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Dynamic analysis of the forced vibration drilling process

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Abstract

For aircraft application, the mechanical assembly of composite and metallic structures using fastener (rivet, nuts and bolt) remains the preferred technology. For aeronautical structure, it is then necessary to drill a huge amount of holes both in the composite and the metallic parts. For CFRP/Ti6Al4V stacks, the drilling remains a critical issue. Indeed the abrasive wear and the thermo-mechanical stress induced by the cutting process lead to a fast damaging phenomena on the tool. To cope with the high quality standards required on the drilled hole, it is necessary to limit the burr height, the delamination of the composite, the roughness and the diameter tolerance. One of the proposed technical solutions is the forced vibration drilling. This process makes it possible to generate segmented and easy to evacuate chip without overloading the cutting tool. This paper presents a new vibration assisted device (VAD) which allows the adjustment of the amplitude of the forced vibration. A dynamical model is developed to optimize the vibration amplitude during the drilling process. This model is based on the identification of the static and the dynamic behavior of the VAD. An experimental protocol using monitored drilling tests was developed to identify the several parameters of the dynamical model. The good correlation between the simulation and the experimental results allows the validation of the proposed methodology.

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Keywords: Vibration drilling, Forced-vibration, Ti6Al4V, CFRP.

1. Introduction

To improve the weight to stiffness ratio, recent aeronautical structures use multi-layer material combination. The joining of those assemblies is most often realized thanks to mechanical fastener. Thus a large number of holes are needed to set the numerous rivets and bolts. In many cases, the multilayer assemblies need to be drilled "one shot" in order to respect the alignment of the drilled holes. To cope with the quality standards associated to the drilling process, new technological issues have emerged. The respect of the quality and the life span of the drilling tools have become a crucial issue due to the abrasive wear of the composite and the thermo-mechanical stress induced by the titanium machining. The different layers have to be drilled simultaneously and meet the quality criteria such as diameter tolerance, roughness, and burr height while avoiding the delamination of the composite [1].

Processing such materials needs to investigate several different machining technologies such as orbital drilling and forced vibration drilling [2]. Some improvement have been also conducted on the drilling tools (material, coating, edge finishing) and the lubrication condition. Another solution is to modify the cinematic of the drilling process. For this purpose, a technology based on vibration assisted drilling is presented. Several types of vibration assisted device have been studied and a comparative study can be found in [3, 4, 5]. This paper focuses on a dynamic study of a new patented vibration assisted device [VAD][5]. For drilling operation, the chip fragmentation is one of the key issue to improve the hole quality, the tool life and the process stability [6, 7]. The integration of a chip breaker on the tool geometry makes it possible to avoid continuous chip formation. In the case of deep hole in ductile materials such as the Ti6Al4V, the chip fragmentation remains critical. Other more effective techniques, such as peck drilling cycle or high pressure lubrication have been developed. For the assembly lines, that

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process are sometimes impossible to use due to the proximity with other parts (electrical wires for example). Compared to these machining techniques, the drilling process based on forced vibrations allows an effective chip fragmentation. Another advantage is that this solution decreases the heat generated at the cutting tool/chip/workpiece contact [6]. In the case of deep drilling, the chip management monitoring are critical. The novelty of this research is represented by the integration of a vibration assisted device (VAD) for drilling application. This paper presents a detailed dynamic characterization of the VAD over the operation frequency domain.

2. Vibration assisted device (VAD): cinematic description

In the present approach, the VAD is a system developed to address drilling machining with the purpose to fragment chips during cutting process. The machine is build in-house and the paper discusses theoretical and experimental aspect regarding the dynamic behavior of the DVS. The technological solution provides the possibility to set the amplitude of forced vibrations, feed and rotational speed for drilling application. These functions were the main improvement underlying the patent proposed by the research team of Materials Process Interaction Laboratory (MPI) of Institute of Mechanics and Materials Bordeaux (I2M) [5].

The vibration assisted drilling system has been initially designed for portable semi-automated drilling units. Such drilling machines are powered by a single pneumatic motor. This motor generates both spindle speed and axial feed rate of the tool [5, 6, 7]. The spindle is engaged into rotation through the upper gear set. A pin linking the upper and lower gear sets, allows the lower gear set to rotate. The rotation of the screw joint gear makes the spindle move forward. The feed rate is set up by the velocity differential between the spindle and the screw joint. Unlike other existing vibration systems, this patented VAD does not require any additional components. The operating principle of this new mechanism is to generate a periodical phase-shift between the two sets of gears. A displacement of the axis of gear 2 is created while maintaining contact between gears 2 and 3 (Fig. 1). The result is a misalignment or an eccentricity E (Fig. 1) between the axis of the first two gears.

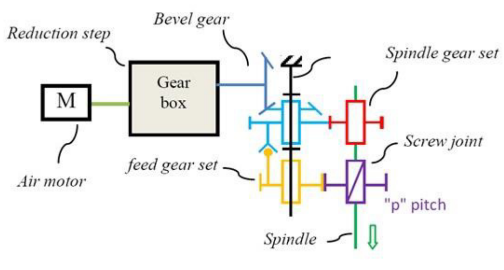

Fig. 1. Cinematic description of the drilling system [1, 2].

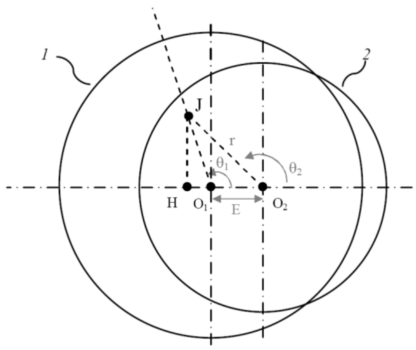

Fig. 2. Geometrical parameters [1, 2].

This misalignment of those two axes induces a variation of the distance between the pin center (J) and the axis of 1 (O_1). Therefore, the angular position of 2 will fluctuate around the angular position of 1 [1, 2].

To investigate the VAD performance, a dynamic study has been conducted. It intended to determine the dynamic characteristics to optimize the vibration parameters (amplitude, frequency) for drilling machining.

3. Experimental characterization

To highlight the dynamic behavior of the VAD, an experimental protocol was designed and built. The dynamic analysis is divided into four separate parts: static load test, frequency impact test, dynamic measurement during rotational speed on the air, and a dynamic analysis during a drilling process.

3.1. Static analysis

A static analysis is performed to evaluate elastic behavior of the VAD and to determine the direct dynamic stiffness parameters. On the developed test bench, three non-contact displacement sensors were used (figure 4). A displacement sensor is positioned on the workpiece block *(DWB)*, another sensor is positioned to measure the relative displacement of the spindle-screw *(DS)* and the last one is used to measure the overall deformation of the entire frame *(DBT)*. For the elastic response of the system a calibrated spring is used for the loading and unloading test.

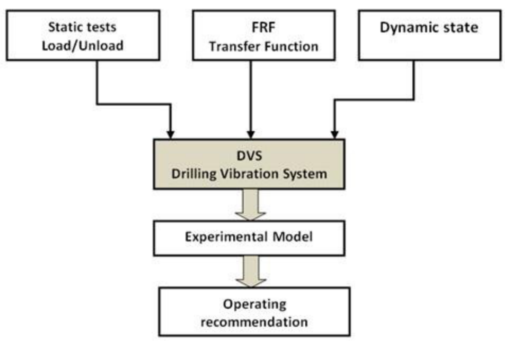

Fig. 3. Research approach.