

Change of energy state in the surface layer at the stages of vacuum ion-plasma treatment process

V V Plikhunov and L M Petrov

JSC “National Institute of Aviation Technologies”, Moscow, Russia

E-mail: info@niat.ru

Abstract. Change of energy state in the surface layer under treatment at the stages of vacuum ion-plasma process is discussed. It is demonstrated that the most informative way to obtain data on the surface condition after the action of plasma streams is a method of contact potential difference used for evaluation of the energy state of the surface. Different examples of the application of this method to evaluate the surface energy state and to determine effectiveness of plasma streams action are presented.

Vacuum ion-plasma (VIP) treatment is one of the widely used technological methods for surface strengthening. This method makes it possible to form external, internal and combination coatings employing a wide range of plasma stream effects.

Provision of the necessary level of performance properties during VIP treatment is achieved by changing the structure of the work surface of structural metal materials under the effect of high-energy gas-metal plasma streams. The influence of plasma streams involves a change in the energy state of the surface layer, which is an estimation characteristic of effectiveness of plasma streams effects as well as a quality criterion of the generated coatings. The importance and the necessity for an investigation into the energy state of the surface layer during surface treatment have been mentioned in [1, 2], however, at present the change of energy state, as a rule, is never taken into consideration. The reason is first of all associated with the lack of reliable and high-quality instrumental equipment that enables us to evaluate the change of energy state of the surface at different treatment stages.

Analysis of the methods used for control of the energy state of the surface layers has permitted to determine that the most informative and on-line method of evaluating the change in the energy state of the surface layer is a method of contact potential difference. According to the value of the surface potential of pre- and post-plasma stream effects we can estimate the effectiveness of these effects on the work surface. Devices that implement the given method are characterized by high sensitivity to external electromagnetic action, which complicates assurance of stability, when measuring surface potential values [3].

The analyzer of the surface energy-state (ASES) [4] designed and produced in the National Institute of Aviation Technologies (NIAT) permits realization of the non-destructive testing of the energy state of the surface of structural metal materials. This method includes the use of technique for measurement, a measuring device, and a procedure for operation with the measuring device and also a procedure for the estimation of measurement results. The principle of this device operation (figure 1) is based on the fact that difference of contact potentials of the specimen and the measuring electrode, which are in contact at the moment of their separation, forms a capacitor with an electric charge Q in



the specimen – measuring electrode system. The feedback electrical circuit provides for conservation of the charge value $Q = \text{const}$ through generation of the compensating voltage Y without any additional voltage sources. With constant speed of the measuring electrode removal, the value of compensating voltage will also increase in direct proportion to time t from the moment of separation of the specimen and the measuring electrode. Thus ASES device allows us to obtain a graph of linear function $V(t) = At$, where A is a constant that determines an angle of inclination α of the straight line $V(t)$ in Cartesian coordinates $V-t$. It should be noted that constant A is directly proportioned to the value of charge Q .

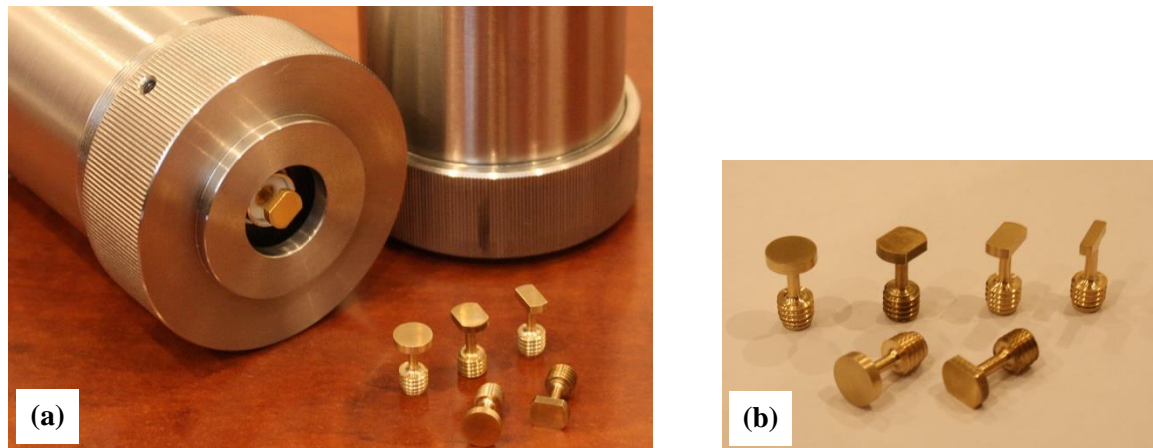


Figure 1. The analyzer of the surface energy-state (a) and replaceable sensors (b).

The energy state of the surface of specimens is compared either from the value of angle α (in this case $Q \sim \text{tg } \alpha$) or from the value of voltage V defined at a given time value t (for instance, $t = 200 \mu\text{s}$). In the latter case we will call voltage V as a reduced surface potential V_p underlying thereby dependence of its values on the selected time period and technical features of the ASES design including size, material and measuring electrode travel speed.

Taking measurements by means of the ASES device in the same conditions, it is possible to compare the energy state of the surface of specimens made in different materials under different types of treatment. Figure 2 presents examples of definition of the reduced surface potential V_p of a 40H steel specimen during VIP treatment with the aid of ASES device.

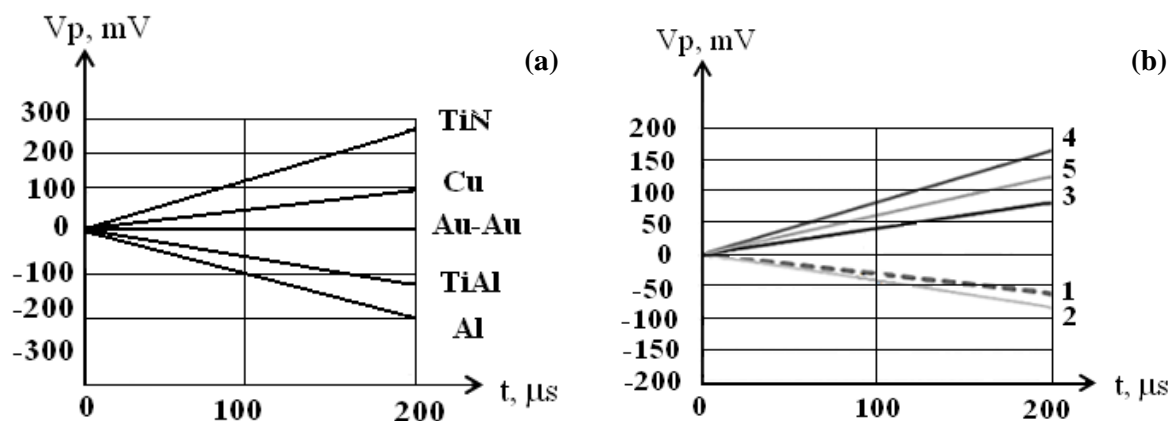


Figure 2. Behaviour of V_p values of coatings relative to the sensor gold-plated electrode (a) and dependent on the modes of electronic heating with assisted Ti deposition (b): 1 – initial condition; 2 – 300 °C (Ti – 1,2 mass %); 3 – 400 °C (Ti – 2,4 mass %); 4 – 500 °C (Ti – 4,8 mass %); 5 – 600 °C (Ti – 5,4 mass %).

The study of variations in V_p values depending on the surface condition of the structural metal materials enabled us to establish the regularities of their change subject to tooling influence as well as different types of surface contamination in the shop-floor atmosphere (dust, oil vapors, coolant, etc.). It has been found that the variations of the reference value V_p indicate that under process effects considerable surface barrier layers are formed, which inhibit generation of high-quality coatings with high level of operational properties [5].

The pursued investigations have permitted to determine effectiveness of the process effects of plasma streams at VIP stages and to substantiate modes of their implementation. It has been found out that in the course of ion etching of 40H steel by argon gas plasma in the mode of semi-self-maintained gas discharge $V_{ref} = -500$ V and the value of V_p changes according to the time of ion stream action. In this case the beginning of ion etching process within one minute is characterized by transition of V_p value from the negative domain to the positive domain (figure 3(a)), which indicates that contaminating adsorbed layers and oxides have been removed from the work surface. The basis for selection of the etching mode is the presence of maximum activation values at the surface. However, the maximum value of V_p is observed under 20 min ion etching mode when there is no surface structure, but there exists a bulk structure, which is confirmed by the variation of the volt-ampere characteristics of the tunnel current (figure 3(b)). The availability of such structure at the surface involves difficulties for development of adhesive diffusion layer at the metal-coating boundary that is non-desirable during VIP treatment. Therefore the time of effective influence of the gas plasma on the surface can be estimated according to the change in energy state of the surface when the contaminating adsorbed layers and oxides are removed and the V_p value transits from the negative domain to the positive one.

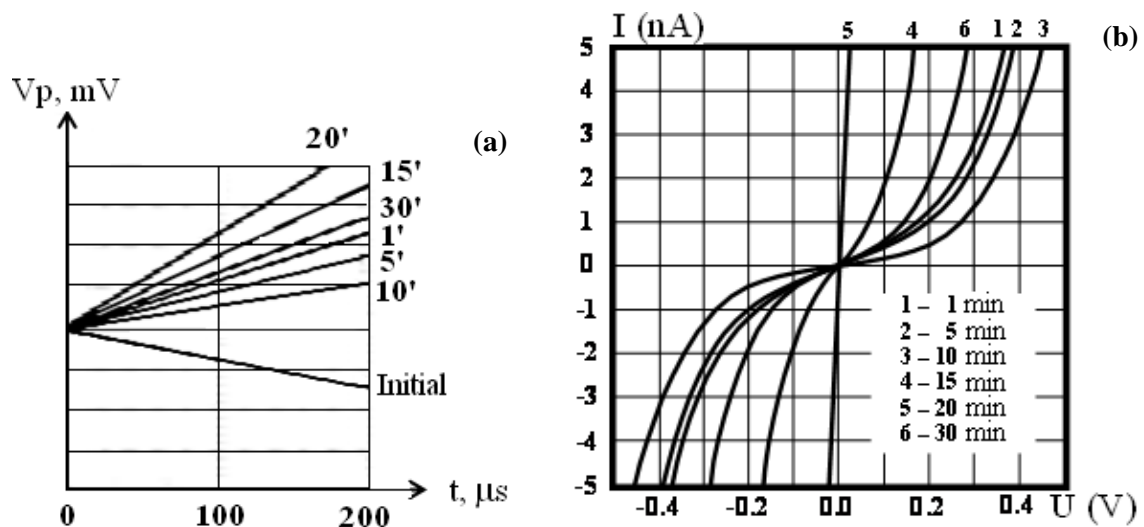


Figure 3. Change in the properties of the surface layer of steel during ion etching ($U = -500$ V) depending on the time of argon gas plasma stream action: change in the energy state (a); variation in the volt-ampere characteristics of the tunnel current (b).

Tooling effects on the surface of structural metal materials lead to the structural changes of the surface layer, generation of a relief with different roughness and change in its energy state.

Thus the method set forth in this paper for measuring variations in values of the energy state of the surface layer after it was affected by plasma streams enables us to estimate their effectiveness and substantiate modes of their implementation.

References

- [1] Sulima A I, Shulov V A and Yagodkin Yu D 1988 *The Surface Layer and Performance Properties of Machine Elements* (Moscow: Machinostroenye)

- [2] Bobrov G V and Iliyina A A 2004 *Application of Inorganic Coatings* (Moscow: Internet Engineering)
- [3] Iliyina A A, Plikhunov V V and Petrov L M 2011 *Aviation Industry* **2** 28–32
- [4] Mush V N, Plikhunov V V and Petrov L M Patent RU 2471198
- [5] Plikhunov V V and Petrov L M 2011 *Proceedings of the 10th International Conference “Films and Coatings”* pp 147–50