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Multiple sensor monitoring in drilling of CFRP/CFRP stacks for cognitive tool wear prediction and product quality assessment

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Abstract

Drilling of stacks made of two overlaid carbon fiber reinforced plastic (CFRP) composite laminates for aeronautical assembly applications is investigated through multiple sensor monitoring and sensor fusion technology. An experimental testing campaign under different drilling conditions is carried out using a monitoring system endowed with thrust force and torque sensors. Advanced signal processing and analysis in the frequency domain are employed for feature extraction and selection to construct sensor fusion feature pattern vectors to be fed to artificial neural network based cognitive paradigms for the identification of correlations with tool wear development.
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1. Introduction

In the aeronautical industry, the reduction of aircraft weight is becoming an increasingly important aim both to meet environmental requirements such as lower emissions and to reduce management costs through lower fuel consumption. Therefore, new structural architectures have been developed through the use of innovative materials including composite materials such as carbon fiber reinforced plastics (CFRP) [1].

Most frequently, CFRP parts are assembled to other parts using mechanical joints such as rivets due to the difficulties to realize welding operations or adhesive joints. For this reason, drilling is the most widespread CFRP machining process in the aeronautical industry. Nevertheless, drilling of CFRP parts is a challenge for manufacturing engineers due to the anisotropic nature of the material, the very rapid tool wear caused by the abrasive carbon fibers and the high concentrated efforts and vibrations that may cause severe damages affecting material integrity, processed surface quality and aspect [2-4].

Although several applications of non-traditional machining processes, such as laser [5] and water-jet machining [6], have been developed for hole-making of composite material laminates, mechanical drilling operations using conventional or special drill bits are primary applications for composite laminates.

With the aim to improve the quality of the drilled holes, a number of research studies have been conducted to investigate the correlation between drilling process parameters, including cutting speed, feed rate, drill bit geometry and composition, and output product quality [7-10]. Efforts have been also spent in the development of models of the thrust force produced during drilling operations, which has been found to directly affect the quality of drilled holes [11-13].

In aeronautical industry, where tight geometrical and dimensional tolerances and surface integrity are required, current practice for CFRP drilling consists in manual drilling processes in which tools are replaced well in advance to avoid any risks of material damage. To fully exploit the tool life and increase productivity while preserving the integrity of the workpiece, on-line real time process monitoring is required, allowing for a reliable in-process control of tool wear growth critical for hole quality assessment and for the automation improvement of the drilling process [14].

In this work, multiple sensor monitoring based on the

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acquisition of thrust force and torque sensor signals is implemented in drilling of CFRP/CFRP stack laminates for the aeronautical industry with the aim to realise cognitive tool wear estimation and hole quality assessment. An advanced methodology for sensor signal processing and feature extraction in the frequency domain is implemented to develop an artificial neural network (ANN) based cognitive paradigm for pattern recognition with the aim to find correlations between the extracted frequency domain sensor signal features and tool condition and hole quality [15-16].

2. Experimental setup

2.1. Workpiece details

The workpiece to be employed for the experimental drilling tests is represented by CFRP/CFRP stacks, with the aim to reproduce the real aeronautical industry operating conditions, in which the CFRP laminates are superimposed and then drilled together to allow for subsequent riveting. The CFRP/CFRP stacks under study are composed by two overlaid symmetrical and balanced laminates. Each laminate has a thickness of 5 mm and is made up of 26 prepreg unidirectional plies arranged according to the following stacking sequence $[\pm45_2/0/90_4/0/90/0_2]_s$. A very thin fiberglass/epoxy ply, reinforced with 0°/90° fabric (areal weight 80 g/m2) is laid on the top and bottom of each laminate. The prepreg plies are made of Toray T300 carbon fibres and CYCOM 977-2 epoxy matrix. Laminates were fabricated by hand layup, vacuum bag moulding and autoclave curing (180 min at 180 °C and 6 bar). The surface texture of the laminates on the bag side is very irregular compared to the mould side. Therefore, the two CFRP laminates of each stack were placed with the bag side in contact to realize the drilling process in the severest possible conditions.

2.2. Experimental procedure

In order to identify the influence of the cutting parameters on the machinability of the composite material under study in terms of tool wear and quality of the holes, different cutting conditions were adopted for the experimental drilling tests: three feed values (0.11 mm/rev, 0.15 mm/rev and 0.20 mm/rev) and three different spindle speeds (2700 rpm, 6000 rpm and 9000 rpm) were employed, as shown in Table 1. For each experimental condition, 60 consecutive holes were realized with the same drill bit. A 2-flute 6.35 mm diameter with 125° point angle twist drill made of tungsten carbide (WC) was used in the experimental campaign. Fig. 1 reports a microscopic view of the tool before drilling. A CNC drilling centre was used for the monitoring of CFRP/CFRP stacks drilling.

Table 1. Experimental testing conditions.

		Spindle Speed (rpm)		
		2700	6000	9000
Feed (mm/rev)	0.11		X	
	0.15	X	X	X
	0.20		X	

Fig. 1. Twist drill employed for the experimental drilling tests.

2.3. Multiple sensor monitoring system

The multiple sensor monitoring system employed during the experimental drilling tests consisted of a force and a torque sensor. The thrust force along the z-direction, F_z, was acquired by a Kistler-9257A piezoelectric dynamometer, while the cutting torque about the z axis, M_z, was acquired using a Kistler-9277A25 piezoelectric dynamometer. The analogue signals acquired by the force and torque sensors were digitalized at 10kHz sampling rate by a National Instruments NI USB-6361 DAQ board. This sampling rate was chosen based on the Nyquist-Shannon sampling theorem.

3. Sensor signals preprocessing and segmentation

The raw sensor signals acquired during the drilling tests included signal portions corresponding to the time instants before and after the actual machining process. With the aim to extract information only when the tool is actually removing material, signal segmentation was carried out in the following way [15]: examination of the raw signal to identify the actual machining portions; removal of the initial and final signal portions, and final verification and acceptance of the segmented signal (Fig. 2). The identification of the start and end of the actual machining portion was carried out on the basis of thresholds fixed on the moving average of the thrust force signals. The torque signals were segmented at the same start and end points of the thrust force signal, obtaining segmented signals with equal duration and number of samplings.

Fig. 2 shows that a drop of thrust force occurs at the interface between the two laminates, which are in contact with their bag sides characterized by very irregular surfaces.

Fig. 3 shows the thrust force signal with increasing number of holes for the operating conditions 6000 rpm - 0.15 mm/rev. It is possible to observe that the thrust force significantly grows with increasing number of holes, ranging from 50 N for hole n.1 to over 200 N for hole n.60.

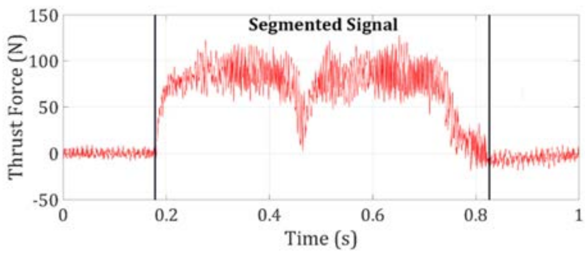

Fig. 2. Segmented signal of thrust force for hole n. 6 at operating conditions 6000 rpm – 0.15 mm/rev.

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