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Determining the Electron Work Function of Metallic Aircraft Components from the Contact Potential Difference

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Abstract—A method has been developed for determining the contact potential difference and electron work function of metallic aircraft components, on the basis of a specialized measuring system. Attention is paid to the determination of the surface layer of the aircraft components, the electronic theory of metals, the contact potential difference, and its measurement by means of static and dynamic capacitors. Methods of nondestructive monitoring of metallic aircraft components are developed and assessed.

Keywords: metals, aviation technology, machine parts, nondestructive monitoring, electron work function, contact potential difference

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INTRODUCTION

In the aircraft industry, multicomponent alloys based on metals such as Fe, Al, Ti, Cu, Ni, Cr, and Mg are widely used. The surface and subsurface layers have the greatest influence on the strength of aircraft components. Accordingly, it is of great importance to develop nondestructive monitoring of the surface of metallic components in aircraft manufacture, operation, and repair.

The surface layers of metal aircraft components may be regarded as consisting of elementary particles: electrons, ions, atoms, and molecules. The electron work function at the metal surface is a fundamental characteristic of the metal, associated with many of its properties. The electron work function of metal in an aircraft component may be determined by measuring the contact potential difference between the component and a standard metal and subsequent comparison with its known electron work function. That permits the development a method of nondestructive monitoring of aircraft components based on the contact potential difference [1].

The contact potential difference appears in surface layers of metals and layers of thickness no more than tens of Angstrom. In metal contact, the valence electrons move from the metal with lower electron work function (and higher Fermi level) to the metal with higher electron work function (and lower Fermi level). That tends to equalize the Fermi level. This electron transition is simultaneous with the transfer of electric charge from the metal with lower electron work function to the metal with higher electron work function. Correspondingly, the surface of the metal with lower electron work function is charged positively, and the surface of the metal with high electron work function is charged negatively. As a result, a contact potential difference appears in the gap between the metals.

MEASUREMENT OF THE CONTACT POTENTIAL DIFFERENCE

The Kelvin–Zisman approach is generally used to measure the contact potential difference in solid-state physics. In this approach, the measuring electrode vibrates. The variation ΔU in the contact potential difference in that case is

$$\Delta U = \frac{RUSAF}{4\pi d}\frac{\cos 2\pi Ft}{1 + A\sin 2\pi Ft}\frac{1}{9\times 10^{11}},$$

where R is the internal resistance of the sensor's measuring electrode; U is the voltage at the capacitor plates, which is the difference between the contact potential difference and the potentiometer voltage; S is the area of the capacitor plates; A is the vibrational amplitude of the measuring electrode; F is the vibrational frequency of the measuring electrode; d is the distance between the capacitor plates; and t is the time, s.

The basic benefits of measuring the contact potential difference on the basis of a dynamic capacitor are that this method is highly sensitive (up to 0.5 mV); permits measurements on small sections of the metallic aircraft component; and is nondestructive. Deficiencies include the need for careful shielding of the measuring capacitor; and the critical importance of constant amplitude A, vibrational frequency F, and gap d. To shield the capacitor, we use a Faraday cylinder, where there are no variable magnetic fields.

In nondestructive monitoring of metal aircraft components, different methods may be used for measurements on bent surfaces and in relatively inaccessible parts of the metal surface. The surface preparation for measurement of the contact potential difference may also differ: removal of protective coatings, special methods of surface cleaning, etc.

MONITORING SYSTEM

On the basis of measurements of the electron work function and contact potential difference for solid metals, specialized nondestructive monitoring of aircraft components is possible. In Fig. 1, we show a system developed for measuring the contact potential difference of metal aircraft components [2]. In this system, the contact potential difference is measured by means of a Micsig TO1104 digital oscillograph, and the sensor elements and wires are magnetically shielded. In addition, the recorded contact potential difference is amplified, and parasitic signals are filtered out.

We have developed a special sensor for use in measuring the contact potential difference. Its electronic circuitry permits vibration of the measuring electrode in contact with the metal components at 410 Hz. The electrode is made from nickel of 99.9% purity. The sensor also includes a preamplifier for the electric signal.

The sensor housing is such that the gap between the measuring electrode and the metal components of interest is 0.5 mm when the electrode is at rest. These design features of the sensor permit reliable measurement of the contact potential difference of metal aircraft components.

In comparison with existing equipment, the proposed device provides values of the contact potential difference between metals that are highly reproducible. In addition, the system significantly improves the nondestructive monitoring of metal aircraft components [3].

Fig. 1. System for measuring the contact potential difference of aircraft components.

CONCLUSIONS

(1) Measurement of the contact potential difference is very promising for nondestructive monitoring of metal aircraft components and may be used in aircraft manufacture, operation, and repair.

(2) Measurement of the contact potential difference gives the best results when determining the electron work function in monitoring the surface of metal aircraft components for contamination, in coating application, and in studying friction and corrosion.

(3) Experience with the system developed for measuring the contact potential difference of aircraft components confirms the utility of its design features. The next step is to develop a method of determining the electron work function on the basis of the contact potential difference for specific materials and aircraft components.

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