Precise Compensation of Component Distortion by an Adaptive Clamping System

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Abstract

Due to the good corrosion behaviour and the high specific strength of titanium alloys, their ratio of the structural weight in modern aircraft developments reaches nearly 15 %. This is twice as much as in the last aircraft generations and leads to the application of large (> 3 m) structural titanium parts like door frames, lintel and sill beams. For these structural parts open die forgings are milled. Hereby, over 95% of the raw material is removed. The quenching process after forging induces residual stress into the forgings. Releasing the stress by removing material can lead to strong part distortion, especially by long and slender parts.

To ensure an economic and scrap free production of these large structural titanium components, a new adaptive clamping system for load-free clamping has been developed to avoid a time-consuming manual adjustment before the finishing processes. In this paper the assembly of one adaptive clamping element and its experimental verification concerning distortion-free clamping is presented.

1 Introduction and Motivation

The use of composite materials has increased enormously in the aerospace industry. To reduce weight and, with it, fuel consumption in new generations of aircraft, bearing structures such as fuselage, wing and tail panels are increasingly produced from composite materials. Due to the good corrosion behaviour and the high specific strength of titanium, next generations of aircrafts will have a larger ratio of titanium parts [1, 2]. However, titanium is a material which is very hard to machine. For the production of titanium frames, forgings are machined with a material removal rate of up to 95% at present. Hereby, residual stresses are released which can deform long and slender structural parts. After releasing the workpiece from the clamping table, distortions up to a few millimetres can occur. The required tolerances cannot be met and the part is scrap [3].

Because of the high economic risk of these expensive components, currently several clamping steps are necessary to minimize the component distortion and to comply with the tolerances. Titanium frames with a length of 4.4 meters currently have to be released from the clamping between the process steps and then clamped again. This is time-consuming, since these large components are clamped by about twenty clamping elements. For a load-free clamping, they all must be adjusted by hand.

To ensure an economic milling of these large structural titanium components for the aerospace industry, a new adaptive clamping system has been developed. The aim of this clamping system is to automatically minimize the part distortion between different milling process steps. The time-consuming manual adjustment for load-free clamping shall be substituted by adaptive clamping elements. With the help of force sensors and servo-hydraulic positioning, an automatic relief of the internal stress of the workpiece shall be possible. The height of each active clamping element will be controlled by a force control to get distortion free clamping.

2 Adaptive Clamping Element

The clamping system consists of several adaptive clamping elements to allow an automated relaxing of clamped workpieces. The assembly of one adaptive clamping element is shown in Fig. 1.

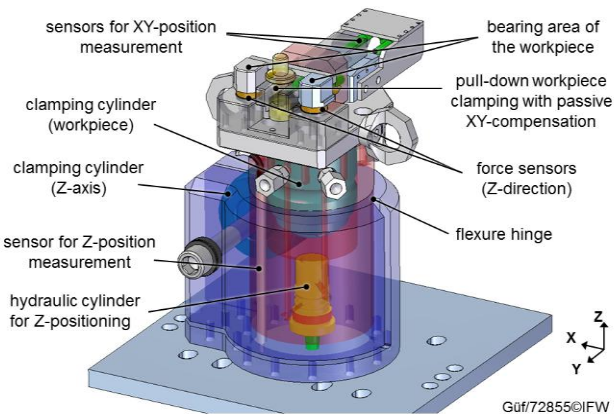

Figure 1: CAD-model of one adaptive clamping element

Each element is equipped with sensors and actuators. With the help of sensors the forces in Z-direction resulting from the residual stresses of the milling process can be measured. A servo-hydraulic positioning system enables a precise variation of the height of the clamping element in the range of Z = ±10 mm. For position control in Z-direction, an inductive sensor is integrated. Hydraulic clamping devices can automatically clamp the workpiece and the positioning axis to ensure high stiffness during the milling process. A displacement of the workpiece in X- and Y-direction (range: X/Y = ±2 mm) after releasing the hydraulic workpiece clamping due to residual stresses can be measured by two inductive sensors.

3 Test Set-up for a Distortion-free Clamping

For the verification of the hydraulic positioning and the automated distortion compensation, a test set-up with one adaptive clamping element (Fig. 2) has been built. The hydraulic positioning in Z-direction is controlled by a servo valve. In first tests, a static positioning accuracy of Z = ±2.5 µm (lowpass filtered with Butterworth filter, 5th order, f_c = 10 Hz) could be reached with the LVDT position sensor.

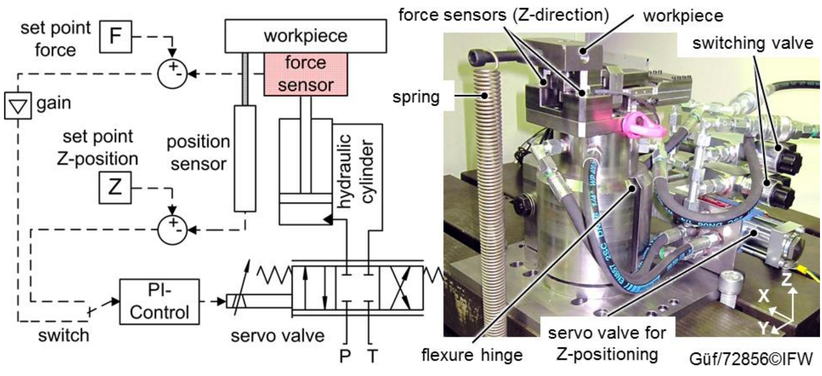

Figure 2: Control diagram and test set-up of one adaptive clamping element

For an automatic release of residual stress induced forces in Z-direction, a force control was developed. It can be switched manually between the position and force control (Fig. 2). A spring (stiffness: c = 2 N/mm) simulates a force in Z-direction resulting from residual stresses. In an experiment the spring was preloaded and the Z-position was controlled at a height of 7 mm. At that position a force of about 22 N was generated by the spring. The force control was activated ten seconds after the start of the measurement. The set-point of the force was set to F = 0 N. The measurement results (lowpass filtered with Butterworth filter, 5th order, fc = 10 Hz) are shown in Fig. 3. The results point out that an automated releasing of residual stresses by the force control is possible.

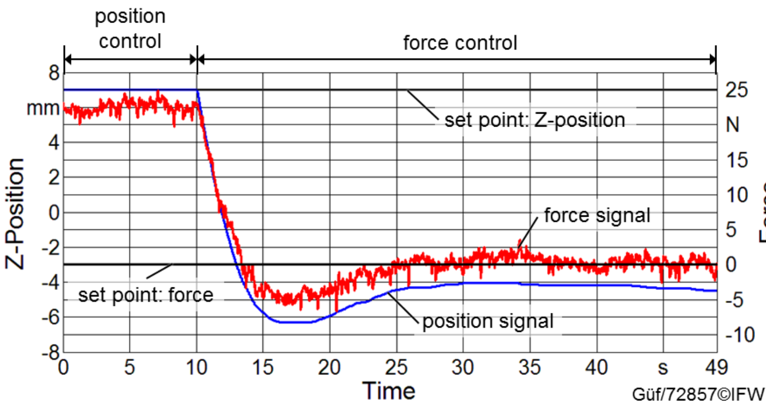

Figure 3: Measurement results with activated force control

4 Conclusion and Outlook

This paper presents an adaptive clamping system for large titanium structural parts, which can automatically compensate distortions due to the release of residual stresses of the milling process. For this purpose, a force control was developed that regulates the Z-position of an adaptive clamping element to obtain distortion free clamping. In future work the force control will be optimized, a complete clamping system with four adaptive and two passive elements will be built up and milling tests on titanium workpieces will be carried out.

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