Vibration suppression methods at high performance drilling

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Abstract. This article discusses the possibility of suppressing vibrations when drilling holes with spiral drills. This article presents two methods of suppressing vibrations: modal analysis and modulation of cutting speed (changes in spindle speed - Spindle Speed Variation - SSV). There is a description of the considered methods with an indication of their advantages and disadvantages. The article also points out to experimental data that characterize the possibility of suppressing vibrations when drilling holes and a comparative analysis of various methods of suppressing vibrations when machining holes in samples of their structural steel. There is an assessment of the possibility of joint application of modal analysis methods and modulation of cutting speed during high-performance drilling.

1. Introduction
Aircraft engineering is one of the most advanced industries, where there are actively introduced innovative technologies and equipment. This is due to high competition, increased demands on the quality and resource of products. One of the ways to improve the competitiveness of enterprises is to reduce machine time during the machining of aircraft parts and technological equipment. This approach is based on the introduction of high-performance numerical control machine tools (NCT), which allow us to achieve high results of processing any types of materials.

One of the obstacles hindering the effective use of high-performance tools and equipment are vibrations during cutting. They lead to a deterioration in the quality of the machined surface, reduces productivity, and accelerates the wear of both the tool and the machine spindle. At the same time, the fact of the introduction of progressive elements of the technological system does not contribute to the reduction of vibrations, and in some cases even leads to their growth, due to the significantly higher frequency of spindle rotation of modern machining centers. Design features of aircraft parts, such as thin walls and canvas, significantly increase their tendency to vibrations.

In many cases, it is necessary to limit the cutting conditions during machining, or to apply various methods of vibration suppression. Now there are several ways to suppress vibrations divided into constructive and software [1-7]. Software methods should be more suitable in the manufacture of aircraft parts, since they do not require any structural changes in instrumental adjustments and clamping accessories.

In turn, among the software methods of suppressing vibrations, there are the followings:

a) application of mathematical modeling or modal analysis, charting stable cutting;

b) modulation of cutting speed, both with the help of mechanical action, and with software of high-performance numerical control machine tools.
Determining the most effective method of suppressing vibrations is an urgent task due to the high cost of aircraft parts. In this case, it is necessary to consider both the various machining processes (milling, turning, drilling, etc.) and various technological systems.

One of the most complex machining processes in terms of vibration reduction is drilling. Drilling with spiral drills is a widespread machining operation. Due to the low rigidity of the tool, the excitation of its regenerative auto-oscillations often accompanied the drilling process. Along with a decrease in the accuracy and quality of the machined surface, tool life and durability of the machine, vibrations can lead to breakage of the drill in the hole, creating additional problems for removing a broken tool. If it is impossible to achieve due to oscillations required accuracy and surface roughness of the holes when drilling, the use of additional operations such as reaming, and boring deployment sharply increases the cost of production.

The possibilities of dealing with vibrations when drilling by software methods are limited to the fact that only the change in cutting speed is practical. In most cases, it leads to a loss of productivity. A number of works consider the approaches to assigning cutting conditions when drilling, ensuring a stable process due to avoiding resonance [1-6]. The proposed approaches suggest a preliminary modeling of the cutting process using either standard software products or special programs developed in high-level languages. Some authors propose to obtain the input parameters of the process, such as, for example, the workability of materials, by conducting field experiments [7]. This method, on the one hand, increases the reliability of the simulation results, but, on the other hand, significantly increases the complexity of the work carried out.

The competing method is periodically change of spindle speed frequency over time (Spindle Speed Variation - SSV). Numerous theoretical and experimental studies of domestic and foreign scientists have confirmed the effectiveness of self-oscillation damping method [8-15]. However, this method has several disadvantages. The most significant of these is the limited frequency of the spindle, at which it performs the specified modulation parameters. This disadvantage may limit the application of the SSV method in the processing of parts from materials for high cutting speeds. Obviously, the greatest difficulties may arise when using this method when processing parts made of aluminum alloys. Cutting speeds during blade processing usually lie in the range of 1000-3000 m/min. However, when drilling with spiral drills, the cutting speeds recommended by the tool manufacturers are 80-250 m/min, which in turn makes it possible to use the SSV method even when machining aluminum parts, especially when using drills of large diameters. Moreover, there are more broad prospects for this method when processing parts are from hard-to-machine materials.

Thus, the purpose of this article is to compare such vibration suppression methods as modulating cutting speed and mathematical modeling or modal analysis when drilling holes with spiral drills.

2. Equipment and methods
We conducted the experiments on vertical milling machine tool with numerical control of model DMG DMC 635V (fig. 1). Due to the absence in the machine control system of the built-in function SSV, a special software utility proposed in the work implemented the modulation of the cutting speed. [18].This program changed the spindle speed by timer. Holes with a diameter of 9 mm were drilled to a depth of 8 mm with a feed of 0.2 mm/rev in a billet of steel 35 with a hardness of 170 HB and dimensions of 105x145x50 mm. This steel is widely used in the aviation industry in the manufacture of clamping accessories for the machining of aircraft parts. The carbide drill Sandvik R840-0900-50-A1A. As a cutting tool, we used the carbide drill Sandvik R840-0900-50-A1A. To register the vibration displacement of the work piece during the cutting process, the study used a piezoelectric contact vibrator AP85-100. Form Talysurf 200 profilometer measured the surface roughness of the holes obtained. The experiment examined the effect of vibrations on the surface quality of the holes. [19].
The experiments have taken into account the capabilities of the machine tool for the actual development of a given depth of modulation of the spindle speed with its allowable power load of 50%, given in the work [21]. Before carrying out experiments on cutting, we had a modal analysis of the technological system performed according to the method described [19]. For the accepted drilling conditions, based on its results, we constructed a diagram of areas of dynamically stable cutting with a constant speed (fig. 2). According to this diagram, we selected an unfavorable spindle speed of 3816 rev/min, corresponding to the onset of self-oscillation excitation.

At this spindle speed, we had two holes drilled. When drilling one of the holes, there was self-oscillation suppression with modulation of the cutting speed, the depth of which was 4%. In accordance with the recommendations of [21], the relative modulation frequency was taken equal to 1 per spindle revolution. When drilling the second hole, there were not vibration reduction methods.
Then we had the holes drilled at spindle speed in the center of the stable cutting areas: 4951, 4444, 4000, 3672, 3354, and 3075 rev/min. At the same time, at those speeds where it is possible to work out the modulation of the cutting speed (3672, 3354, 3075 rev/min), we had two holes drilled. When drilling one of the holes, a cutting speed modulation was applied with a depth of 4% and a relative frequency of 1 per spindle revolution. It was necessary to do to assess the effect of modulation of cutting speed on the quality of the surface of the hole, drilled in stable conditions and calculated on the data obtained by the method of modal analysis. At rotational frequencies, where it is impossible to work out the modulation of speed, the machine spindle (4951, 4444, 4000 rev/min) we had one hole drilled through. Measurement of surface roughness was for all holes obtained during the implementation of the experiment.

3. Results and discussion
According to the results of the experiment, we had a diagram constructed, which shows the roughness value for various processing conditions (fig. 3).

![Figure 3. The surface roughness of the holes under different processing conditions](image)

The surface quality of the hole drilled at a speed of 3816 rev/min using modulation of the cutting speed is two times higher than that of the hole drilled without applying modulation (Ra =0.95 μm vs. Ra=1.9 μm). The surface roughness achieved is better than the surface roughness of the holes processed at 4000 and 4444 rev/min, calculated using the modal analysis method (Ra=0.98 μm and Ra=1.25 μm). This testifies to the effectiveness of the method of modulating the cutting speed in suppressing vibrations during drilling.

Modulation of cutting speed, in some cases, can improve the quality of the machined surface of the holes obtained at rotational frequencies calculated using the modal analysis method. These experiments conducted at rotational frequencies of 3354 and 3672 rev/min confirmed it. However, such results are not always stable. For example, when drilling holes at a speed of 3075 rev/min, the surface quality of the hole obtained using modulation of the cutting speed is worse than the quality of the hole obtained without using this method. The fact that the modulation parameters for drilling holes at different frequencies of rotation of the spins were the same can explain it. In turn, in some studies, we noted that different modulation parameters are used for different spindle speeds to ensure the best surface quality.
of the holes. In some cases, modulation of the cutting speed at a certain depth and modulation frequency can enhance self-oscillations, thus worsening the quality of the surface to be treated.

4. Conclusion
The vibration reduction methods considered in this paper using modal analysis and software modeling of cutting speed are effective and allow you to achieve a stable drilling process and a given hole surface quality. However, these methods have the following features considered when using them in specific technological systems.

1. Cutting speed modulation is not applicable at high spindle speeds. The specific cut-off frequency depends on the features of the spindle of the milling machine tool used, primarily on its inertia. For example, for the model DMG DMC635, the maximum rotational speed of its spindle is 4000 rev/min. Consequently, the use of cutting-speed modulation to suppress self-oscillations is almost impossible when drilling aluminum alloys that are widely used in aircraft manufacturing. In addition, the applicability of modulation of the cutting speed decreases with decreasing diameter of the drill used.

2. Modal analysis allows calculate the rotational speeds that ensure a stable cutting process without restriction on their value. This makes this method universal and ensures its wide applicability for any aviation materials and any drill diameters.

3. It seems promising jointly apply the methods of modal analysis and modeling of cutting speed. Assigning modulation parameters that are optimal for a particular technological system can improve the surface quality of the holes. Moreover, the modulation of cutting speed can change the shape and location of stable cutting areas for a specific technological system. Further studies to determine the recommended modulation parameters both can confirm this hypothesis when working on different cutting conditions and when processing a large range of different sizes and types of materials.

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