Inspection Features of Constructive Technological Coatings of Composite Elements for new Generation Liquid Propellant Engines (LPE)

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Abstract. The problem to increase the reliability of aircrafts and to reduce the cost factor of putting the load into space has become acute with space development. The main units of rocket propulsion system are liquid-propellant engines (LPE) which constitute 20…40% of the overall cost of a spaceship.
This article considers the eddy-current technique of thickness inspection of functional galvanic coatings of parts made of nonmagnetic and weak-magnetic heat resistant conductive materials. First of all, these are nickel, copper and silver coatings to solder different parts of LPE including honeycomb constructions.
The difficulties of thickness inspection in this case come from:
40% changes in specific conductivity and magnetic permeability within one part;
local inspection for the area is not more than 5 mm^2;
required measurement accuracy is not more than 8…10%.
This made us develop a new methodical approach to designing of NDT means and metrological assurance.
The new eddy-current thickness gauge which helped us to solve the problem of thickness inspection at different combinations of base and coating materials is reported.
The study also discusses the features of metrological assurance for the inspection process with the use of reference and industrial standards, which were produced by selective gravimetric method, and on-site samples.
As a result we developed a unique technique for the thickness inspection of different coatings including nickel coatings to be soldered on the parts of modern LPE.

Evolution of space exploration has raised urgent problems of reliability enhancement of aircrafts and problems of unit cost decline of effective load bringing into space. Main units of modern space rocket power plant are liquid-propellant engines (LPE), which make 20-40% cost of the rocket.
The quality and life time of an LPEs is significantly determined by the quality of a combustion chamber operating in sever conditions of high temperatures, pressures, hostile environments and mechanical loads. The set of the above conditions and the requirement for multiple uses of LPE make it necessary to apply nickel and chrome coatings on inner surfaces of chambers to protect them from the effect of high temperature erosion. The coatings themselves also provide optimal thermal conditions of inner surfaces and prevent erosion removal of metal by high temperature and high speed gas streams that, in its turn, provides the stability of strength and geometric characteristics of a chamber. This is particularly important for the conditions of nonexpendable trials. The chamber walls are honeycomb structures, with the elements being soldered. The coatings are also applied to provide reliable soldering, namely galvanic nickel-copper and silver coatings. Failure to

comply with the parameters of chamber coating at the stage of its manufacturing, trials and operation of LPE is not permitted. Therefore, the inspection of surface coatings has become more significant.

In fig. 1 the section of the LPE chamber body is shown. The part of a wall with a channel manufactured as a soldered construction is shown enlarged. The reliability of soldering is determined by the quality of copper coating on a metal steel base made of heat-resistant steel.

Thus, the problem of thickness inspection of coatings boils down to the inspection of nickel, silver and copper coatings on non-magnetic and light magnetic bases made of heat-resistant steels. Moreover, complex geometric configuration requires high localization of inspection. The thickness of coatings may range from a few µm up to several hundreds µm. The eddy-current technique satisfies these demands.

The major advantage of the technique is that it allows carrying out operation monitoring, with the equipment being relatively small and small plane probes providing high reliability of the inspection.

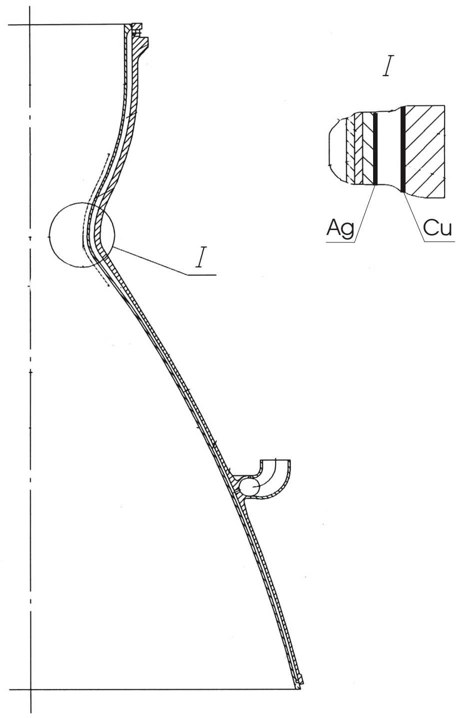


Fig. 1. Section of a combustion chamber body

The principal requirement for eddy-current inspection of thickness of conducting coatings on electrically conducting base is to discern electromagnetic parameters of their materials. For instance, for non-magnetic base and the coating, their specific conductance should differ at least 1.2…1.5 times. The materials of the base and the coating used in our case meet all these requirements.

Fig. 2 shows hodographs of relative added voltage of a plane eddy-current probe subject to coating thickness variation for various specific conductances of the base and the coating. The hodographs show that the wide variety of combinations of electromagnetic properties of both the base and the coating results in a large number of calibration curves for thickness gages. They can be made by thickness reference samples for each specific combination of metals that makes some problems for metrological provision.

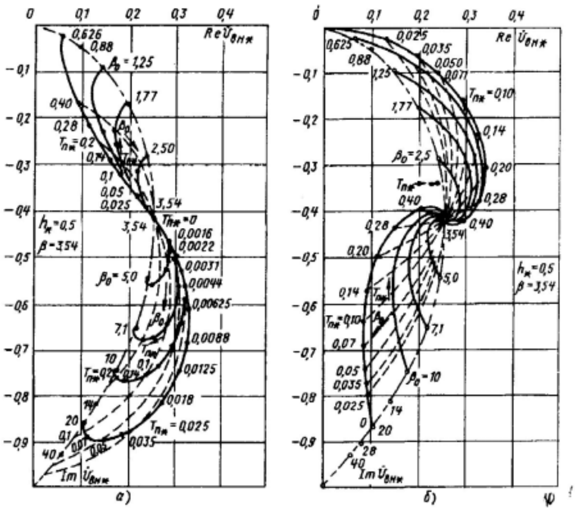
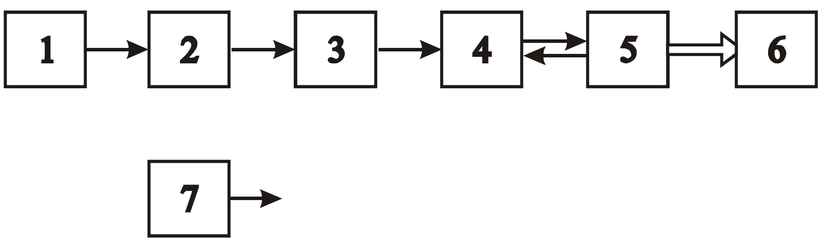


Fig. 2. Hodographs of added voltage of a plane eddy-current probe from surface thickness for various specific conductance

All the above requirements eventually led to the structure chart of the thickness gage shown in fig. 3. Active oscillator 1 produces sinusoidal current. Parametric plane eddy-current probe 2 engaged in a parallel resonance circuit is the load for the active oscillator. Tuned-circuit Q-factor and its initial detuning are chosen so that it would provide as much amplitude sensitivity to the coating thickness variation as possible for most possible combinations of base and coating materials. The variation of voltage at the output of the probe when approaching to a tested object changes partially due to the quality factor change of the circuit (influence of an active component of induced resistance upon the probe) and partially due to the variation of natural resonance frequency of the circuit (detuning change) because of the influence of an inductive component of induced resistance upon the probe. High frequency voltage at the output of the probe 2 goes to the input of an amplitude detector 3. Rectified voltage from the amplitude detector goes to the microcontroller through an amplifier 4. The microcontroller 4 sets an initial bias and gain for the amplifier 4, converts the input voltage into a digital code, processes the code according to the given algorithm and transfers the obtained volumes of coating thickness to the indication block 6. Power supply of all thickness gage units is provided by a stabilized power supply block 7. Fig. 4 shows the front view of the thickness gage.



1 – active oscillator, 2 – plane eddy-current probe,
3 – amplitude detector, 4 – programmable amplifier,
5 – built-in microcontroller, 6 –display, 7 – stabilized power supply block

Fig. 3. Structure chart of galvanic coating thickness gage

Fig. 4. Galvanic coating thickness gage TL-1MP

The device consists of an electronic unit 1, a plane eddy-current probe 2 for highly local inspection, being connected by a cable. On the front panel of the electronic unit 1 there is a handy digital indicator 1.1 displaying the volumes of thickness in μm and a control panel 1.2 with a minimal number of buttons so that an operator was not confused. The device is self-educating, i.e. when necessary to inspect coatings with new combination of electromagnetic properties of the base and the coating, the operator can enter new calibration characteristic.

Probe 2 consists of a coil winded over a ferrite core of a small diameter which is placed into a rod 2.1. The rod is sprung and can move into the probe body 2.2. The spring provides a constant hold-down pressure to a tested surface. The tip of the rod is protected by a corundum cover.

It has been mentioned that to calibrate thickness gages we need certified thickness reference samples for the whole range thicknesses and they should be made of the materials identical to the tested ones and the process of sample production should be followed. And in case of a complex geometric configuration of a tested object, e.g. ribs, it is necessary to have reference samples of the same shape to illuminate the influence of edge effect on the signal from probe. Thus, metrological provision for galvanic coating thickness inspection by non-destructive techniques calls for definite system of scientific, technical and organizational works to achieve the unity and provide reliability of measurement results. Therefore, the need to complex solution of the metrological problem of galvanic coating thickness inspection emerged.

For this purpose we have elaborated a special metrological scheme providing high reliability of inspection, see fig. 5.

To provide reliable and displayed information about coating thickness is possible in case basic provisions and requirements for techniques and means of non-destructive testing are standardized and there is all necessary metrological equipment.

The primary measures are the ones which are certified by the direct measurement method. They provide the maximum compliance with the state standard of length. Their main purpose is certification and periodical calibration of thickness gages. On the assumption of the complexity of their manufacturing and the requirement for the storage longevity of metrological characteristics, such measures can significantly differ from real tested objects by properties.

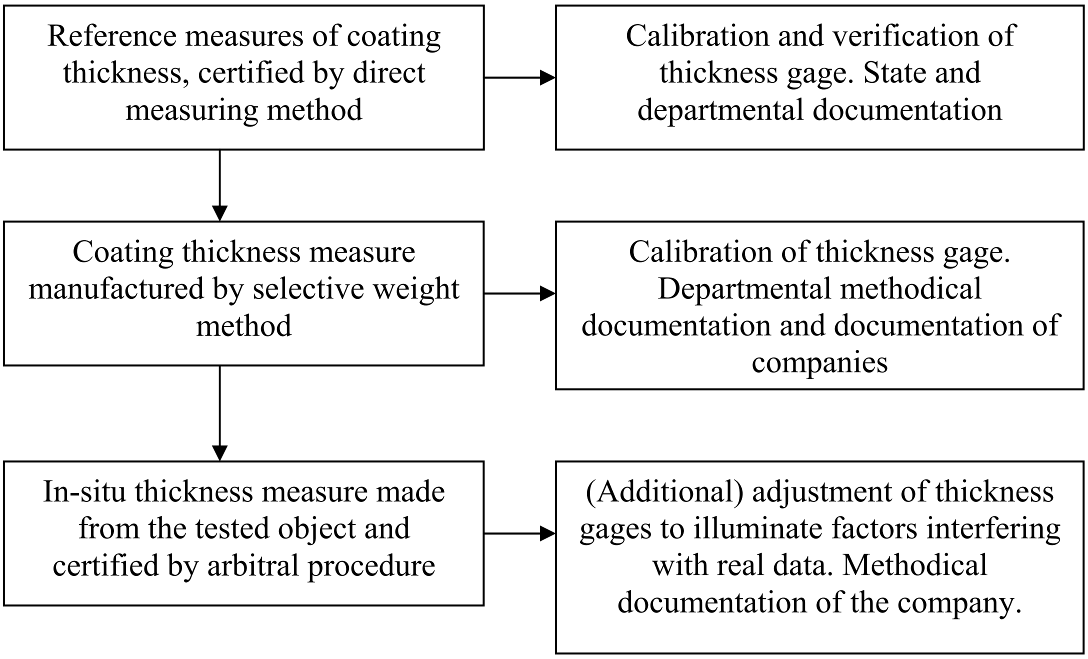


Fig. 5. Metrological provision for galvanic coating thickness inspection

To manufacture thickness measures with the properties identical to the tested material, the selective weight method of manufacturing and certification of thickness measures is developed and patented. In this case, the measures are made of the material of a real object following the same technology.

The main idea of the method boils down to the following. The coating is sputtered on one side of a plate, made of the base material, of 90…100 mm in diameter. The plate is weighted before and after sputtering. The weights tell us the thickness taking into account the area and the density of the coating. To increase the accuracy of measurements, after sputtering, the sample is tested by a non-calibrated thickness gage (e.g. TL-1MP) and the area with equal test indication (equal thickness) is found. The coating that does not belong to the area of equal indication is to be removed and weighing repeats. Thus, we obtain a thickness measure with an error of 3…5%.

The application of real object thickness measures made of the object material allows to eliminate interfering factors such as curvature of surface, small size etc.

Thus, mutual cooperation of two Russian companies “RII MSIA “Spectrum” and SPA “Energomash” has provided material security for galvanic coating thickness inspection of parts and components of LPEs. The eddy-current thickness gage TL-1MP intended to test thickness of electrically conducting coatings on electrically conducting base at various combinations of electromagnetic properties of materials. Metrological provision and the first lot of equipment has been manufactured.

The application of the thickness gages together with other means of non-destructive testing let us provide the reliability of LPE up to the required level at a considerably lower number of trials of a limited lot of equipment. Along with, it let us decrease the expenses on preparation of LPEs to flights.