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Electroplastic Processing of Titanium Implants

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Abstract

The results of experimental studies of samples of titanium for implants when exposed to pulsed electric currents. Excitation of longitudinal and transverse vibrations to the sample under these influences can be used in their electroplastic processing and introduction into the bone tissue. When exposed to pulses of surface layers of titanium sample are experiencing significant dynamic load. The possibility of increasing amplitudes with decreasing duration of pulses of electric current was shown. This allows to exclude the heating of implants during such impacts. The peculiarities of ponderomotive effects in titanium samples related to its unique electrical and mechanical properties, precluding the practical manifestation of the classic skin-effect and its impact on the generation of oscillatory processes in the moments of passage of the leading and trailing edges of current pulse.

Keywords: titanium, implant, vibration, acceleration, magnetic field, skin effect.

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1. INTRODUCTION

Titanium and its alloys find nowadays a wide use as a material for prosthetic bone cells [1, 2]. This is due to the compatibility of titanium with biological materials [3] and the possibilities of modern technological processes of adaptation in form, surface structure and volume of the implants [4]. Many of the properties of titanium and its alloys can be considered as an advantage and as the deficiencies in the manufacture of implants [5]. Such features of the Titan include:

- extremely high corrosion resistance, due to the ability of titanium to form on the surface of a thin (5-15 μm) continuous film of oxide TiO_2, tightly bound with a mass of metal;
- specific strength (ratio of strength and density) the best titanium alloys reaches 30-35 or more, almost twice the specific strength of alloy steels;

- poor anti-friction properties due to the coating of titanium on many materials, titanium is paired with a Titan may not work on friction;
- poor machinability, similar to the machinability of stainless steels is austenitic;
- large chemical activity, the tendency to grain growth at high temperature and phase transformation during the welding cycle cause difficulties in welding of titanium.

These properties of titanium and its alloys complicate the treatment of the products and the process of installation of implants in conjunction with bone tissues. One of the ways of improving the processability of titanium implants can be effects of pulsed currents on the titanium samples, which ensures the manifestation of the effect of electroelasticity [6]. The use of electroplastic effects when working with titanium samples requires taking into account very specific properties of titanium and its alloys [7] related by passing through it pulse current. To assess the possibility of using titanium samples in terms of electroelasticity is the study of the ponderomotive properties of titanium in the conditions of action of pulsed currents.

2. RESEARCH METHODOLOGY

Samples of wire made from titanium were tested on the stand, the block diagram of which is shown in Fig.1. The power of the shaper pulse current runs from the three-phase AC network with voltage of 380 V. Driven key allows you to specify single and periodic current pulse with controlled amplitude and duration. The passage of the pulse through the sample is accompanied by the excitation of vibro-acoustic oscillations in the sample. For the analysis of the processes vibrational processes with multi-component high-frequency vibration sensors (accelerometers АП20) was recorded in the synchronous mode, the data acquisition module NI USB-4431 with the use of the software package LabVIEW. To analyze the characteristics of the flow of pulsed current through the sample synchronously with the recording of vibrations was performed by recording magnetic field changes in the vicinity of the sample in the form of a signal from a contactless Hall sensor type DRV5053. Most of the experiments were carried out with exposure to single pulses of current, which virtually eliminates the temperature rise of the sample and to exclude the influence of temperature effects. This is due to unacceptable heating of samples in case of their interaction with bone tissues.

Large specific electrical resistance of titanium and its alloys [7] leads in particular to higher values of skin layer. For relatively thin samples in the result there is practically no skin effect, limiting the amount of current in the moments of arrival of the pulse

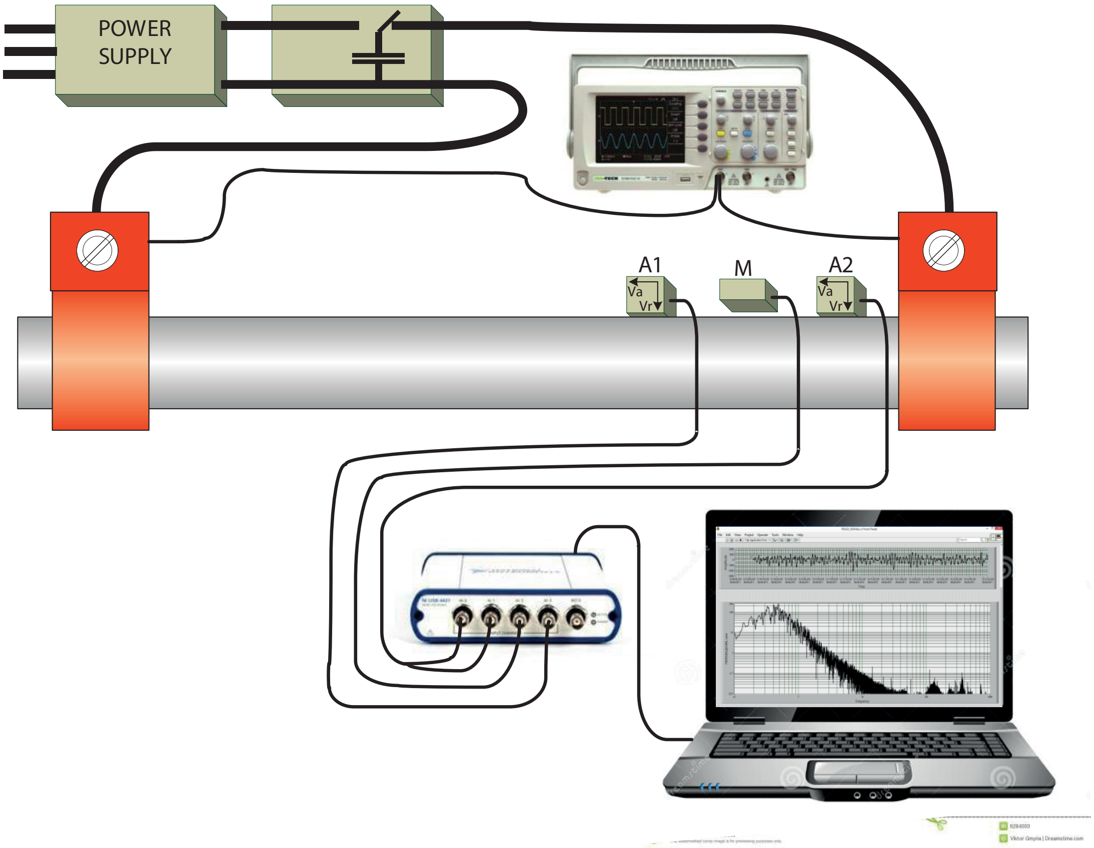

Figure 1: The structure of the stand for testing samples of titanium by the action of the pulse current from the acceleration sensors A1 and A2 and the magnetic field M.

edge current. The total current through the titanium sample according to the absolute value is substantially lower than in the case of high conductors (silver, copper and gold) due to the high resistivity of the titanium. Change the self-magnetic field of current-carrying conductor As in the case of typical skin effect gives rise to induced EMF, which increases the electric field on the surface of the titanium sample causes an increase in current in the initial moment of time in the surface layer, which for titanium due to the large thickness of the skin layer is not accompanied by the almost complete lack of current over the cross section, as it manifests itself to the skin effect.

As a result of the nature of the change of the magnetic flux collected by the magnetic field sensor for the titanium samples have significant differences from the similar results for samples with high conductivity [8], for which the current increase occurs relatively slowly. On the other hand for materials such as Nickel (as well as for other materials – ferromagnets) the skin effect is significantly stronger than for metals commonly used as conductors, such as copper, silver, aluminum and gold (Fig.2). When testing the effects of current on the titanium samples, it is necessary to consider the increased contact resistance on the surface of samples associated with the presence

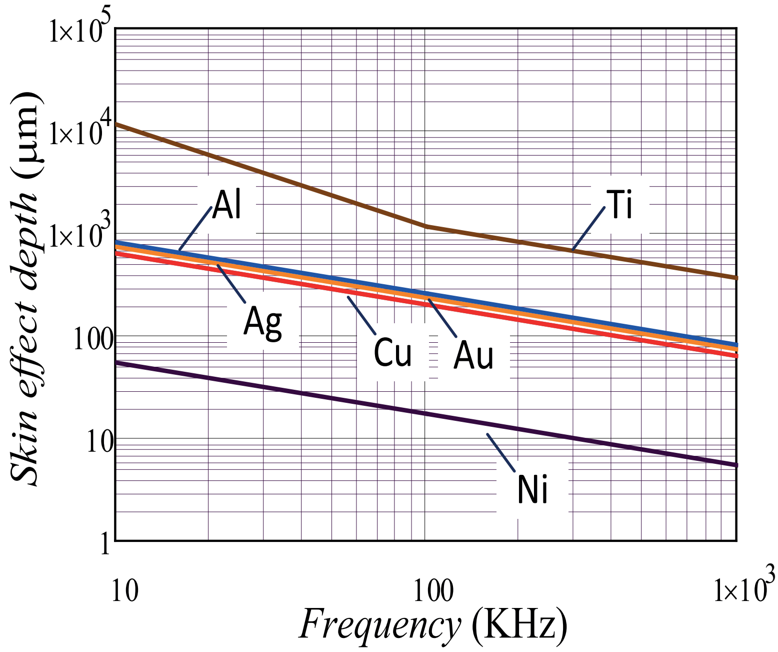

Figure 2: The dependence of the depth of the skin layer with frequency for different metals.

of titanium dioxide films [5, 9], as well as large variation of electric resistivity, which is typical for titanium and its alloys [7]. These features make it necessary to use to control the current through the sample non-contact sensors of the magnetic flux [10].

3. RESULTS

In Fig.3 shows the dependence of the signals of the acceleration measured by accelerometer on the surface of the titanium sample in the form of wire with a diameter of 3 mm from time to time. Longitudinal (axial) vibrations appear in the form of short pulses of acceleration during the passage of the leading and trailing edges of current pulse. These pulses form a damped oscillatory processes which are superimposed on one another and are relatively quickly damped. Transverse (radial) vibrations are formed as a result of the superposition of oscillations under the leading and trailing edges of the current pulse and are characterized by a relatively slow decay. It should be noted that the magnitude of the acceleration in the longitudinal direction is significantly greater than the amplitude of oscillations in the transverse direction. The amplitude of the oscillations, as well as their scope depend not only on the amplitude of the current pulse, but also to a large extent on its duration. Important is the phase relationship of the oscillations generated by the front and rear fronts of the current pulse. If these phases are the same, there is a significant increase in overall vibration

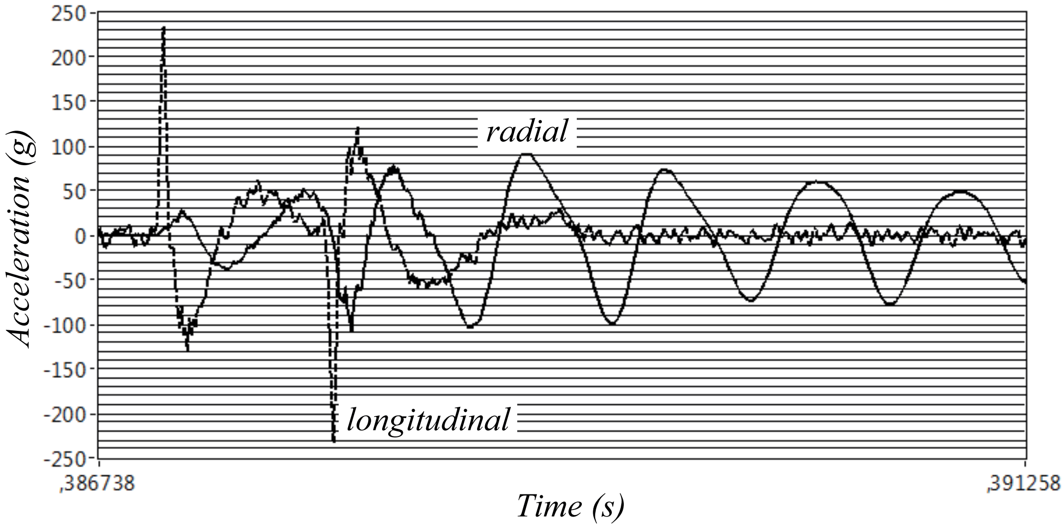

Figure 3: Strong acceleration of the surface layers of the sample of titanium. Radial – solid, axial - bar.

amplitude. If there is a mismatch of the phases of the oscillatory processes are largely suppressed.

In Fig.4 shows the dependence of the amplitude of oscillations in transverse and longitudinal directions from the duration of the current pulse. It should be noted that the nature of these dependencies is significantly different that allows you to practice by controlling the duration of the current pulse to adjust the amplitude of both transverse and longitudinal oscillations. This feature can be used in the process of installing the implant in the bone tissue. The experiments with titanium samples show, and if the vibrational response depends mainly on points in time corresponding to the action of the leading and trailing edges of the current pulse, the vibration level is negligible, as confirmed by the results of measurements. To ensure large vibration amplitudes it is possible to take advantage of the increase in the amplitude of the current pulse. The magnitude of the voltages applied to the sample are relatively small and pose no danger to living organisms. In Fig.5 shows simultaneous recordings of the oscillatory process in the transverse direction and the magnitude of the circular component of the magnetic induction. Significant is the presence of spikes in the level of magnetic induction in the points corresponding to the passage of the fronts of the current pulse. This effect can be seen as confirmation of the reduction of surface resistance for the titanium samples due to the influence of the EMF of self-induction for large values of the depth of the skin layer comparable to the size of the sample. This phenomenon is not observed on the samples of materials a thin skin-layer, although the General nature of the manifestations of the ponderomotive processes has a similar character. For materials such as copper or silver characterized by gradually the knots in the ring component of the magnetic induction within skin-effect time constant.

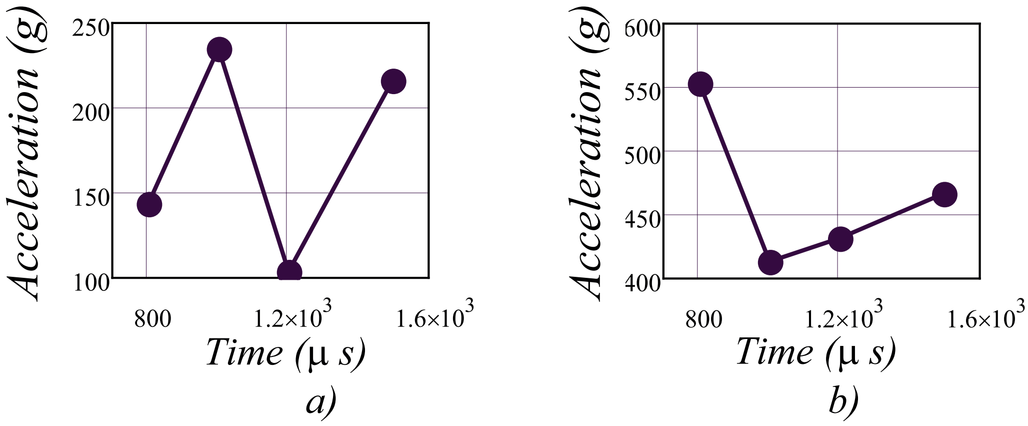

Figure 4: The dependence of the magnitude of the radial (a) longitudinal and (b) acceleration at the surface of the sample depending on the duration of the current pulse.

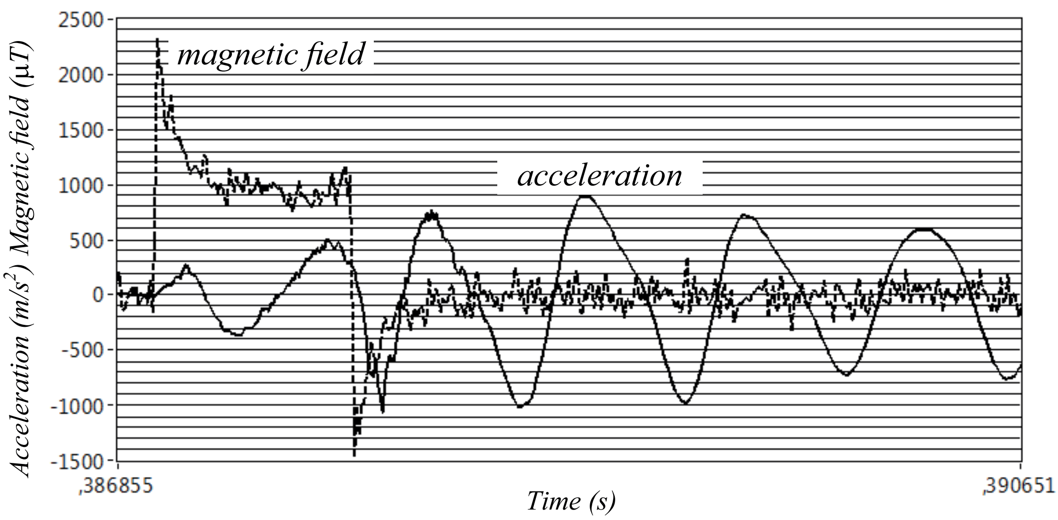

Figure 5: The signals of the lateral acceleration and the annular component of the magnetic induction for the titanium specimen in the form of a rod with a diameter of 3 mm..

The method allows to develop rules for management of electric effects that are used during electroplastic processing of implants from titanium and its alloys. Such effects are also possible in the process of installation of implants in bone tissue, which is important due to the significant forces of friction on the surface of titanium implants. As an example, the comparative characteristic manifestation of ponderomotive phenomena in Fig.6 shows the data for various metals, including titanium. This figure shows large variation characteristics of the vibration responses for the same impact, depending on the sample material. Thus, if such materials as silver, gold and copper are the differences relatively small, ferromagnetic materials provide a much greater vibration response. In the case of titanium, when such a response is relatively weak, the possibility of controlling its characteristics by changing the parameters of the current pulse is particularly important.

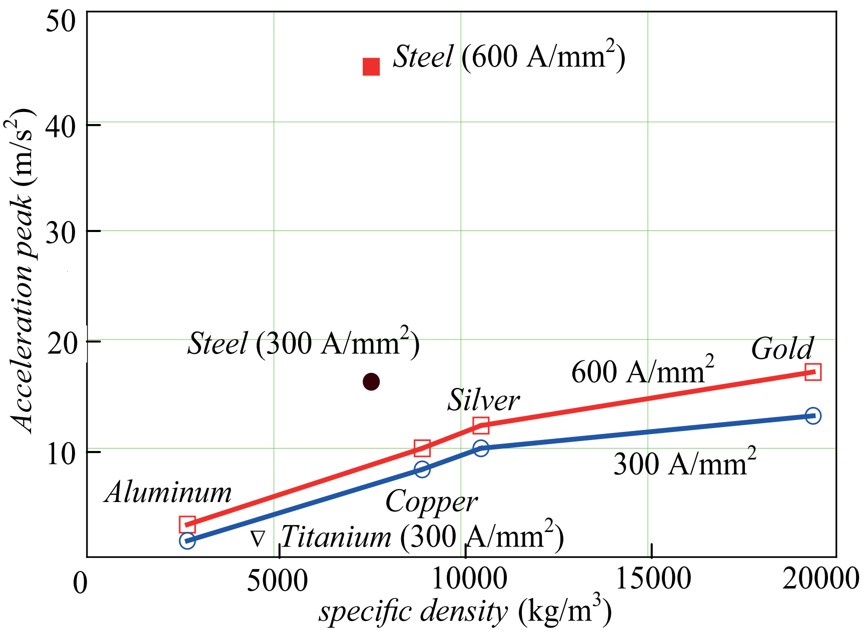

Figure 6: Comparison of the peak acceleration for samples of different materials with the passage of current pulses with density 300 and 600 A/mm^2.

4. CONCLUSION

The obtained results show the possibility of controlling the amplitude of the excited mechanical vibrations not only by regulating the amplitude of the current pulses, but due to the choice of the material and time parameters of impulses. The specific properties of titanium and needs to be taken into account, the PI building systems electroplastic processing of it, and also in the case of using the excitation of vibro-acoustic processes in implants when installed in the bone tissue.

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