Application laser ultrasound defectoscopy for control of solder joints of thin-walled products

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Abstract
The technology of space propulsion engines is very sophisticated and includes a number of processes that are crucially important for their safe service. One of them is soldering of thin rib shells. Conventional methods are not efficient for non-destructive testing of these joints with proper sensitivity and resolution. Contact laser-ultrasonic evaluation (CLUE) was efficiently used for detection of 1 mm2 small dry joint in soldrib sandwich. The results of combustion chamber testing with CLUE are presented. Some perspectives of industrial control of propulsion systems with CLUE are discussed.

Keywords: combustion chambers, non-soldered defect, laser ultrasound, Non-destructive testing (NDT), liquid rocket engines

The creation of RST of new generations should be based on deep design, engineering and material science researches. New material decisions determine the level of design and engineering developments, improving the quality of RST products.

There are various materials and technologies, such as vacuum-compression brazing, friction-stir welding, etc, used in RST manufacturing process to create complex compounds. Widely used in RST traditional methods and means of nondestructive testing (NDT) do not provide the required level of data reliability on the presence of micro defects in complex compounds (according to preliminary estimates, the disclosure of crack can be up to several micrometers, and the solder skips up to few tens of micrometers). The complexity of NDT technology development for soldered joints is due to the peculiarities of devices construction, for instance, liquid rocket propellant (LRP) cameras, and also due to permissible sizes of defects, which materially affects the reliability and strength of engines.

The analysis showed that modern ultrasound methods with excitation of ultrasonic waves by piezoelectric transducers cannot be used for NDT of solder joints of LRP combustion chambers. This is due to high values of the ultrasonic pulse duration, the depth of the "dead zone" and the diameter of the probing beam.

Currently one of the most promising NDT methods for solder joints of nozzles of LRP combustion chambers quality control is laser-ultrasonic method with the use of thermo-optical excitation of acoustic waves.

Figure 1 – Appearance of the sub-header ring of the upper nozzle zone of LRP chamber 14D23
The analysis of control methods showed that the use of destructive methods is economically unjustified due to the high cost and complexity of the nozzles of LRP chambers design. Using conventional NDT methods, such as magnetic, x-ray and ultrasound, did not lead to any positive result due to various reasons. It is necessary to apply new methods and to develop new means of non-destructive testing.

One of the ways to solve the problem of quality control of the nozzles solder joints manufacture is the use of contact laser-ultrasonic evaluation with thermo-optical excitation of ultrasonic vibrations.

Ultrasonic signals are generated in the near zone due to the thermo-optical excitation. Shape of acoustic pulse during the thermo-optical excitation is defined by the characteristics of the environment - light absorption coefficient, speed of sound, and the parameters of laser - pulse duration and spot diameter. The main task is to separate the influence of laser pulse shape and physical environment on the profile of the acoustic signal. To solve this problem, it is proposed to use the method of transfer functions.

A phased approach allows to calculate the OA-signal form, excited in the absorbing medium, and to analyze the diffraction distortions of the pulse during the spreading in the near zone, and also to take into account the geometric features that affect the transformation of the signal.

Distant spread zone of the ultrasonic pulses is similar by its geometric characteristics to the cylinders (rib) and the plates (outer wall), so it is possible to describe the equations of the normal distribution of ultrasonic waves in plates and cylinders.

Due to the presence of different types of waves, the signal from cavity when receiving OA-images on the edge of the soldered joint is only lost during the second reflection. It became a defining moment of the interpretation of OA-images when developing a method of quality control in the manufacture of soldered joints on the basis of the laser-ultrasonic flaw detection.

Critical size of the solder skips, obtained by the use of the strength theory methods, has allowed to establish requirements for the development of a new type of OA-converter to control the defects of the nozzles of LRP chambers. The novelty of the developed converter includes:

1) the generator is absent in the design of the converter, i.e. the transition to the generation of ultrasonic pulses released directly in the material of the wall of LRP nozzle;
2) the structure of converter includes optical lens for the laser radiation focusing and the reduction of the generated ultrasonic beam diameter;
3) the profile of the contact surface of the converter (OA-prism) is consistent with the geometry of the control surface of the nozzle of LRP chamber;
4) the structure of converter includes wedge damper which eliminates spurious signals in the distant zone of the ultrasonic pulses spread.

The application of the developed converter with the direct generation of ultrasonic pulses in the body of the wall material of the nozzle of LRP chamber has allowed us to obtain new informative signals reflected from the boundary surface of environments (edge-to-air) in defective manufacture of soldered joints. For the correct interpretation of such signals, the depth markers method has been developed. The essence of this method is the application of characteristic depths markers on the OA-image (b-scan) (Fig. 2).
The obtained results allowed us to develop a technique of contact laser-ultrasonic evaluation for the soldered joints manufacture. The methodology is proposed, the main stages are considered. The peculiarities of the source data required for control are investigated. The recommendations for starting position of the means determination are formulated (Fig. 3). The control process algorithm and the way of interpretation of the results obtained for the different zones of the nozzle of LRP chamber is developed.

The results of approbation of the developed contact laser-ultrasonic evaluation method of the soldered joints of thin-walled rockets manufacture are given. The accuracy of the results obtained using the method is confirmed by the hydraulic testing of samples of the nozzle of LRP chamber before destruction, followed by metallographic studies of soldered joints.
References


