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Adaptive Machining for Efficient Manufacture and Repair of CFRP Components

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During all phases of CFRP manufacturing, reworking and repair, deviations of composite components from nominal shape play a decisive role. The automation of conventional NC machining processes runs into limits here. These tasks can be accomplished with geometrically adaptive machining, as adaptation technology is used when components are shaped individually and hence NC machining with "fixed" NC programs is not feasible.

Adaptive machining technology can be used successfully for more efficient post-machining of large and complex CFRP components. Typical applications include the use of post-machining to minimize air gaps and the need for shimming. This technique involves adaptive machining of adjacent components. Another important application is the automated removal of sacrificial material.

The reworking and repair of CFRP structures is extremely time-consuming if the preparation of the repair area is carried out manually. Mobile and stationary automation solutions for scarfing can dramatically shorten aircraft-on-ground times and substantially improve the quality of patch repair preparations. The recently developed mobile milling machine is equipped with an optical scanner and adaptive machining software and is able to automatically prepare CFRP structures of any shape for patch repair.

Introduction

Conventional NC technology is not sufficient for the automation of geometrically demanding machining tasks. Instead, the actual geometry of the components must be captured with measuring and scanning methods before adaptation technology can be used to adapt the NC programs to the individual component geometry

Geometrically adaptive machining technology has been used successfully for quite some time in the manufacture and repair of aero-engine and turbine components. This is because the geometrical deviations of the workpieces and the high demands placed on NC machining with respect to accuracy play an important role here.

It shall be shown in the following that adaptive machining systems can also be used efficiently during the manufacture and repair of composite components [refer also to 1 & 2].

1 Measuring and Scanning

1.1 Measuring and scanning methods

The starting point of every adaptive machining process is the capture of component geometry. There is a wide variety of tactile measuring methods and optical scanning systems available for this purpose – from the classic machine-integrated tactile probe to the robot-guided structured light scanner.

During the design of an adaptive machining system, the specified accuracies and the geometrical task description are decisive. For large-scale CFRP structures which are to be milled in three dimensions over their entire surface, optical scanners are the devices of choice.

A second important aspect is the decision as to whether geometrical data capture should be integrated into the NC machine or whether a separate scanning system would be more advantageous.

In general, machine-integrated scanning is the preferred system configuration. However, the choice of scanning methods is largely limited to line scanners.

If separate units are used for scanning and for NC machining, additional expenses and effort may be required for materials handling and possibly for fixtures and component referencing as well.

1.2 Optical scanning on NC machines

There is an overwhelming variety of scanning technologies available for separate scanning units. In contrast, the possibilities for machine-integrated geometrical data capture are currently limited largely to touch trigger probes.

To remedy this situation, a solution has been developed that permits 6-axis scanning with line scanners in 5-axis NC machines. Here the spindle is used as the sixth controlled axis. With this solution process-integrated and machine-integrated scanning of components can be realized (Fig. 1).

This innovative software solution does not require any additional wiring and thus permits simple integration of line scanning into NC machines.

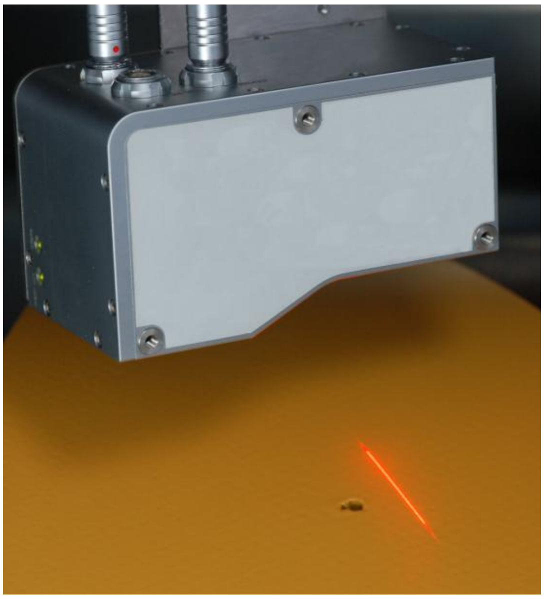

Fig. 1: Machine-integrated line scanning of composite components

2 Geometrically Adaptive NC Machining

Adaptive machining technology compensates for both individual deviations from nominal shape and inaccurate clamping positions. As a result, each individual workpiece can be machined within the specified tolerances and geometrically critical NC processes can be fully automated.

2.1 Geometrical adaptation

In the first step on the way to geometrically adapted NC programs, the adapted target surface of the individual component is determined on the basis of the nominal CAD geometry and the measured or scanned geometry of the actual part.

The calculation of the target surface, which describes the final geometry of the component to undergo adaptive milling, depends on the particular application and the extent of the shape deviations. When calculating the adapted target surface, one also has to take account of factors such as minimum wall thicknesses and aerodynamic rules, etc.

For different applications, the causes and types of shape deviations – as well as the goal of the shape adaptation – can be totally different. For this reason, adaptive machining solutions are by definition application-specific.

2.2 Adaptation of the NC programs

The final result of the adaptation process is an NC program adapted to the actual (i.e. measured or scanned) geometry. The milling tool thus follows the actual component contours and not the nominal CAD geometry. To calculate the geometrically adapted NC program, the tool centre point is computed according to the displacement of the corresponding tool touch point.

This algorithm can take account of any kind of milling tool geometry and refers only to a single line of the NC code. As a result, it is independent of the machining technology and path strategy and is therefore universally applicable.

2.3 Open software solution

With "OpenARMS" (Open Adaptive Repair and Manufacturing Software) BCT provides a flexible solution for adaptive machining. The software package runs on a PC and is connected via LAN to the NC control of the multi-axis machine. It can be employed to automate a large number of processes such as milling, grinding and fusion welding.

The modular and flexible software design enables the user to rapidly realize a wide range of different applications. A large variety of interfaces for NC post-processors and machine kinematics permits operation with a wide range of controls and NC equipment.

3 Applications in the Field of CFRP

3.1 Composite manufacturing

Geometrical deviations create problems during many steps in CFRP manufacturing. The automation of conventional NC processes runs into limits here. However, these tasks can be accomplished with geometrically adaptive machining to achieve automated post-machining processes.

Modern CFRP-based aircraft are composed of several aircraft structures, each of which is constituted of individual airframe components. As a result, there is a huge number of component interfaces to be managed. In comparison with the relatively easy assembly of machined metal components, the assembly of composite components is more challenging. This is due to the composite components' anisotropic behaviour and their large shape and geometrical variability. As the use and size of CFRP components have increased, dimensional tolerances have also tightened dramatically, making adaptive machining more crucial than ever before.

BCT is involved in the European collaborative project LOCOMACHS "Low-cost manufacturing and assembly of composite and hybrid structures" [3]. This project is investigating several post-machining operations and adaptive machining applications.

A typical adaptive machining operation is sacrificial machining. The majority of composite applications for sacrificial machining are for the production of skin components; here the main focus is on managing the thickness of composite skins in order to maintain critical component weights and mechanical properties. This is usually accomplished by performing sacrificial machining as necessary after taking thickness measurements of the panel being inspected.

Another application is the machining of mating surfaces to minimize shimming operations. Because of the geometrical variation of each individual manufactured component, a manual shimming process is still used. The aim of adaptive machining is to generate a 3D contoured surface on a panel that matches a similar 3D contour on a mating panel or substructure in order to achieve flush fitting, which minimizes or even eliminates the need for structural shims.

3.2 Automated scarfing for reworking and repair

Large integral composite components cannot be replaced if they are damaged. Therefore, mobile repair capabilities for carrying out repair on aircraft are essential. To rework composite components during the manufacturing process, similar methods are applied.

The manual repair of CFRP structures is time-consuming. In particular, the preparation of the repair area via scarfing is very work-intensive.

With geometrically adaptive 5-axis milling, CFRP components with different shapes can be scarfed fully automatically. This substantially reduces machining times and aircraft-on-ground times while improving the quality of the repair preparations.

The individual steps in automatic scarfing with the software solution “OpenARMS-CompR” are described below.

Scarfing geometry

Patch patterns and scarfed areas of all kinds can be milled. The geometry of the scarfed area – either cone-shaped or stepped – is given by the master milling program, e. g. 2½D pocket milling with 3 axes.

For circular and rectangular patches the software offers an integrated NC path generator (Fig. 2). Special shapes can be generated with commonly used CAM packages and then imported.

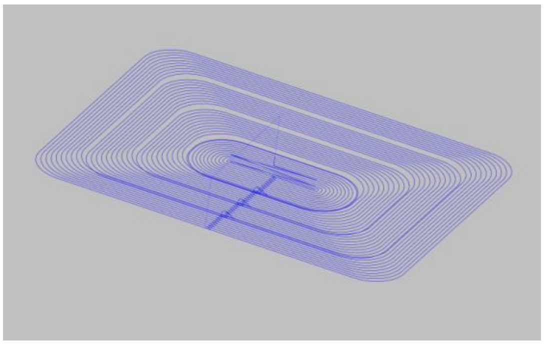

Fig. 2: Nominal NC path for a rectangular patch

Scanning

The scarfed areas are generated on "unknown" component geometries. No CAD data of any kind are required.

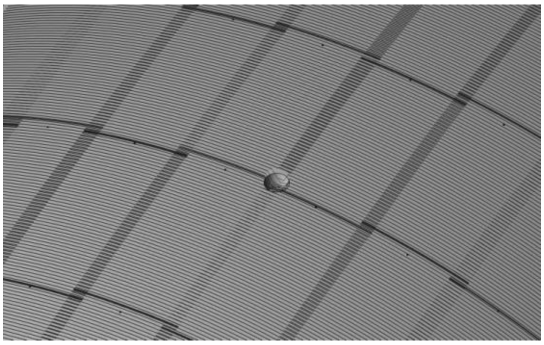

Fig. 3: Scanning data of a 3D component

The line scanner first captures the topology of the damaged area and then scans the 3D geometry with a high degree of accuracy (Fig. 1 and Fig. 3).

Adaptation

First a 3D surface model reproducing the actual geometry of the damaged area is generated from the scanned points.

The 3-axis master milling program described in 2D geometry is then transferred to this 3D surface geometry. The geometrically adapted milling programs have 5 axes and run parallel to the contours of the actual geometry of the damaged area (Fig. 4).

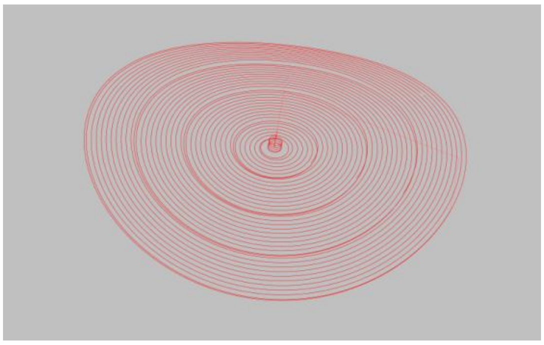

Fig. 4: Geometric adaptation of NC paths

5-axis milling

On the mobile or stationary NC machine 5-axis milling of the scarfed area is then performed. Milling strategies and cutting tool geometries of all kinds can be used here.

4 System Solutions

The modular software concept can be adapted – and expanded – in a flexible manner to perform a wide range of tasks for the post-machining, repair and reworking of CFRP components.

For adaptation to different tasks the software for adaptive NC machining can be installed on both mobile and stationary NC milling machines.

4.1 Stationary systems

Stationary NC systems are used for post-machining and reworking during the production of CFRP structural components. The software solutions for machine-integrated scanning, adaptive machining and automatic scarfing can be integrated easily into all commonly used NC machines and NC controls.

4.2 Mobile milling machine for repair preparations

For the repair of composite aircraft a mobile 5-axis milling machine and the corresponding processes have been developed (Fig. 5). With this equipment automatic scarfing can be performed directly on aircraft as part of the preparations for patch repairs.

These developments were initiated by the WIWeB (Wehrwissenschaftliches Institut für Werk- und Betriebsstoffe). Apart from WIWeB the companies Primacon Maschinenbau GmbH (5-axis milling machines), Hufschmied Zerspanungssysteme GmbH (milling tools) and BCT Steuerungs- und DV-Systeme

GmbH (software and system integration) are participating in the development consortium.

The 5-axis NC milling machine is portable and easy to use. It is docked onto the CFRP component or aircraft via the vacuum clamping element. The steps for carrying out the scarfing are described in Section 3.2.

Fig. 5: Prototype mobile milling machine (photo © WIWeB, Primacon)

Preliminary studies [4] have shown that milling is more effective than laser ablation for material removal. Various milling strategies have been developed and optimized in [5].

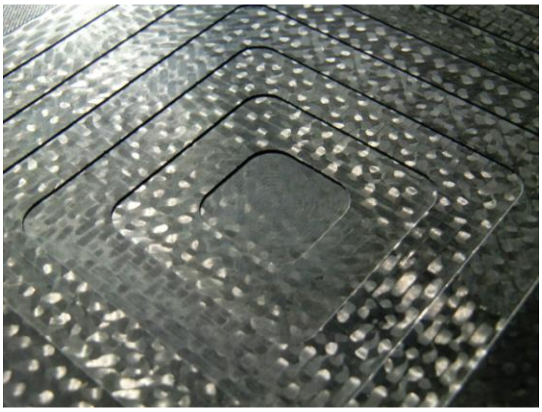

Fig. 6: Stepped scarfing (photo © WIWeB, Hufschmied)

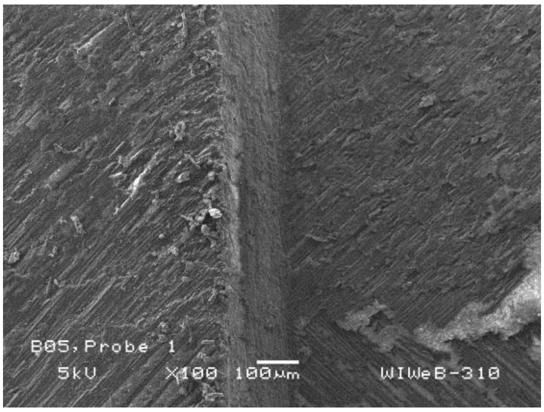

Fig. 7: REM image of a step (photo © WIWeB)

To achieve perfect preparation of the repair area, all aspects of scarfing by milling must be examined meticulously [6]. The development level achieved in the overall system shows that the scarfed areas permit optimal patch repairs both with respect to macroscopic geometry (Fig. 6) and microscopic surface embossing (Fig. 7).

The mobile milling solution for automatic preparation of patch repairs will be presented at the ILA Berlin Air Show in September 2012.

Conclusion

During all phases of CFRP manufacturing and repair, deviations of composite components from nominal shape play a decisive role.

Adaptive machining compensates for both individual deviations from nominal shape and inaccurate clamping positions. This makes it possible to automate geometrically critical NC processes such as post-machining, reworking and repair of composite structures.

An innovative solution for the mobile repair of composite aircrafts shows the huge capabilities of integrated adaptive machining solutions in the field of composites.

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