

Self-Adjusting Cutting Parameter Technique for Drilling Multi-Stacked Material

Jeremy Jallageas
NOOV Technologies

Matthieu Ayfre
Aquitaine Science Transfert

Mehdi Cherif, Jean-Yves K'nevez, and Olivier Cahuc
University of Bordeaux

ABSTRACT

This study investigates the self-adjusted cutting parameter technique to improve the drilling of multi-stacked material. The technique consists in changing the cutting strategy automatically, according to the material being machined. The success of this technique relies on an accurate signal analysis, whatever the process setting. Motor current or thrust force are mostly used as incoming signals. Today, analyses are based on the thresholding method. This consists in assigning lower and upper limits for each type of material. The material is then identified when the signal level is stabilized in between one of the thresholds. Good results are observed as long as signal steps are significantly distinct. This is the case when drilling TA6V-CFRP stacks. However, thrust force level remains roughly unchanged for AA7175-CFRP stacks, leading to overlapping thresholds. These boundary limits may also change with tool geometry, wear condition, cutting parameters, etc. The thresholding method is therefore not optimal for industrial uses.

The paper presents a new method, able to differentiate composites from metallic materials, in real-time and independently of any process parameters (drill geometry, tool wear, etc.). The proposed approach based on Discrete Wavelet Transform (DWT) is able to detect specific frequency characteristics generated by material cutting. Using this method, improvements can be made to the self-adjusted cutting parameter technique for multi-stacked drilling application. Results are validated experimentally using thrust force signals measured while drilling various multi-materials under different process parameters.

CITATION: Jallageas, J., Ayfre, M., Cherif, M., K'nevez, J. et al., "Self-Adjusting Cutting Parameter Technique for Drilling Multi-Stacked material," *SAE Int. J. Mater. Manf.* 9(1):2016, doi:10.4271/2015-01-2502.

INTRODUCTION

Improvements in aerospace structures require different types of materials to be used in conjunction, in order to increase the strength-to-weight ratio. To achieve this, layers of metal (e.g. aluminium, titanium) and composite (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, each layer of the multi-material has to be drilled simultaneously to minimize errors and to obtain tight tolerances during the assembly process [1]. However, machining properties differ from one material to another and make drilling operations more complex. Firstly, quality criteria (roughness, burr height, composite push-out, etc. [2]) associated with the hole are difficult to achieve. Secondly, tool life time is shortened and machining costs tend to increase.

To improve multi-material drilling, research tends to optimize drill bit geometry and cutting parameters [3,4,5,6,7]. Other studies consider the use of vibration-assisted drilling to solve the problem of chip evacuation [8]. This paper focuses on the self-adjusted cutting parameter technique for drilling multi-stacked material. A new method, currently patent-pending, is hereafter described to help material recognition.

CUTTING PARAMETERS FOR DRILLING MULTI-MATERIAL

Aerospace structures are mainly made of titanium (TA6V), aluminum (2024, 7175) and composite (CFRP). The literature shows that titanium requires a low cutting speed and positive feed rates to decrease tool engagement time [1,5]. In contrast, the optimum drilling process for CFRP is drilling at high speeds and low feeds to prevent, especially, delamination and push out [2]. Cutting needs accurate cutting parameters to ensure well-shaped chip ribbons and to

avoid burr formation [1,3]. When these results are extended to a drilling diameter of 9.52mm, the setting ranges of cutting parameters for each material can be represented as following (Fig. 1).

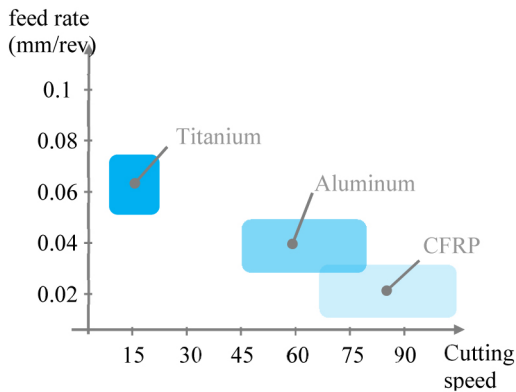


Fig. 1. Setting range of cutting parameters based on the material, for a 9.52mm tool diameter

As can be seen in Figure 1, there is no real common domain between the different areas. This becomes an issue when drilling a multi-material composed of two or three different types of material in one machining operation, especially when it includes a titanium layer. To deal with this, two solutions already exist:

- The first consists in identifying the optimal cutting parameters for the materials which compose the stack and the drill bit geometry used. The best setting found will remain the same during drilling. For a Titanium-CFRP stack, the cutting speed setup is slow, to meet Ti requirements, but the feed is kept low to prevent CFRP delamination. This method is convenient for positive feed drilling units or other portable pneumatic drill machines because they have no control loop (Fig. 2a).
- The second solution consists in adjusting the cutting parameters according to the position of the drill in the workpiece. Thus, a suitable cutting strategy can be defined as if each material were being drilled separately (Fig. 2b). This technique is applied on machines equipped with a numerical controller, such as CNC machines or electric drilling units. However, this approach involves knowing in advance the composition of the multi-material. But the stacking sequence and the thickness of each layer may often vary, depending on the drilling location. In consequence, production management is becoming more complicated and the risk of using a non-adapted machining program is high.

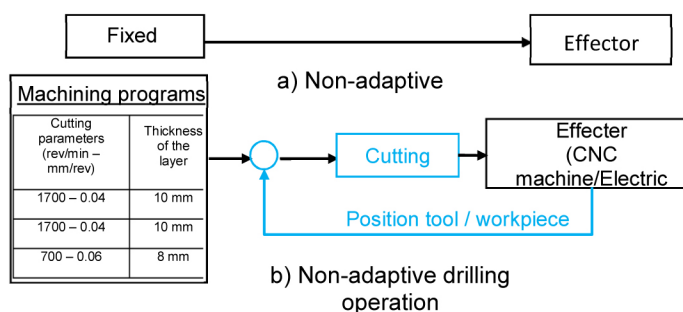


Fig. 2. Description of the two process flows for drilling multi-material

To overcome this difficulty, a recent technique called “self-adjusted cutting parameters” has appeared. The aim of this technique is to adjust the cutting parameters automatically, as the drill penetrates into the workpiece, and without knowing the composition of the multi-material beforehand. The drilling process is monitored by measuring a physical variable. The signal obtained is then analyzed into two sub-processes:

- Detection of the different types of transition (tool entry, layer interface and tool exit).
- Recognition of the drilled material.

After the analysis is completed, the system should be able to identify the material then automatically adapt the cutting parameter, based on its preset machining strategies. Figure 3 gives an overview of the entire system.

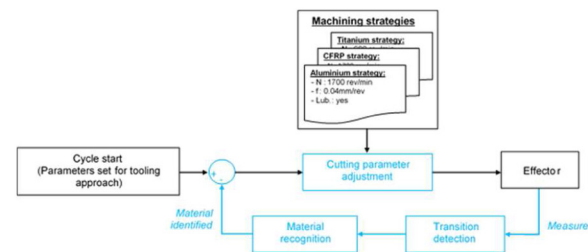


Fig. 3. Overview of the self-adjusted cutting parameters drilling technique

To obtain a powerful system, the following specifications have to be respected:

- The analysis has to be done in “real-time”.
- The analysis has to be robust and not influenced by any changes in tool geometry or wear, machine, environment, etc.

In the following, only the thrust force (F_z) will be considered as a physical variable for the monitoring system. However, other types of signal might be used, such as acoustic sensor, electrical power consumption, etc

DETECTION OF TRANSITIONS

The aim of this first phase consists in detecting the different types of transition (Fig. 4):

- Type I: air to workpiece. This transition coincides with the first tool-workpiece contact.
- Type II: material to material. This occurs when the tool exits from one layer and enters another.
- Type III: material to air. This third type of transition appears when the tool exits from the last layer.

A transition can be defined as the shift from one “stable” state to another. From this definition there are two resulting properties. Firstly, the level of the thrust force measured at time t is different from that measured at time $t-1$. Secondly, the evolution of the signal

must be brief and located in time. Therefore, it is important to make the difference between transitions from other phenomena, such as tool wear or unexpected thrust peaks.

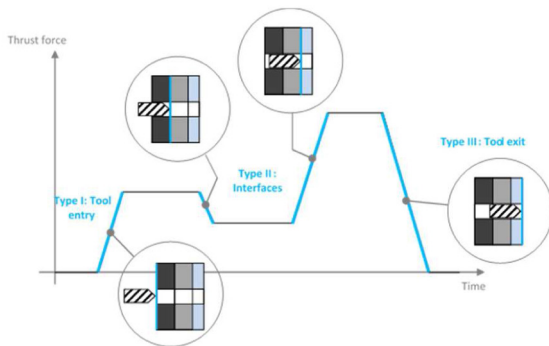


Fig. 4. Schematization of the different transitions

To highlight the transitions, a low pass filter can be applied on the row signal to isolate the constant part of the thrust force. It can be seen that the tool entry is characterized by an increase in thrust force (F_z), in contrast to the tool exit, where F_z becomes close to zero.

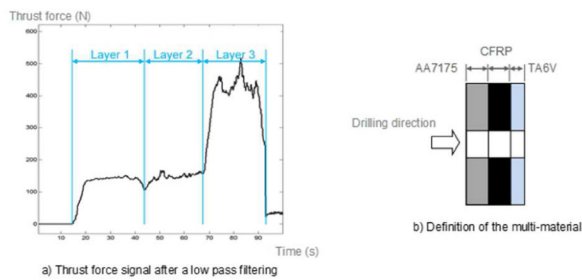


Fig. 5. Example of thrust force measured while drilling a multi-material (Alu.-CFRP-Ti.) with a 9.52mm diameter tool at constant feed and speed (N:600 rev/min - f:0.038 mm/rev).

However, identifying the interfaces is rather more complicated. To illustrate the difficulty, several tests have been done on different multi-materials (Fig. 6).

The results show a good correlation between wide variations in thrust level and interfaces. This observation is linked to the machinability classification of each material (Fig. 7). On the one hand, an increase in F_z while drilling means that an interface m_n to m_{n+1} occurs (e.g. CFRP/Alu, Alu/Ti, CFRP/Ti). On the other hand, a decrease in thrust force results in an m_n to m_{n-1} interface. In their study, Gouleau et al. [10] reached the same conclusion.

Furthermore, one can notice some signal slots at the interface (Fig. 6b and 6d). This short decrease in F_z is usually due to a gap between two layers, which temporarily interrupts the cutting process. In addition, during the period preceding the tool exit, F_z increases slightly. This may be due to a springback of the thin layer of the rest of the material that still remains to be drilled. Taking these irregularities into account improves the accuracy and the strength of the algorithm for the transition detection.

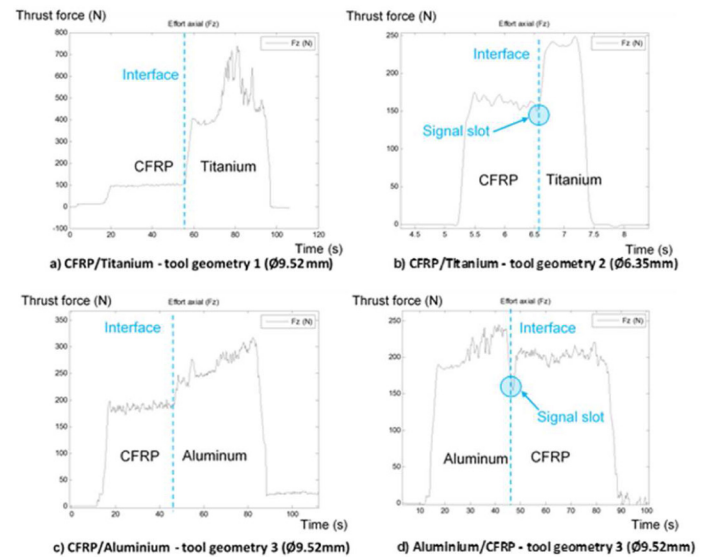


Fig. 6. Filtrated thrust force measured during drilling different multi-materials, stacking sequences (CFRP/Alu or Alu/CFRP) and tool geometries.



Fig. 7. Classification of machinability in terms of thrust force

MATERIAL RECOGNITION

The second phase of the system aims to recognize the material drilled. It must be a “blind” identification, i.e. none of the process parameters is known (e.g. stacking sequence, diameter of the tool etc.).

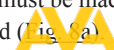
Unlike transition detection, this phase is a critical step in the self-adjustment drilling process. Indeed, a mistake in identification can lead to hole defects or tool breakages. Given the complexity of the problem, we have restricted the study to differentiate two types of material: metallic and composite. Based on the information collected in the literature [11], two methods can be considered to distinguish composite from metallic: the thresholding method and the slope analyzing method.

Literature Review of Material Recognition Method

Thresholding Method

The principle of this method is based on several studies [6,10,12,13]. The results show significant variations in thrust force level depending on the material drilled (TA6V, 7175 and CFRP). As we have seen (Fig. 7), for a drilling configuration F_z will be highest when machining titanium, then decrease in the aluminum layers and reach a lower level in the composite.

To implement this method, the F_z level extrema measured in each material used in the stack must be identified. The minimum and maximum values (threshold values) will define a specific thrust range and then be associated to a material. Thus, during drilling, the identification of the material must be made according to the range in which the signal is established (Fig. 8a).



Documents

Document Sharing Hub