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Measuring control of construction materials parameters in order to increase reliability of engineering objects

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Abstract. The use of string and string elements find widespread practical application in technology. In the field of measuring technology, there are many devices in which the sensitive elements are elements in the form of strings: strain gauges, accelerometers, crack meters, etc. String sensors are widely used due to its simplicity and low cost. The present paper demonstrates that preliminary studies of structural materials for the parameters of structural materials caused by a group of factors, such as surface properties, chemical composition, processing technology, can be achieved using modern methods of scanning probe, confocal, electron raster microscopy, spectroscopy, and x-ray.

1. Introduction

Strings and string elements are widely used in the technique. In the field of measurement technology, there are many devices in which the sensitive elements are elements in the form of strings: strain gauges, accelerometers, crack gauges, etc. String sensors are widely used due to their simplicity and low cost. The paper presents studies of the structural materials properties using modern methods of scanning probe, confocal, electron scanning microscopy, spectroscopy, radiography [1].

2. Samples of the hypothesis

The concept of the proposed study is based on the hypothesis that the rate of degradation can be significantly influenced by factors such as the surface topography, especially in the elemental and chemical compositions, which also need to be taken into account. The use of phase-chronometric method with the theory of measurements reduction opens up new opportunities to study the behavior and degradation properties of structural materials, including elastic and rheological [2,3].

Many scientists conduct comprehensive researches of the structural materials properties. The study of materials is of particular interest that undergoes mechanical stress during operation [4]. Elastic modules in this case are dependent on the frequency of the applied force, and the mechanical characteristics of the construction materials are not constant values, as is commonly considered, even for a specific product, but vary in time under the influence of external influencing factors [5-8].

Strings and string elements which are widely used not only in musical instruments but also in the other fields, for example, there are many different string strain gauges, string accelerometers, crack meters, etc. in measuring equipment, were chosen as a constructive element for the present research. String sensors are widely used due to their simplicity and low cost.

Oscillations of systems on the example of strings in various environments are widely considered. The questions of studying natural frequencies are widely covered and the features of changes in natural frequencies, numerical-analytical modelling of strings free oscillations problems and rods in various media, etc. are established in the scientific literature.

A mathematical model of the degradation process of an elastic element (string) using the example of a linear oscillator with variable parameters is proposed, and the possibility of observing changes in its properties is demonstrated.

Parameters that directly relate to the properties of the structural material from which the string under study is made are estimated using mathematical modeling of the string oscillation process taking into account the degradation of the structural material using the example of a linear oscillator with variable parameters in the form of:

$$\ddot{x} + 2\beta(t)\dot{x} + \omega_0{}^2 x = 0 \tag{1}$$

where x - is the deviation from the equilibrium position;
$\beta(t)$ - attenuation coefficient, slowly varying in time, directly related to changes in material properties;
ω_0 - natural angular frequency.
The known variable replacement

$$x = v(t)e^{-\int \beta(t)dt} \tag{2}$$

allows converting the original equation to the form

$$\ddot{\upsilon} + \Omega^2(t)\upsilon = 0 \tag{3}$$

here $\Omega^2(t) = \omega_0{}^2 - \beta^2(t) - \dot{\beta}(t)$.

Application of the generating function

$$\varphi = \frac{1}{2} m_{\vartriangle}(t) v^2 ctgQ \tag{4}$$

provides a transition using the Hamilton formalism from variables p, v to canonical variables action - phase (P, Q).

The achievement of this result is guaranteed by the fact that the information capacity of gating, determined by quantization errors of time intervals δτc and high-speed recording of discrete samples of the coordinate δz or phase δφ, is significantly higher than that of the existing approaches. At the same time, the gain in the value of information capacity on the basis of achievements in the field of fast processes metrology, radio electronics and optics compared with the variant caused by the "mechanical" increase in accuracy is estimated by the expression

$$\mathrm{I}_2' - \mathrm{I}_1 = \log_2\left[\frac{\Delta\varphi}{\delta\varphi} \cdot \frac{2\sigma_{\tau 0}}{\delta\tau_c}\right] \tag{5}$$

where δτc - errors in the quantization of time intervals, $\delta\varphi$ - errors in the registration of discrete phase samples; $\Delta\varphi$ - phase increment; $\sigma_{\tau 0}$ - root-mean-square deviation of the measurement of the time instant τ0, corresponding to the triggering of the chronometric system.

The proposed measuring system is implemented in the form of a test bench, an analogue to which is the installation that provides measurement of the vibrations addition and the demonstration of the mechanical resonance phenomena, given in paper.

The design provides the sensitivity of phase relationships, due to the measurement of which it is possible to control the degradation of the slowly changing properties of structural materials in time. Such engineering implementation of the measurement setup makes it possible to measure some peculiarities of string vibrations, for example, the dependence of the spectral composition of the vibrations on the tension and conditions of the string excitation, etc.

The principle of the stand operation is the next: the string is fixed on the one side motionless, and on the other it is necessary to provide adjustable tension through the feedback system. To register the oscillation period, the measuring system emitter-receiver is used. Free damped oscillations are excited automatically. The period of oscillation is measured using the photovoltaic method. The laser diode and the receiving photodiode are matched in wavelength. The luminous flux is modulated by passing

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the zero position of the string. The error of measurement of time intervals is no more than $5 \cdot 10^{-8}$ seconds.

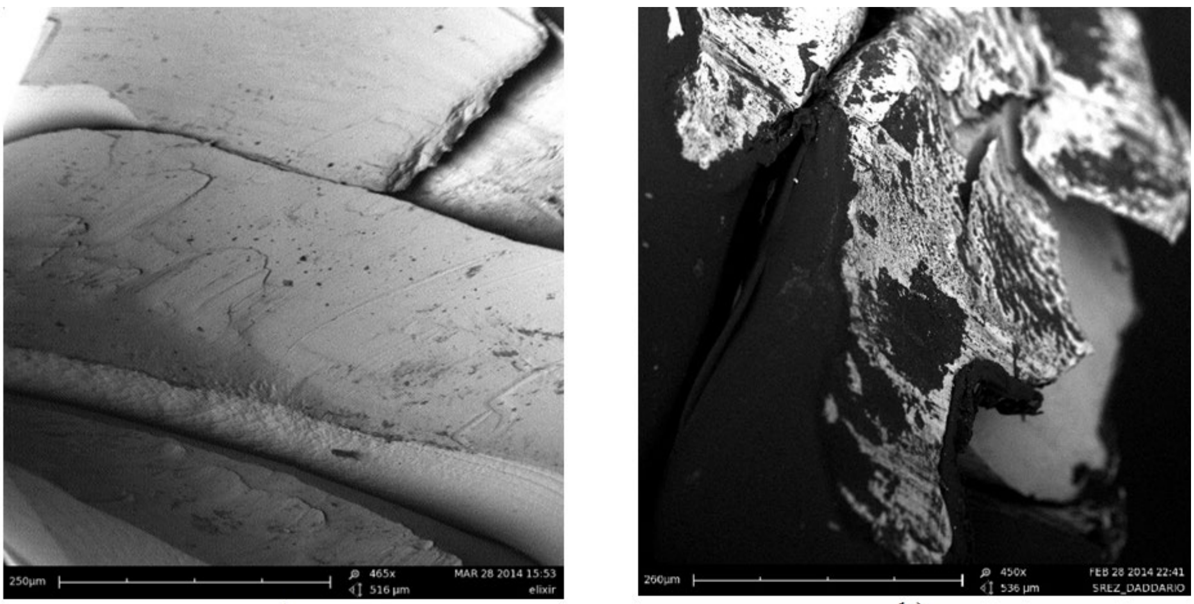
As the example of the implementation of such measuring systems installation, providing a measurement of the oscillations addition and demonstration of the mechanical resonance phenomena can be considered. The proposed design provides the sensitivity of phase relationships, due to the measurement of which it is possible to control the degradation of the slowly varying properties of structural materials in time.

A whole group of factors can influence the results of a measurement experiment and the degradation of the structural materials properties: surface properties, chemical composition, type of treatment, etc.

This paper presents the results of research on guitar strings, as the most widely distributed and industrially manufactured using the atomic-force microscopy, scanning electron microscopy, providing a study of the topography and surface structure, as well as the results of elemental and chemical analysis using spectroscopy.

3. Results

In figure 1, strings are presented in a cut and it can be seen that coatings from D'addario and Elixir manufacturers reflect electrons differently, which indicates that manufacturers use different materials as protective coatings. At the first measurements of features in the structure of the strings' surface were not detected. Two weeks later repeated studies were conducted. At the same time, during a break between studies, the strings were not subjected to any mechanical or chemical influences. But, as it can be seen from figure 2, the covering of the D'addario string, even before exploitation, began to peel intensively.



a) b)

Figure 1. (a) SEM image of the ElixirPolyWeb (USA) string cut surface; (b) SEM image of the D'addario EXP26 (USA) string cut surface

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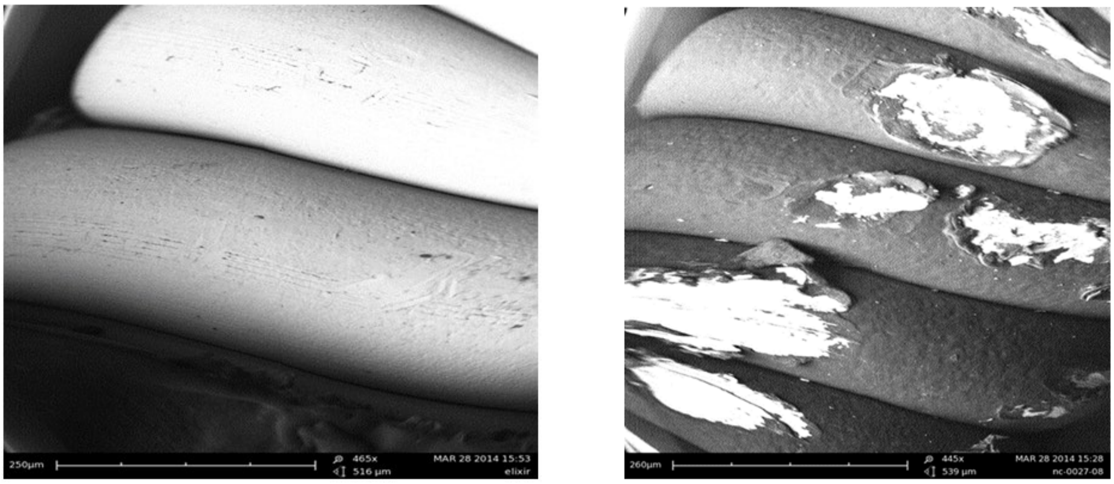


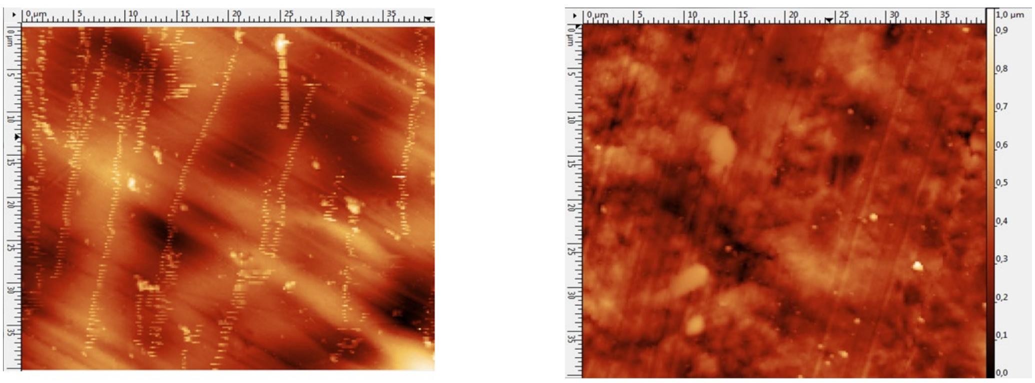
a) b)

Figure 2. (a) SEM image of the Elixir PolyWeb (USA) string surface; (b) SEM image of the D'addario EXP26 (USA) string surface

Figure 3 (a) shows the surface relief of the strings D'addario EXP26, the scan area is 40x40 μm. After a series of measurements, it was found that vertical bands are not image defects, but represent a feature of the surface structure. The investigated string has a winding and a protective coating.

Strings with braid are considered. The strings are presented in a cut, which shows that the coatings of the manufacturers D'addario and Elixir reflect electrons differently, which indicates the different properties of the protective coatings. Figure 3 (b) shows the relief of the Elixir PolyWeb string surface, the scanning area is 40x40 μm. It can be noted that the surface structure of this sample differs markedly from the previous one, the surface is more uniform, therefore at this stage it can be noted that the manufacturers D'addario and Elixir apply different protective coatings for their strings.

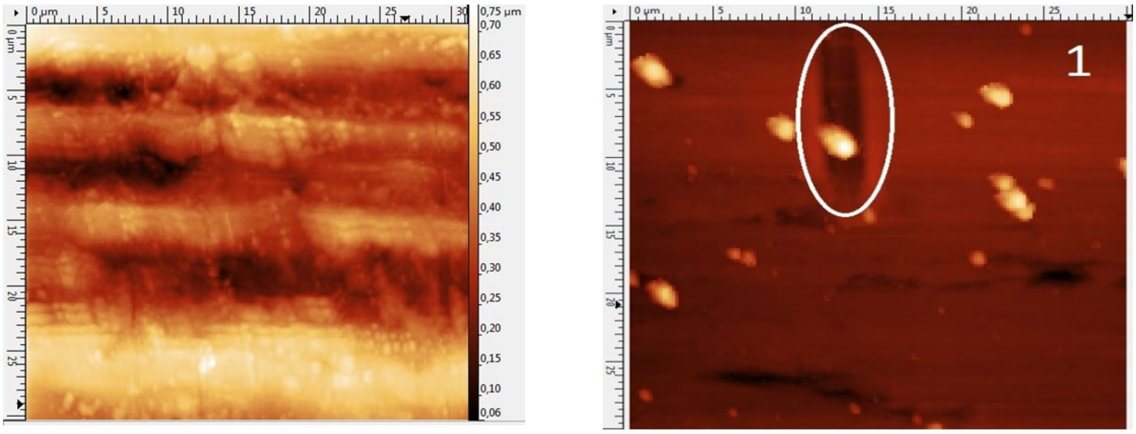
Since the degradation of a structural material properties is significantly influenced by a group of factors such as surface properties, chemical composition, type and duration of processing, measuring the parameters of the strings under investigation prior to testing them as a harmonic oscillator provides a priori information for accurately determining the residual life of the structural material. The presented results of the string surfaces studies by atomic force microscopy make it possible to determine the initial state of the parameter β(t) of expression (1) more accurately.



a) b)

Figure 3. (a) AFM image of D’addario EXP26 (USA) string surface; (b) AFM image of Elixir PolyWeb (USA) string surface

Figure 4 shows the relief of the D'addario EXP26 strings surface, the scan area is 30x30 µm. Strings do not have any winding or coating. On the AFM image of the surface of the strings, one can see longitudinal "furrows", which are a technological feature of the strings' manufacture. In order to obtain the required shape and size of the section, the string is pulled through the spinnerets. Mr. Musician "Bronze Age" has the scan area of 30x30 microns. Strings do not have winding and coating. The difference in heights in comparison with foreign analogues differs by 2-2.5 times and in general the surface structure is very heterogeneous. It can also be noted that the traces of the broach are practically invisible, which indicates that when making strings of the domestic producer, another technology is used.



a) b)

Figure 4. (a) AFM image of D'addario EXP26 (USA); (b) AFM image of Mr. Musician "Bronze Age" (Russia).

The selected area (1) shows a surface defect of 1x9 µm, which is an indicator of a serious violation of the manufacturing technology.

The time intervals (period and its multiple fractions, corresponding to the passage of the corresponding phases of oscillations) measuring result obtained with a Ntegra Spectra microscope is influenced by such groups of factors as the change in the dimensions of the string as a result of stretching, the surface roughness, and the tension of the sample. Estimates of the effect of these parameters on the measurement result are given below.

Table 1 shows the result of calculating the effect of a change in the diameter of a string caused by tension and a continuous force action for the period of its oscillations.

Table 1. The effect of the change in the diameter of a string on the period of its oscillation

Measurement number	Δd = 5 µm, increment of the period, µs.
1	49,6 (2,23%)
2	49,7 (1,67%)
3	49,5 (1,33%)
4	40,1 (0,79%)
5	38,3 (0,57%)
6	39,7 (0,44%)

A change in diameter of 5 µm leads to a period change of 0.2 to several microseconds. The influence of the roughness of the string surface on the periods of oscillations is associated with a change in the outer diameter. It is shown that if the period of free damped oscillations is T1 = 0.006648184 s, then a two times decrease in the roughness of the string surface to Ra = 1.3 µm will lead to a change in the period of free damped oscillations within ± 2 µs.

The spectra obtained from the surface of GHS strings and the Mr. Musician "Bronze Age" with the help of Auger electron spectroscopy are shown in figure 5.

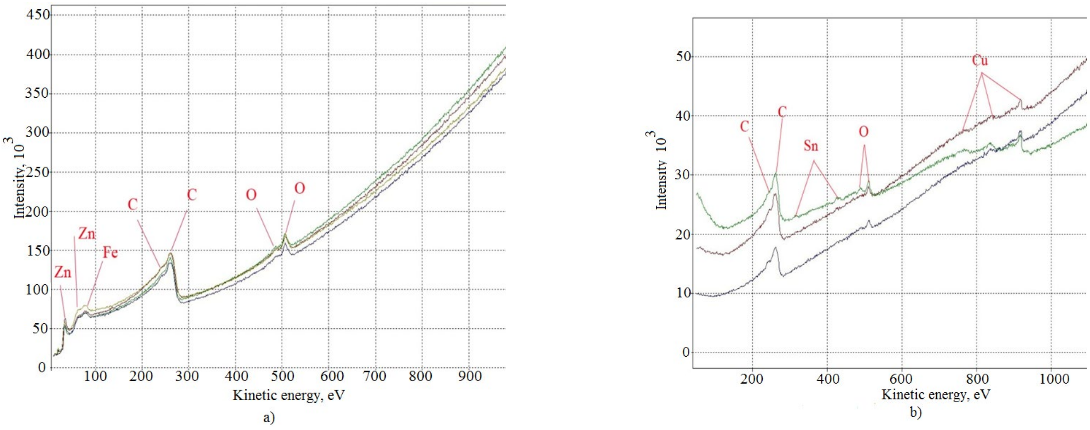


Figure 5. (a) Auger electron spectroscopy energy spectrum of GHS (USA) string; (b) Auger electron spectroscopy energy spectrum of Mr. Musician "The Bronze Age"(Russia) string

4. Conclusion

The presented results of the measuring control of the structural materials properties' degradation open fundamentally new possibilities for evaluation in the process of functioning, increasing the accuracy of determining the physical parameters and properties of structural materials by several orders of magnitude, and as a result, there are reduction of time and increase of reliability of design and technological development.

The paper shows that preliminary studies of structural materials in order to control the parameters of structural materials caused by the influence of a group of factors, such as surface properties, chemical composition, processing technology, can be provided by using modern methods of scanning probe, confocal, electron scanning microscopy, spectroscopy, X-ray.

The results of the strings' surface investigations by the methods of atomic force microscopy (AFM) and scanning electron microscopy (SEM), which provide research of topography and surface structure are presented. The results of elemental and chemical analysis by Auger electron spectroscopy are presented.

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