Technological efficiency of introducing the energy of the ultrasonic field in the area of processing holes in complex packages of composite materials and titanium alloys

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Abstract. The possibility of improving the quality of holes in complex packages of composite materials and titanium alloys for drilling operations by using the energy of ultrasonic vibrations introduced into the processing zone is considered. The design of two experimental installations based on a vertical drilling machine and an industrial robot is described.

1. Introduction
Currently, in the aviation industry both in Russia and abroad, there is a tendency to increase the share of the use of composite materials in various structural elements of aircraft [1]. The use of composite materials is the only possible way to reduce the weight of the structure and improve flight performance, which helps to reduce fuel consumption and increase the payload of aircraft. At the same time, parts from km-position materials of various brands are interfaced with structural elements from aluminum and (or) titanium alloys, forming complex packets. As a rule, parts of the power frame of the airframe and bypass-forming elements are made of aluminum and titanium alloys. The number of dissimilar materials in packages usually does not exceed three (titanium alloy, aluminum alloy, composite material), and the total number of layers can reach five or more. The composition of a complex package and the sequence of layers depends on the design features and purpose of the parts to be joined. The vast majority of connections are made by installing the connecting elements in pre-machined holes. Since the constituent elements of such multilayer packets have different physical and mechanical properties (for example, low thermal conductivity and a tendency to adhesion of titanium alloys, pronounced anisotropy of the properties of the composite material), therefore, during their drilling, the following defects arise: delamination, destruction, uncut fibers, tearing melting the polymer matrix, changing the shape of the holes, breaking them, the formation of burns on the treated surfaces, etc. In turn, a decrease in the quality of the holes can lead to high contact loads, a decrease in the resource, and the destruction of joints in complex packages.

2. Description of theoretical research
Significant experience has been gained in the intensification of machining processes using the energy of ultrasonic vibrations at the Regional Technological Center for Industrial Internet in Mechanical Engineering and at the Department of Innovative Technologies in Mechanical Engineering of UiSTU [2], which the authors proposed to use for drilling holes in complex packages.
Evaluation of the effectiveness of introducing the energy of the ultrasonic field into the drilling zone of complex packages of composite materials in the form of two-layer packages consisting of a sheet of titanium alloy VT-6, OST 1.90218-76, thickness $H_1$ and a sheet of composite material VKU-39 (binder PRISM EP2400 RS; carbon tape IMS 24K), $H_2$ thick in two experimental installations, created on the basis of the Proma B-1832FN / 400 vertical drilling machine and the KUKA KR16 R2010 industrial robot, equipped with an electric spindle with stepless speed control. As a spindle, a milling spindle of the GDZ-80 brand with a power of 2.2 kW (400 Hz; 220 V) with a variable speed of up to 24,000 rpm, equipped with a set of ER20 collet chucks, was used. General types of installations are presented in Fig. 1 and 2.

In the first case, ultrasonic vibrations were applied through the conductor sleeve, perpendicularly, in the second - through the titanium sheet along (parallel to) the axis of the drill. To generate ultrasonic vibrations, an ultrasonic generator UZG-641A manufactured by NPP "AVIASTEC" with a power of $R_{vy} = 0.12$ kW is used, which generates electrical signals with a frequency of 22 kHz. Further, the electrical signals entering the ultrasonic head are transformed using a piezoelectric transducer into mechanical vibrations of the same frequency and transmitted, depending on the design of the assembled experimental setup, either to the drill through the conductive sleeve (Fig. 1), or to the stage with a complex package (Fig. 2).

Figure 1. General view of the installation of the experimental setup based on a vertical drilling machine: 1 - drill; 2 - an ultrasonic waveguide with a conductor sleeve; 3 - clamping bar; 4-5 - a complex package; 6 - mounting plate; 7 – dynamometer

The installations allow experiments to be carried out with superimposed unmodulated, amplitude-modulated or frequency-modulated ultrasonic vibrations on a drill or on a stage with a complex package of a sheet of titanium alloy and composite material.

The development of research methods and experimental setups was carried out taking into account the accumulated experience of domestic scientific schools and aviation enterprises [3-6].

During the research, carbide drills SER 108MDRILL Ø4.7-0.03 mm DIN 6539 Ti-NAMITE-COATED from SGS were used, recommended for drilling workpieces from titanium and aluminum alloys, as well as non-metallic materials.
The cutting forces $P_z$, $P_y$, $P_x$ and the torque $M_{cr}$ were measured using a UDM-100 dynamometer equipped with Kyowa kfg-5-120-c1-11 strain gages. The dynamometer was fixed on the table of the experimental setup. When measuring the components of the cutting force, the electric signal from the UDM-100 strain gages was fed to the LTR EU-2 amplifier. Previously, the dynamometer was calibrated and carried out static calibration.

The diameters and deviations in various layers of the part were checked (composite material, titanium alloy was made on a DMU 50 machine using a Heidenhain TS649 measuring probe, at four different points of hole depth, which allows simultaneous estimation of roundness deviations. Assessment of the area of delamination zones, chips and flaking of the composite material Skm was calculated from the results of direct measurements of the overall dimensions of these defects on a horizontal bar comparator IZA-2.

![General view of the installation of an experimental installation based on the industrial robot KUKA KR 16 R2010 for studying the process of ultrasonic drilling: a - side view; b - top view of the treatment area.](image-url)
3. Results

An analysis of the results of preliminary experiments confirmed the positive effect of the energy of ultrasonic vibrations on the drilling process of complex packages consisting of a composite material and a titanium alloy. Currently, research is ongoing and technological preparation is being carried out for pilot tests in real production conditions for the manufacture of LA MS-21 and IL-76MD-90A units.

Thus, a methodology has been prepared for experiments based on multivariate planning for evaluating the quality of holes in complex packages of composite materials and titanium alloys for drilling operations by using the energy of ultrasonic vibrations introduced into the processing zone. The design of two experimental installations based on a vertical drilling machine and a robotic complex has been developed.

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