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Development of a new drilling tool for machining of CFRP-metal-composites

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Abstract
Materials made of carbon-fibre-reinforced-plastic (CFRP) get more and more important in the field of automotive and aircraft manufacturing. They are often combined with metals, like Aluminium, Steel or Titanium to improve their mechanical properties. These two materials are therefore combined with joint elements like bolts or rivets. It is necessary to drill both components simultaneously in one processing operation to ensure the best fitting conditions. An ideal machining of both components cannot be ensured with conventional drilling tools since both materials have different requirements concerning the tool geometry and cutting parameters. This can lead to defects in the CFRP and expensive rework is inevitable. This is an issue particulary in aircraft manufacturing, where high demands are placed on the dimensional and shape accuracies of the workpieces.
The given paper shows the development of a new drilling tool for machining of CFRP-metal composite materials. To approach the contrary requirements of each material, the drilling tool will work in two operating directions with multiple cutting edges. In order to prevent rework, a special adjustable cutting edge is used to machine the CFRP-layer. Therefore two concepts are developed. The first one uses a microcontroller-driven stepper motor, integrated in the tool body. The other uses compressed air to move a piston, connected to a positioning mechanism that moves the cutting edge to the final diameter. Both concepts were designed, manufactured and examined.

Drilling in two operating directions; multi-material-machining; mechanical manufacturing processes

1. Introduction

In the field of automotive and aircraft manufacturing, carbon-fibre reinforced plastics (CFRP) are becoming increasingly important [1]. Due to their high stability with simultaneous low density, these materials are perfectly suited for lightweight constructions. To improve their mechanical properties, these are often combined with metals to hybrid materials. These are used for load-bearing structures, e.g. in aircraft construction. For a save connection, both materials are drilled simultaneously and fitted with joint elements like bolts or rivets. This machining operation constitutes a huge challenge to the tools, as both materials have different requirements concerning the tool geometry and cutting parameters [2]. Therefore, defects on the CFRP can occur and expensive rework is inevitable. Conventional tools for machining of hybrid materials usually end with a bore diameter of < 15 mm. To solve this problem, a drilling tool with multiple cutting edges for each material component was developed. This is intended to machine high-quality bores in the hybrid material in two working directions with a high degree of accuracy and repeatability.

2. Solution approach

Initially, machining tests were carried out in the individual components CFRP, steel (DP600) and aluminium (EN-AW 7022) in order to identify suitable tool geometries and cutting parameters and to analyse the processes during machining in detail. During this experiments, it was shown, that there are no overlaps neither in the cutting parameters, nor in the tool geometries. The best results for machining of steel and aluminium were gained with cutting speeds of v_c = 100 m/min, feed rates of f = 0,17 mm/rev and a point angle of 118°. It was found, that by using a cutting speed of v_c = 150 m/min, a low feed rate (f = 0,02 mm/rev – 0,07 mm/rev) and a point angle of 90°, defects in CFRP could be held in a small area around the bore.

In order to enable reliable machining of hybrid materials up to a diameter of 30 mm, a drilling tool is developed that works with several independent cutting edges. These ensure that the tool can execute several process steps during one machining operation. This is to avoid subsequent reworking of the hybrid material. For research purposes, the workpiece thickness will consist of 8 mm (4 mm metal and 4 mm CFRP). The tool will work in two cutting directions during the drilling process, starting with the metal component. In the first process step, a pre-drill head creates a bore in the hybrid material, which is 2 mm smaller than the final diameter. During this process step, defects are expected in the CFRP-material. By selecting suitable process parameters, these defects can be kept within a one-millimeter range around the bore. The first process step continues until a second cutting-edge finishes the upper layer of the hybrid material. The drilling process is then briefly stopped and a third cutting edge is moved out of the tool body which finishes the CFRP-material during the backwards motion. To realise the cutting-edge adjustment, two tool concepts were developed.

2.1. Electromechanical cutting-edge adjustment

The first concept to realise the cutting-edge adjustment will work electromechanical (Figure 1, left). Therefore, a stepper motor is integrated within the tool body, driven by a microcontroller. For the internal power supply, a rechargeable battery is used. A shaft with an eccentric area on its circumference is attached to the stepper motor. The cutting edge adjustment is activated by two infrared diodes mounted on the tool body. One of these is used to receive the control signal. Initially, the shaft is rotated in steps of 1.8° by a total of 180°. In the course of this rotary movement, a cutting edge holder is moved out of the tool body. This sequence is monitored by the microcontroller, which then sends a signal back to the machine tool to confirm the cutting edge adjustment. The CFRP component is thus finished by the subsequent extension movement. During the backwards motion, all defects that have occurred on the CFRP component are removed and the bore is machined to its final diameter.

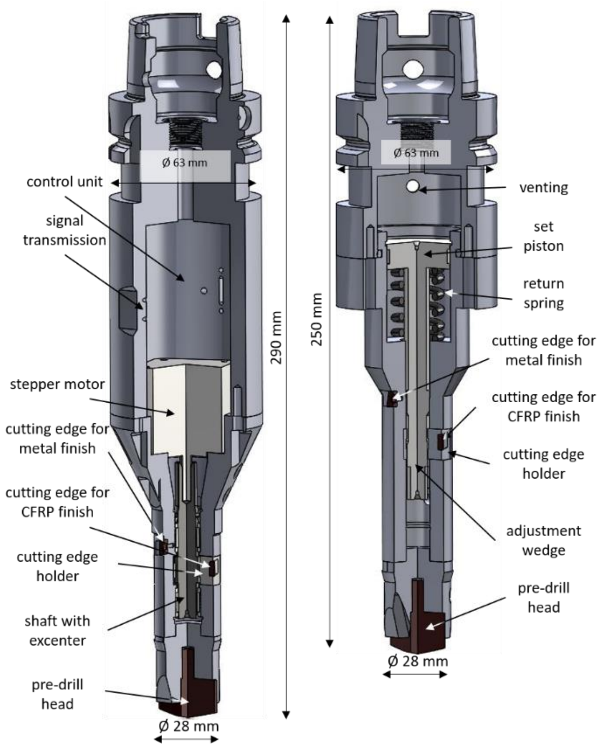

Figure 1. Drilling tool with electromecanical (left) and mechanical cutting-edge adjustment (right)

At the transition between metal and CFRP, the infrared diode receives the signal for the retraction movement from the machine control system. This leads the stepper motor to rotate the shaft back to the starting position whereby the cutting edge is moved back into the tool body.

2.2. Pneumatical cutting-edge adjustment

The second concept for the realisation of the cutting-edge adjustment will work pneumatically (Figure 1, right). For this purpose, compressed air is applied to a piston inside the tool body. This air is led through the machine spindle into the tool where a pressure of up to six bar is built up. A shaft is located on the piston, which uses two wedges to move the cutting edge holder. One is used to extend the cutting edge out of the tool body, whereas the other realises the return movement. The contact surface to the cutting edge holder has a 40° angle to prevent jamming during the axial movement. Once the CFRP component has been machined, the air supply through the machine spindle is stopped whereby the air in the pressure chamber is released through a vent hole. The piston is then returned to its starting position by a return spring. This loosens the wedge connection on the insert holder, which then moves back into the tool body.

3. Analysis of the two concepts

The two tool prototypes were designed and manufactured. First tests were carried out on a CNC machining centre. Aspects such as the time required to control the cutting edges, the exact traverse path of the cutting edges and the repeat accuracy were investigated. To record the measured values, a dial gauge was used, which was placed firmly on the spindle housing. In the course of the investigations, it was shown that both concepts are able to move the cutting edge out of the tool body. Thereby, the electromechanical concept achieved very low positioning tolerances (± 0,0005 mm) with a high repeatable accuracy (± 0,005 mm). The cutting edge adjustment with the pneumatic system works as well. Tests have shown, that the positioning tolerances (± 0,0115 mm) and repeatability accuracy (± 0,015 mm) was considerable higher compared to the electromechanical solution. This deviation results from the internal mechanics, which needs to be optimised. Problems occurred during the retraction movement. On average, it took about 7 seconds for the cutting edge to be retracted into the tool body, which is too long for the cutting process. Therefore, it is necessary to optimize this concept with regard to the venting of the tool in order to accelerate the retraction movement.

4. Conclusion

Drilling of composites made of CFRP and metal represents a major technical challenge, as the individual components have contrary requirements with regard to the cutting materials and parameters as well as the tool geometries. Therefore, a tooling concept was developed to machine quality bores in such hybrid materials. By using an adjustable cutting edge, which can be moved outside of the drilling tool body, a machining in two working directions is possible. To realise the cutting edge adjustment, two concepts were worked out. The first one uses a stepper motor while the second moves the cutting edge pneumatically through a piston and an adjustment wedge. For both concepts, tool prototypes were manufactured. It was shown, that the electromechanical concept works without any problems. For the pneumatic actuation drive, further adjustments must be made before machining tests can be carried out at present time. For future work, the cutting behaviour of both concepts will be analysed.

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