allows using rapid non-destructive testing in production conditions using modern methods and tools. The use of such a rapid method can increase the reliability of the control of manufacturing carbon products, used in the production of aluminum. It can also help to prevent the construction of cells with materials whose physical and mechanical properties are outside specifications and can contribute to an improvement of cell technical and economic performance parameters.

**Keywords:** Carbon materials in aluminum electrolysis cells, nondestructive testing, physico-mechanical properties of carbon materials, acoustic control methods, frequencies of natural oscillations.

### **1. Introduction**

The quality of carbon products used in the production of aluminum largely affects both the operating period of the electrolysis cell and its main technical and economic parameters. The operability of carbon blocks is significantly affected by their porosity. Porosity of pressed and prebaked carbon products, including bottom blocks and prebaked anodes, is in a certain way related to the mechanical strength of such products: with an increase in porosity, the mechanical strength decreases (due to weakening of adhesion between particles of carbon material), while a decrease in porosity entails an increase in the mechanical strength of the block. At first sight, it seems that in case of a strong decrease in the block porosity, its increasing mechanical strength should contribute to its greater durability and operability. However, with a decrease in porosity, the internal stresses, occurring in the body of the block when it is saturated with molten salts, will begin to appear. These stresses, proportional to the capillary pressure of the penetrating salts and directed from the inside of the block, will weaken the cohesion of the carbon particles, which, in turn, will result in a significant increase in the block volume and its disintegration. To a great extent, treatment of carbon products with electrolyte depends on their porosity and, consequently, on the average size of the pore radius, which increases with increase of the total porosity of the carbon block [1]. Table 1 shows the capillary pressure of melts (for 1000 °C), calculated depending on the pore radius [2]. These data indicate that the internal stresses arising in the cathode blocks of aluminum cells with penetration of molten salts, should

**Table 1. The average pore radius in the cathode blocks with different porosities and capillary pressure for sodium fluoride and cryolite-alumina melts**

Porosity, %	Average pore radius, mm	Capillary pressure, Pa	
		NaF	Na <sub>3</sub> AlF <sub>6</sub> +12,5% Al <sub>2</sub> O <sub>3</sub>
12.6	0.0201	14130	1770
13.8	0.0228	12900	1560
14.8	0.0330	8500	1075
15.5	0.0398	7200	890
17.2	0.0457	6195	725

increase with a decrease of their porosity or pore radius. It should be pointed out that these data are calculated for conditions without taking into the account the effects of aluminum dissolved in the electrolyte, which further increases the capillary pressure, and consequently, increases the penetration of molten salt into the pores of the carbon material. The performance of carbon products used in the production of aluminum is, therefore, largely affected by their porosity.

## 2. Method essence

It is commonly known that, in order to control the physico-mechanical properties of various kinds of materials and products, which are largely affected by porosity, acoustic control methods are used, including those based on measuring natural oscillations frequencies (NOF) of products [3]. This is due to a significant difference in the conditions of propagation of acoustic oscillations in the material and the air that fills in the pores (the sound velocity  $C_1$  in carbon block is 2000–3000 m/s, while in the air it is around 300 m/s). When using NOF measuring, an indicator was introduced, a sound index (SI), being an integrated characteristic of physico-mechanical properties, which is largely determined by the porosity of the monitored products. The sound index is an interval of the reduced acoustic wave propagation velocity (velocity of propagation of longitudinal elastic oscillations in indefinitely long thin rod) in the material. The sound index is denoted by an odd integer number equal to the average value of the parameter in a particular gradation  $C_1$ , expressed in m/s and multiplied by  $10^{-2}$ . The sound velocity is interrelated by means of a known relation (Equation 1) with important parameters characterizing the physico-mechanical properties of the material *modulus of elasticity* (Young's modulus)  $E$  and the material density  $\rho$ .

$$C_1 = \sqrt{E/\rho}. \quad (1)$$

In turn, the sound velocity in carbon products is associated with the correlation dependence with its strength, structural, and other physico-mechanical properties and electrophysical characteristics. In particular, a close correlation was established between the ultrasonic velocity and strength, porosity, bulk density, and specific electrical resistivity of carbon products [4]. It should be noted that the Young's modulus, which largely determines the sound velocity, is by itself a very important parameter affecting the deformation of blocks under static and dynamic loads to which the blocks are exposed in the process of their operation. A number of companies include this parameter as one of the main indicators characterizing physico-mechanical properties of carbon blocks [ 1].

At present time, the following principles of picking carbon products used in the production of aluminum are generally used in the aluminum industry. Specific electrical resistivity (SER) and mechanical compressive strength are chosen as the basic parameters for picking carbon products. The above indicators are assessed based on the results of measurements made on samples (cores) selected from the prebaked blanks, as well as based on the results of measurements of SER of cathode and anode blocks [ 4]. Based on SER gradation and mechanical strength, the

requirements have been developed for sets of carbon blocks, on the basis of which the manufacturer prepares sets with similar electrical and mechanical properties, which are then shipped to customers producing aluminum for assembly and overhaul of electrolysis cells. Such requirements are legally binding, i.e. included in contracts for the supply of products. A number of companies additionally include the Young's modulus, which is usually determined using acoustic control methods, to the number of main indicators characterizing physico-mechanical properties of products used for the production of aluminum.

### **3. Using method**

A while ago, the acoustic control method was developed and widely spread in the production of electrode products, which is based on measuring NOF [5]. Production of bottom blocks with standardized physico-mechanical properties was also established in accordance with specially developed specifications TU 48-4804-27-91, which is provided for putting a mark on blocks indicating the results of the acoustic control in the form of sound indices, SI. Such blocks were supplied at the request of plants manufacturing aluminum, and the results of acoustic control, marked on the blocks, were taken into the account when selecting sets used for assembly of cells. Technical and economic feasibility of using the acoustic method based on measuring NOF was demonstrated in the production and use of carbon bottom blocks and prebaked anodes with standardized physico-mechanical properties in the form of SI. In the future, mainly due to organizational reasons, these works in relation to control of such carbon products were practically stopped. However, in relation to other types of products, primarily various kinds of abrasive tools, similar work continued. In 2007, GOST (all-Union State Standard) R 52710 – 2007 was developed and put into operation titled “Abrasive tool. Acoustic method of determination of hardness and sound index of reduced acoustic wave velocity” in accordance with which a similar control is currently being carried out at a number of enterprises producing and consuming abrasive products. This GOST can be used as a basis for reference norms and specifications or as a standard providing the possibility of similar acoustic control of carbon products. Since that time, there have been at least two generations of tools of ZVUK type which implement the acoustic control method based on measurement of NOF. At present, "Zvuk-203M" and "Zvuk-130" manufactured by OOO "ZVUK" have passed the official tests, have been certified, have been included in the National Register of Measuring Equipment, are widely used in Russia and are exported to other countries.

In our opinion, the presented materials give evidence of the need and feasibility of continuing earlier work on the development and mastering the acoustic method for control of physico-mechanical properties and quality of the bottom blocks and prebaked anodes of aluminum electrolysis cells at a new up-to-date level, which in turn can contribute to an increase in the efficiency of using carbon products in the production of aluminum.

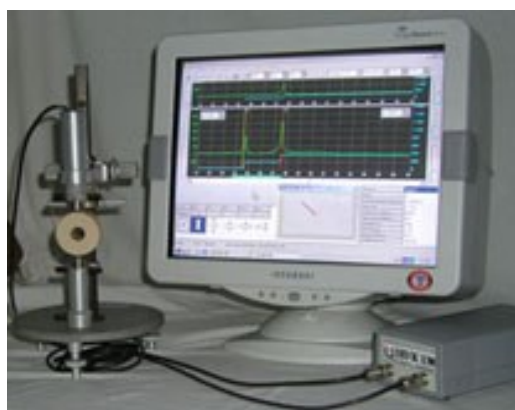
During 2015–2018, the proactive work was carried out [6], which showed that the modern certified acoustic control tools of "Zvuk" type of various modifications can be used directly in process for quick express control of carbon products currently used in aluminum production. In addition, in the recent work of Canadian experts [7], in relation with nondestructive control of prebaked carbon anodes, it was proposed to use the fast nondestructive method of control of quality of anodes, based on vibromodal analysis of their NOF spectrum. It was demonstrated that the proposed approach makes it possible to detect and distinguish between different types of internal defects of the anode. It was discovered that some modes (types) of acoustic oscillations are sensitive to the presence and orientation of cracks in the anode block, while other types of oscillations are associated primarily with changes in the physico-mechanical properties of anodes. Based on the above results are rather promising, the modal analysis will be further improved and specialized in further works.

#### 4. Application Prospects

Should be taken into the account that natural-vibration frequency meters devices type "Zvuk" (Figure 1 and Figure 2) can be directly used to measure NOF of both bottom blocks and prebaked anodes in the process of their production and operation. Therefore, the main directions for the further development of nondestructive acoustic control method based on measuring and analysis of NOF spectrum of the examined products may be laid down.



**Figure 1. Device "Zvuk-203M" realize the free vibration method.**

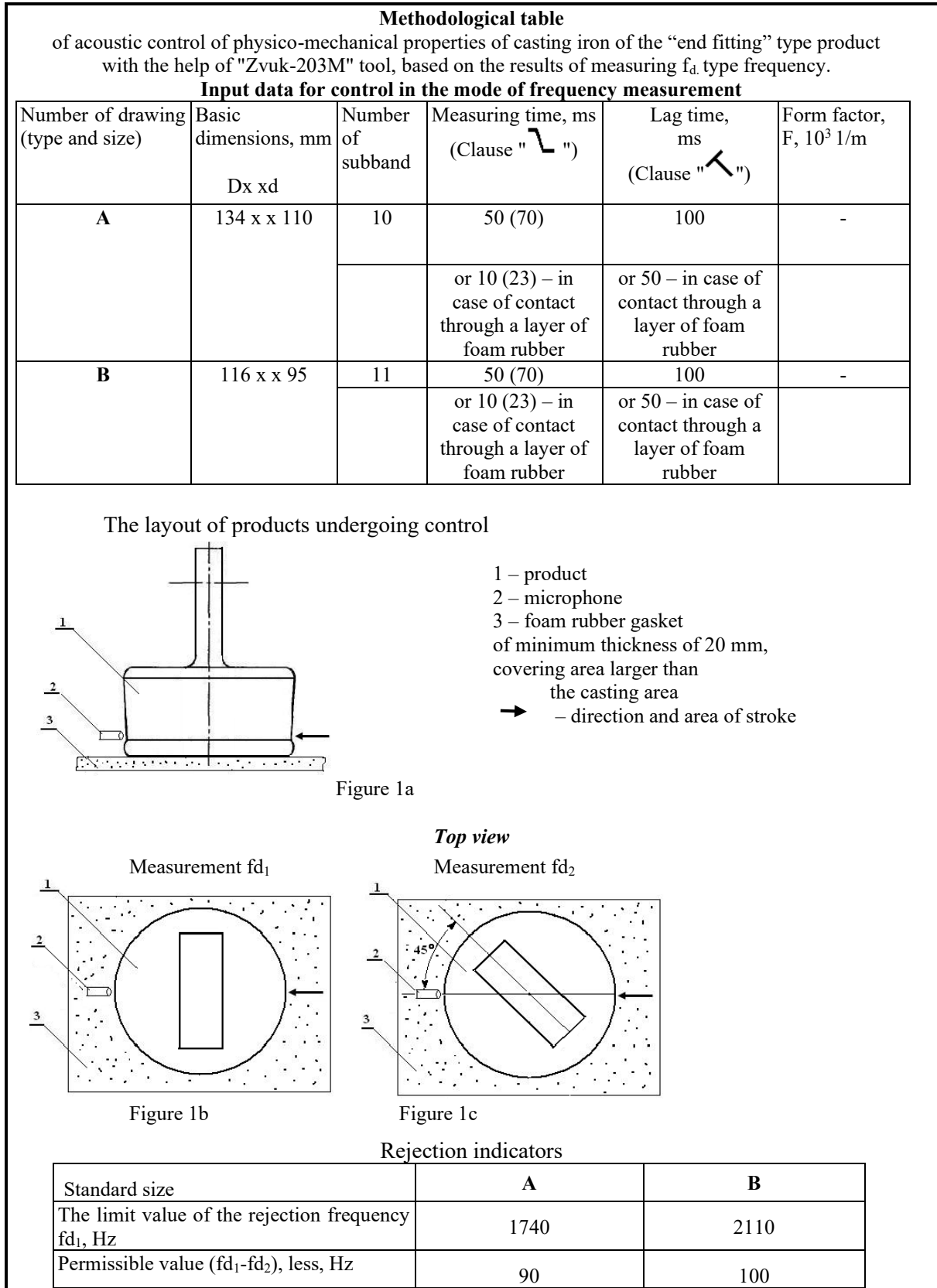


**Figure 2. Device "Zvuk-130" realize the forced oscillation method (resonant method).**

At the first stage, it is advisable to start accumulation of statistical data to determine physico-mechanical properties of carbon bottom blocks and prebaked anodes supplied for assembly and overhaul of electrolyzers, in order to determine and record the real picture of distribution of physico-mechanical properties of products in a particular electrolyser according to the acoustic characteristics (certification of the monitored item). This will make it possible to establish the presence of interrelation between the results of the acoustic control and the strength characteristics and SER of these products. On the other hand, it will help to avoid ingress of products into cells with properties which are significantly different from those predetermined by the quality control requirements. The results of such certification of carbon blocks used in a particular electrolyser may be useful when deciding on its overhaul or decommissioning. In process, fast control with the help of this method using "Zvuk-203M" tool and by way of obtaining the monitoring results averaged for the entire product takes maximum 3–5 minutes. Moreover, it does not need any significant preparation or special positioning of products under control. Figures 3 and 4 show examples of using of "Zvuk-203M" tool for testing products made of other materials: refractory products and cast iron. Figure 3 shows control of large refractory blocks used in metallurgy, in process. Figure 4 shows a methodological table of acoustic control of physico-mechanical properties of cast iron of the "end fitting" type product, which, with the help of "Zvuk-203M" tool, makes it possible not only to determine physico-mechanical properties of the product material, but also, due to more sophisticated control methodology, to detect cracks and other structural damage of the material of the monitored product. Use of such sophisticated technique in relation to carbon blocks could make it possible to monitor several components of the NOF spectrum in order to identify products with significant frequency deviations in the NOF spectrum, which makes it possible to identify products with major defects and structural discontinuity, similar to vibromodal analysis [7].



**Figure 3. Control of large refractory blocks used in metallurgy, in process.**



**Figure 4. Methodological table of acoustic control of physico-mechanical properties of casting iron of the “end fitting” type product.**

In case of the development of regulatory documentation similar to the above-mentioned GOST R 52710-2007 [8] with the code name “Carbon products: Acoustic method for determining physico-mechanical properties and sound indices based on the sound velocity”, the established optimal values of sound characteristics can be included in the specifications for carbon products, which are shipped to the enterprises producing aluminum, for assembly and overhaul of electrolyzers. Such requirements may be further included in contracts for the supply of products.

## 5. Conclusion

In conclusion, it's worth noting that use of acoustic nondestructive control, based on NOF measuring, makes it possible to carry out quick, reliable and repeatable assessment of physico-mechanical properties of real products in process, which should contribute to the most efficient use of the tested products, as well as better mutual understanding between manufacturers and consumers of carbon products used in aluminum production.

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