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Metrology assisted assembly of airplane structure elements

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Abstract

Geometric deformations in large components like airplane shells caused by e.g. gravitation influences have to be compensated before assembly. The research objective is to develop a metrology assisted robot based assembly system that detects deformations and compensate them through force controlled movements of the robots. The determination of robot compensation movements uses a model of the components deformation behaviour. For the determination of the model parameters an identification process is developed, which uses samples of the real component deformation behaviour caused by defined external forces to approximate the parameters (e.g. stiffness) of the component.

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1. Introduction

Conventionally, the production of large products is characterized by small lot sizes, consumer specific products and high prices. In most cases this kind of production includes a high proportion of manual work. A fully automated production of individualized products is difficult to implement, because the required huge production systems are in most cases specifically designed, i.e. for only one product or component. These systems are cost-intensive and, under consideration of the small lot sizes, not efficiently applicable for all assembly tasks [1].

Because of the large dimensions and proportionally small tolerances, standard production systems (like industrial robots) can not reach the necessary production requirements. A method to increase the precision of standard production systems is to use metrology systems as assisting units that can detect production deviations and compensate them through adjustments of production parameters.

One field where such metrology assisted production system could increase the production efficiency is the airplane industry. The airplane structure consist of many large components, which have to be assembled to the final airplane structure. The assembly of these large, flexible components is a complex task, as the parts have to be positioned precisely and need to be untwisted before they can be assembled. Traditionally fixed jigs are used to guarantee the correct shape of the products. Nowadays, more and more programmable jigs and robots in combination with large volume metrology systems are used to increase the flexibility of the production systems. These systems operate on the principle of positioning by measurement. The metrology systems measure production deviations, like geometric deformations, and the control unit determines compensation movements of the kinematics.

However these compensation process can not be processed automatically, as the reaction to external forces of each part is unknown and can not be planned in advance. Models to describe this components behavior which are needed for an automatic control, do not exist yet. The use of the flexibility of a robotic system in combination with metrology systems, as a

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programmable jig for a more efficient, automated assembly process [2], needs new control algorithms which are suitable for an automated control without manual intervention by workers. This paper describes the development and implementation of positioning and force torque sensors, which are needed for a metrology assisted robot based positioning and untwisting process of airplane structure elements.

2. Description of the airplane structure and the assembly process

The fuselage of modern airplanes is constructed with shell elements. These shells consist of the skin panel (planking) and the inner framework, which is build with stringers, clips and frames (see figure 1). The mechanical advantage of this structure is the use of the panel for the absorption of the loads induced during flight. [3]

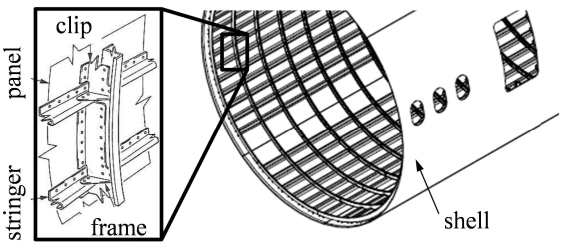

Fig. 1 Design of an aircraft section (based on [3], [4])

For the production of the fuselage, the hull is divided into several sections. The sections are built by using a variable number of shell elements, which are joined with rivets. The dimensions of the sections depend on the airplane. For a typical plane the length varies between nine and eighteen meters. Last-generation airplanes are equipped with a hull structure consisting of aluminum or aluminum alloys. For this material the parts are built with standard forming processes followed by milling processes. Airplanes currently being developed consist of fiber composite materials like CFRP (carbon fiber reinforced plastic). [4] This paper focuses on the assembly of CFRP sections.

2.1. Production and assembly of an airplane section

The production process starts with the layup of the skin panel by pasting preimpregnated carbon-fiber on a forming tool. For the impregnation of the fibers special resins are used. These resins build a matrix which connects the single fibers to get a stable structure with a fixed fiber alignment. After panel production the assembly of the section starts. The assembly is divided into three main steps:

1. Stringer integration
2. Shell assembly
3. Section assembly

During stringer integration consolidated stringers are assembled to the unconsolidated panel, which has a diameter of about six meters and a length of nine to eighteen meters. The shape and geometry of the unconsolidated flexible panel is ensured through a forming tool, that maps the geometry of the airplane structure,

2.2. Shell assembly

The challenge in shell assembly is to untwist a large, deformed panel (mainly due to gravity) and to join it unstressed with frames, which stiffen the panel. The joining is done indirectly with clips, which also accommodate gaps between the panel and the frames. The joining technologies for this process are bonding and riveting.

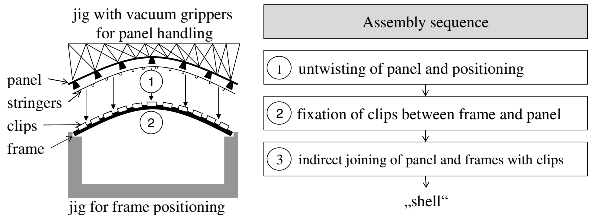

Fig. 2 Classical shell assembly

The panel is set in shape by vacuum grippers, which pull the part against a contour that maps the geometry of the part (on appr. 120m²). The vacuum grippers form the upper jig of the assembly station to position the panel to frames, which are mounted in the lower jig of the assembly station (see figure 2). By moving the upper jig downwards, the panel and frames are aligned. After alignment the clips are manually fixed between the frames and the panel for the subsequent joining by riveting.

2.3. Section assembly

For the assembly of a section all components have to be aligned. One section consists of four shell elements (left and right side shell, upper shell, lower shell) and the floor grid. To fulfill the tolerance requirements the side shells have to be positioned and untwisted. The untwisting is needed to compensate for deformations of the shell (mainly due to gravity). A manipulator system has been developed for this process [5] and is already used in series production. The side shells are grasped by vacuum and mechanical grippers and positioned by several linear actuators. The process is monitored by several force/torque sensors and global and local measurement systems. As the product does not fit to the shape tolerances, the actuators can not reach the desired grasping point exactly. Also the positions of measuring points are only estimations. An iterative process determines the deviations between target and desired position and minimizes the residual [5]. The control of the station is done automatically, as long as force limits are not exceeded. In case of exceeding forces the process needs to be continued manually, as data from force/torque sensors is not viable for automatic control.

The principles of this semi-automatic process in section assembly are being used and enhanced for the control of an