

New Vibration System for Advanced Drilling Composite-Metallic Stacks

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ABSTRACT

To reduce the weight of aero structures, composite materials are combined with metallic parts. These multilayer materials are one-shot drilled during the assembly process. During drilling, interactions appear between the different layers creating new quality issues. To improve machining efficiency, the portable semi-automated drilling units commonly used for such operations need to be upgraded. For this purpose, vibration systems have been recently introduced into drilling units. This article first considers the effect of the reciprocating axial movement on the quality of the machined surface, then focuses on the effect of the oscillation parameters (frequency, magnitude) on the cutting process (cutting forces, thermal load, etc.). Experimental and numerical results are used to find the method that produces the optimal vibration setting. This method is then applied to the case of drilling composite-metallic stack. We conclude that specific vibration parameters need to be set up according to the type of material drilled (composite, metallic). A new vibration system concept has therefore been specifically developed to adapt the oscillation magnitudes to each kind of material. The entire mechanism of the system is shown and analytically modeled. In conclusion, the article describes briefly the auto-adaptive drilling technique for an understanding of the benefit of the new vibration system when associated with this technique.

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INTRODUCTION

Improvements in aerospace structures have led to the use of different types of materials in conjunction, in order to increase the strength-to-weight ratio. To do so, layers of metal (e.g. aluminum, titanium) and composites (e.g. Carbon Fiber Reinforced Plastic) are stacked up to form multi-materials.

Because of the large dimensions and the complex geometries of the structure elements, the multi-layer material has to be drilled one shot to minimize errors and to obtain tight tolerances during the assembly process [1]. However, machining properties can differ from one material to another and make drilling operations more complex: quality criteria (roughness, burr height, composite push-out, etc. [2]) are difficult to achieve, tool lifetime is shortened and machining costs increase.

Whenever possible, priority is given to the drilling configuration where composite layers are supported by metallic parts, in order to prevent delamination damage [3]. However, this method involves an efficient evacuation of hot metallic chips (usually under ribbon forms) to prevent jamming in the drill flutes which can lead to tool breakages and damage to the composite part (such as scratches, chamfer at interface, etc.) [4]. Research results have therefore proposed changes in drill bit geometries and cutting parameters [4,5,6,7,8]. However, these modifications are usually not enough to guarantee well-broken chips and so the portable semi-automated drilling equipment (so-called drilling units), commonly used for such operations needs to be upgraded. In this regard, vibration-assisted drilling (VAD) seems hopeful.

PRESENTATION OF VIBRATION-ASSISTED DRILLING

Overview of the Different Vibration Technologies

In the early 50's, Prof V.N. Poduraev, from the Bauman Institute of Moscow, was the first to point out the major interest of the vibration benefits during the machining process. For drilling operations, the vibration system gives the tool a reciprocating axial displacement in addition to the feed rate ([figure 1](#)).

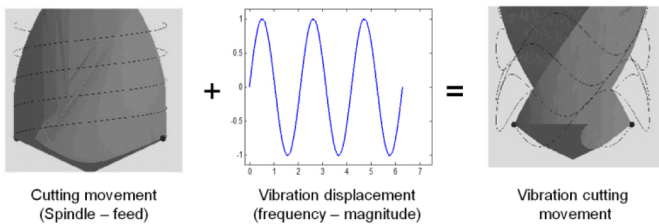


Figure 1. Principle of vibration-assisted drilling

This movement is characterized by the magnitude and the frequency of oscillations. Vibrations are generated either by amplification of the ploughing vibration (self-excited vibration), or by imposed displacement (force-excited vibration). Many studies have looked at the different aspects of VAD [[9,10,11](#)]. Vibration system technologies can be roughly differentiated into three groups (cf. [figure 2](#)). The choice of system depends on the range of frequencies and the vibration magnitudes. Drilling units require force-excited oscillators ([figure 2](#), category 2), since the vibration system has to be self-sufficient (no external energy supply) and able to provide steady oscillations whatever the drilling position.

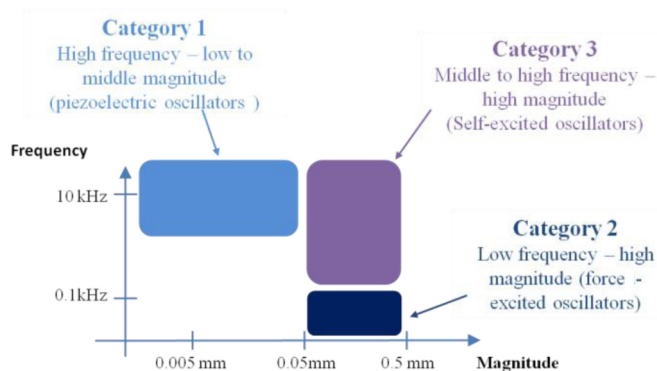


Figure 2. Setting range of vibration parameters

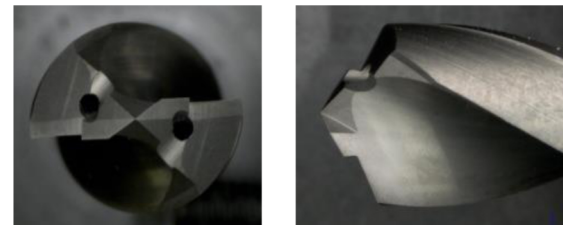
Regardless of the system used, the first part of our work consisted in analyzing the effect of VAD on the machining quality, using conventional parameters.

INFLUENCE OF VAD ON DRILLING PERFORMANCE

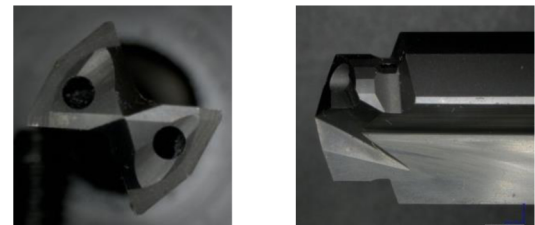
As explained in the introduction, VAD plays the role of chip breaker and prevents damage due to the evacuation of long metal chips. However, adding vibration may have side effects, especially on the surface quality. The experiments presented here, aim to highlight the impact of VAD.

Experimental Setup and Protocol

To test the effect of VAD, a series of 9.52 mm diameter drillings were carried out on a CFRP/AA7175 stack, with and without vibration system. Micro-lubrication was sprayed on the cutting area through the center of the tool. The same experiment was repeated for both tool geometries ([figure 3](#)). [Table 1](#) describes the experimental protocol in detail.



a. Tool 1 - Two-fluted drill with double point



b. Tool 2 - Two-fluted stepped drill without helix angle

Figure 3. Different tool geometries

Table 1. Experimental protocol

#	Cutting parameters	Tool	Vibration parameters
1	Vc : 18 m/min f : 0.058 mm/rev	No.1	25 Hz – oscillations magnitude 0.2 mm
2	Vc : 18 m/min f : 0.058 mm/rev	No.2	25 Hz – oscillations magnitude 0.2 mm
3	Vc : 18 m/min f : 0.058 mm/rev	No.1	Without vibration
4	Vc : 18 m/min f : 0.058 mm/rev	No.2	Without vibration

All the tests were performed at the Mechanical and Engineering Institute (I2M) of Bordeaux (France) where a special bench has been designed to measure the complete mechanical torsor (including 3 components of thrust force and 3 of torque). In addition, the heat diffusion into the workpiece was observed using a thermal infrared camera. [Figure 4](#) gives an overview of the experimental setup.

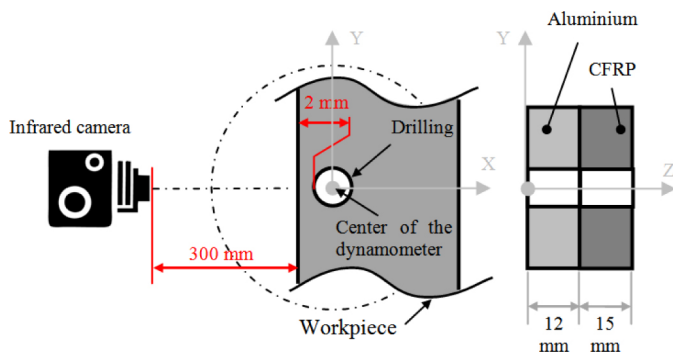
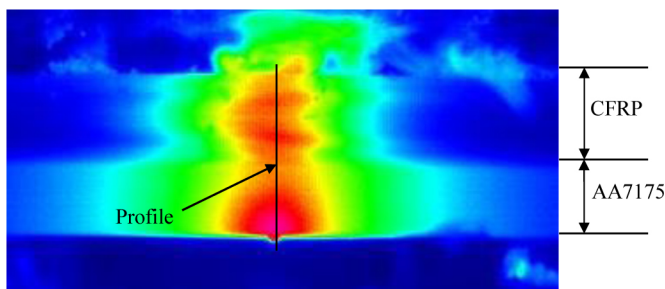


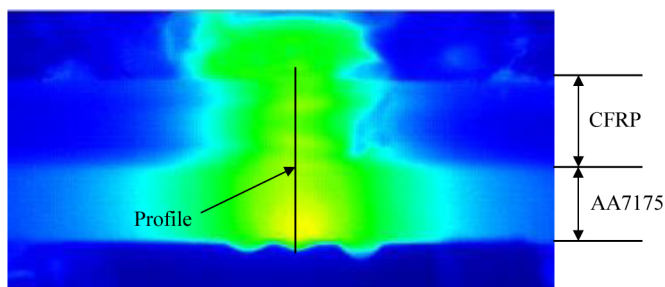
Figure 4. Experimental setup

Influence on Thermal Aspects

Observation of heat transfer into the workpiece is an interesting aspect of the process. For instance, it gives an understanding of the origin of quality defects linked to temperature, such as burn, burr, push out, etc. Due to the difficulty in measuring the emissivity of both materials, absolute temperature could not be obtained, hence the thermal results come from a comparative study. Figure 5 compares the heat diffusion during drilling exit of tool no.1, for both vibration conditions (with and without vibration system). It shows the benefits of using the vibration system in terms of heat level.



a. Without vibration system

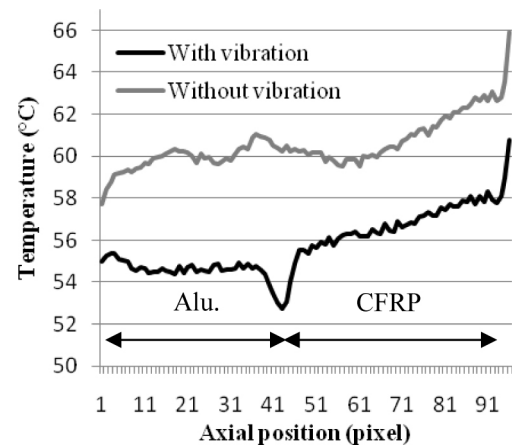


b. With vibration system

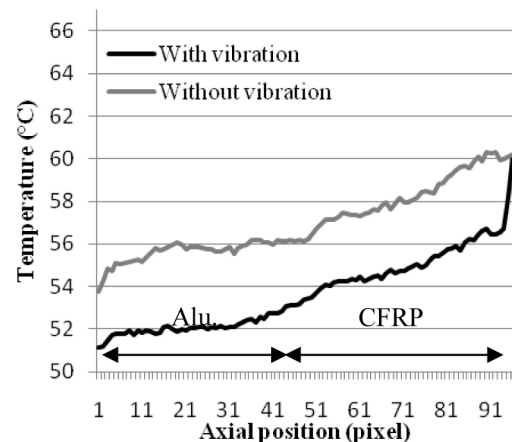
Figure 5. Thermal profile during the drilling process

Deeper analyses of the effect of VAD on heat generation are shown in figure 6 with the evolution of the temperature along the profile (figure 5). From these two graphs, it is obvious that oscillating cutting provides benefits concerning the heat flux received by the workpiece. The reason for this difference is not clear. Three assumptions can be made: axial

displacement creates a natural cooling of the tool by the air; the oscillations improve the lubrication circulation, or, the heat decreases as the instant feed rate increases.



a. Profile for the tool 1



b. Profile for the tool 2

Figure 6. Temperature variation along the profile for both tools

For the composite part, this drop in temperature reduces the risk of delamination and push out. Moreover, it decreases the thermally affected zone, and helps to prevent matrix degradations. Concerning the metal part, improvement at the hole exit can be expected. If this were the case, it would confirm the results found in the literature [12,13] which show that low frequency vibratory techniques reduce burr formation.

Influence of VAD for Aluminum Machining

The main quality criteria associated with aluminum machining are: diameter, roughness and burr height. Figure 9 evaluates the effect of VAD on all these criteria. The same comparison is made for the two tool geometries.