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INNOVATIVE ASSEMBLY TECHNOLOGY AND ASSISTANCE SYSTEMS FOR LARGE COMPONENTS IN AIRCRAFT ASSEMBLY

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Abstract: *The global competition challenges aircraft manufactures in high wage countries. The assembly of large components is distinguished by fixed position assembly. Due to a high variant and changing tasks an automation is not economically compared to small and average components. Worker perform a lot of process steps manually and several production resources are necessary. Nowadays, fixed appliances are used in the positioning of fuselages to assemble an aircraft section with the help of component jigs in assigned areas, which picture and support the geometry of components. To comply the required tolerances the appliances have to feature high rigidity and accuracy in shape, which is achieved only by heavy and expensive appliances. Aircraft manufacturer require a huge amount of different resources and personnel, so there are high costs. The aircraft manufacturers deal with a varying number of items, growing product variants and an increase of requirements for their products. To meet the varying demand and increasing product variants more flexible product systems are required. Due to these high costs the demand for automated reconfigurable assembly systems, which offer a high flexibility and lower manufacturing costs, has grown. The research project "IProGro" deals with this challenge and develops innovative production systems for large parts. On one hand the flexibility is reached by a reconfigurable fixture for the parts on the other hand it is achieved by assistance systems, which guide staff during assembly processes.*

Key words: *Large components, aircraft, reconfigurable assembly system, laser projection, Assistance System, mechatronic modularization.*

1. INTRODUCTION

The research project IProGro is a consecutive research project of RePlaMo. The motivation of the research project RePlaMo was to develop a reconfigurable handling system with high adaptability and low manufacturing costs. Assembly companies in high wage countries face global competition by being able to react quickly on product changes. Assembly systems for large parts require high one-time investment for automated production equipment, thus it must be usable over a long term. Large products are usually produced with long life cycles. The inability to integrate new production processes in the assembly system during a life cycle makes a continuous development of production processes uneconomical. Many complex assembly processes such as in the aircraft assembly are manually done by high experienced workers. Due to the demographic change, new strategies are needed to master the challenge of integrating rather unexperienced persons whereas at the same time the complexity of the production processes increases [1]. IProGro ties up to RePlaMo and empowers companies to integrate state of the art production technology during the life cycle to amongst others help workers with different levels of experience.

2. MOTIVATION FOR IProGro

Objective of the research project IProGro is the development of production technologies for the processing and assembly of large components. Due to many different variants, small piece numbers and long development times associated production systems and resources are not developed continuously. According to the long development times product life cycles of decades in aircraft construction are common. New production technologies are often integrated with the first introduction of new models [2]. The research priorities focuses large components made of carbon fiber reinforced plastics (CFRP). The project is designed to implement new semi-automated production technologies. The objective of the project is the protection of the location of industry in high-wage countries. There is a high application of CFRP in the transport sector. The production and processing of CFRP is very expensive so there is a need of efficient production and processing technologies. Another signifi-

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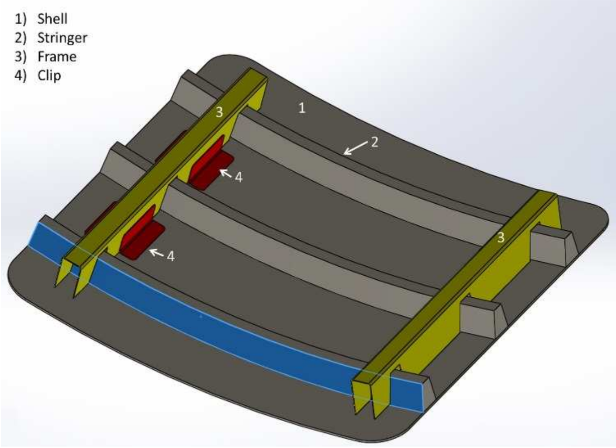

Fig. 1. CAD example of a fuselage.

cant point is the assistance system. Today the assembly of airplanes is executed in fixed position assembly. This people-intensive work has to be performed by qualified persons. Although the level of education increases in high wage countries, it conflicts with the demographic change [3]. Hence staff needs to be assisted in the future. This can be achieved by assistance systems assisting workers to guarantee the quality or to guide staff with a lower educational background. Both protect the location of industry in high wage countries. A possible demonstration case which considers these emphases is adhesive bonding. It meets the special requirements of fiber reinforced plastics and is easy to automate. Today clips are used to connect frames to the shell see
Fig. **1**. Several hundred clips are riveted to the shell. The disadvantage of the rivets is the additional weight which is added to the structure. Thus airplane manufacturers go to great lengths to implement adhesive bonds in the future [4].

In order to set up this kind of system these four work packages were defined in the research project IProGro:

- Assistance system
- Surface treatment
- Inspection system
- Adaptive gripper systems
- Demonstration area

In the following the results of these work packages are presented.

3. ASSISTANCE SYSTEMS

The first task of the work package "assistance system" was the definition of a possible scenario. High wage countries depend on flexible production of sophisticated products which are produced in high quality [5]. Automation helps to reach this objective. However a complete automation is not useful at all times. Job shop production offers this high flexibility but it conflicts with labor costs, so that semi-automated assembly is the right choice. This assembly can be improved by assistance systems that support workers. This can be done with visual, haptic or acoustical signals which guide staff during assembly processes. One solution for visual assistance systems are projection lasers. Laser projectors display precise outlines, templates, patterns or other

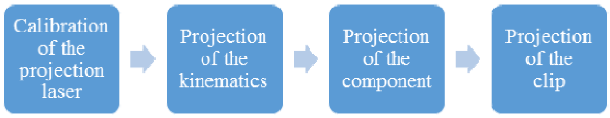

Fig. 2. Requirements of the projection laser.

shapes on surfaces by projecting laser lines see Fig. 2. In the research project IProGro two projection lasers are installed. These should support the worker specifically in his work. The requirement of the projection lasers subdivided into the following steps (Fig. 2):

First of all, the projection laser must be calibrated. These four so-called targets were attached to the demonstrator and deposited the positions in a calibration file. The targets are in the middle equipped with a mirror who throws the laser projection back see Fig. 3. With the calibration file together the projection laser can be calibrated in the work environment. The accuracy of the later projections depends on the accuracy of the calibration of the projection laser. In order to make this process as high-precision as possible special holders were manufactured for the targets and attached to the corners of the demonstration area. The position of the target was heard at the corners of the demonstration area by 2 meters. This prevents, that the kinematics or components blocks the view of the projection system to the target and the calibration process cannot be performed. This were measured with a laser tracker to determine the exact positions of the targets and to be deposited in the calibration file. Thus, the accuracy of the positions could be increased significantly and the calibration of the projection laser made more quickly and efficiently.

In the second step, the projection laser assists the worker in the positioning of the four gripping-kinematics see Fig. 4. The positions of the kinematics depend on the component. The grab points are defined in the CAD system and thus determines the position of the kinematics. In this case, it is sufficient to project the baseplate and the orientation of the kinematic. For this purpose, the baseplate was drawn in the CAD system and stored as projection file in the system. After the calibration of the projection laser through the worker, the first kinematic can projected. For each kinematic the worker confirmed the correct position of the kinematic and can move on to the next. Thus, the worker may be assisted in the positioning of the kinematics and thus the error rate can be minimized.

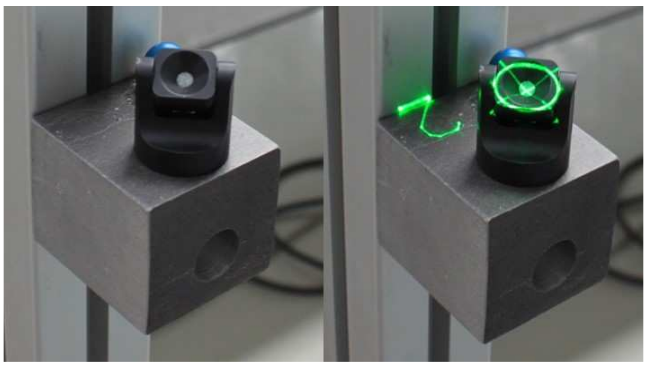

Fig. 3. Calibration Targets.

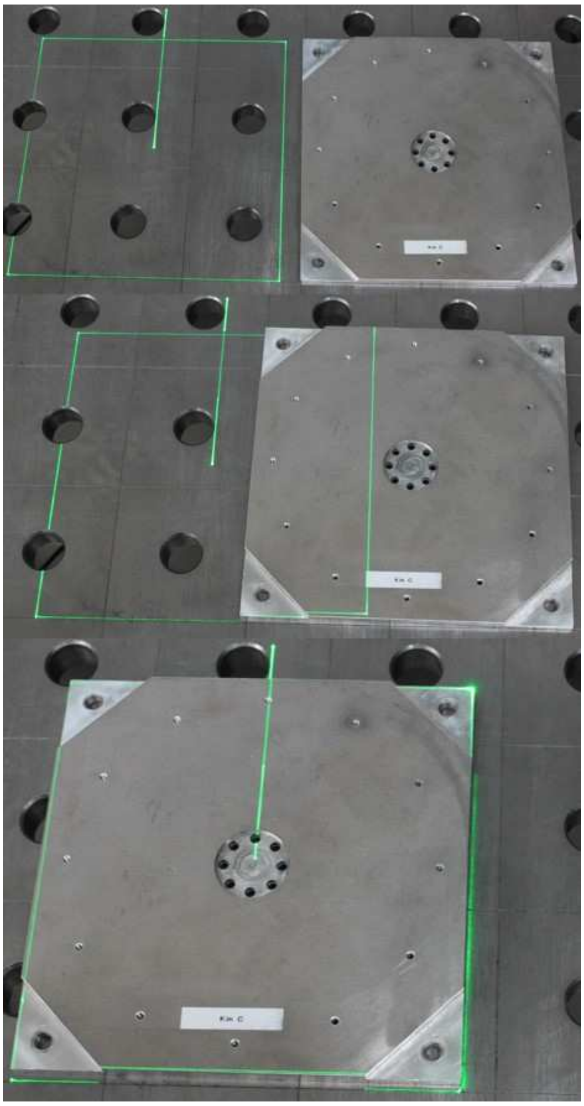

Fig. 4. Example for the positioning of a kinematic.

Are all kinematics accurately positioned the worker can initiate through the confirmation on the panel the third step. In this, the component should be positioned on the grippers. The projection laser show the worker the position in which the component is to be stored in the grippers. As at the projection of the different kinematics, the complete component must not be projected. Because the laser projection consisting of only one laser point the projection of the more indistinctly the more needs to be projected. It is sufficient to represent the external shape of the component. The worker positions the component on the grippers until he sees the complete outer contour of the component. Thereby the rough positioning is already provided by the position of the individual kinematics the worker only complete the trim adjustment. If the component is placed in the correct position the worker can initiate the next step.

In the fourth step the CAD clip is projected on the component see Fig. 5. The projection of the clip has two advantages. First, the worker will immediately recognize whether the robot prepares the component to the right place for the clip. Second, the worker show the exact position with the orientation for the clip, which minimizes the error rate of a false bonded clip. The difficulty

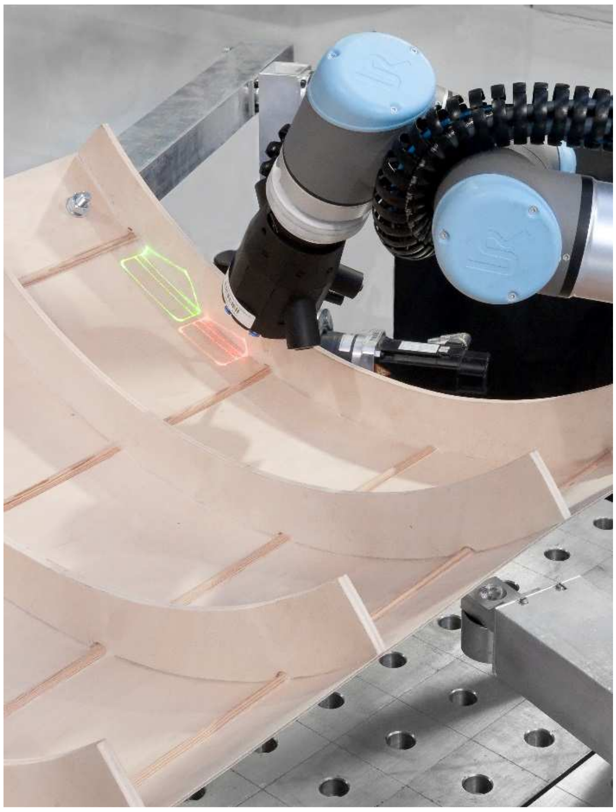

Fig. 5. Projection example of two clips.

here is to project the clip on the curved component. There are two things to consider. First, the projection laser can only project the CAD file. This means that in the cad file even the exact curvature need to be drawn. In the projection software the geometry of the component cannot be modified. Only the position of the projection can be changed in the software. Second, the height of the projection is of crucial point. Because the projections usually cannot be projected at a 90° angle, a parallax error can be caused by an incorrectly adjusted height. Thus, the projections are distorted projected on false positions. In order to avoid these errors further targets are attached to the kinematics or directly on the component. Thus should always be the correct height of the projected area can be identified and stored in the projection file.

4. SURFACE TREATMENT

With the increased application of new materials such as carbon-fiber reinforced plastics (CFRP), there is a need for new, efficient production technologies. For the assembly of CFRP are new joining technologies necessary which take into account the specific requirements of these materials. Adhesive bonding is a possible joining technology for this task. It is a combination of cohesion and adhesion. While the cohesion is influenced by the chemistry of the adhesive, the adhesion can be manipulated by a surface treatment. Atmospheric plasma is one possibility for this kind of treatment. Plasma is called an ionized gas containing a significant proportion of free charge carriers such as ions or electrons [6]. Within a plasma tip an electrical discharge happens. This discharge is spaced out with compressed air. Outer boundary layers significantly affect surface properties (Fig. 6).

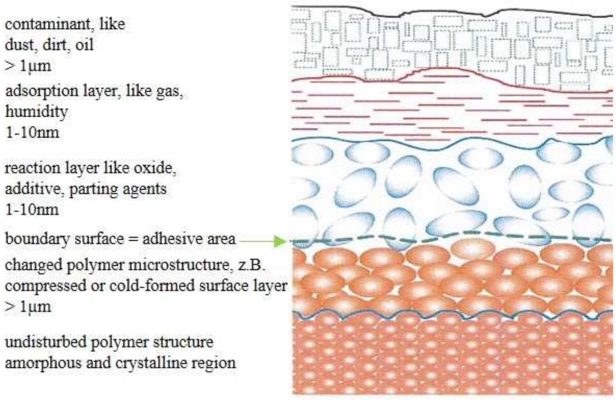

Fig. 6. Influence of external boundary layers on surface properties [8].

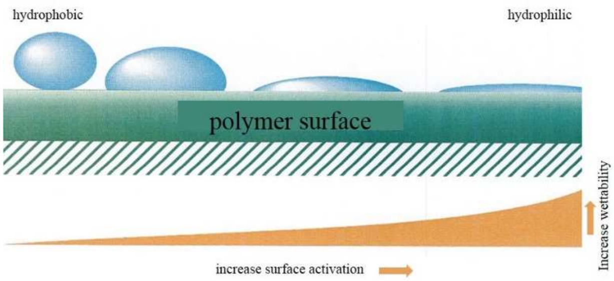

Fig. 7. Influence of surface activation on the wettability of polymer surfaces [8].

The aim of pre-treatment with plasma is degreased in order to increase the wettability of the carbon-fiber-reinforced plastics and to provide improved adhesion to the surface (Fig. 7). The aim of the treatment with plasma is an improved wettability and increased adhesion the CFRP. In addition to that a treatment degreases and cleans the surface. The plasma itself creates free radicals at the surface of the substrate and enhances the surface energy. The surface energy is an indicator for the adhesion. Fiber reinforced plastics possess a low surface energy that is why they are hard to bond and a surface treatment is necessary. With atmospheric plasma the surface energy can be increases form 28mN/m² up to 72 mJ/m² [7]. After a treatment the worker can add the adhesive to the treated surface. An inspection system is needed to control the adhesive application. This is explained in the following.

5. INSPECTION SYSTEM

On the basics of the high quality requirements of the processing and joining operations must be monitored. Inspection systems are implemented in the system to control the quality. The measurement of adhesion with optical devices is not possible to this day. That is why thermography is implemented inside the process. The active thermography uses the heat conductance of materials (Fig. 8). The part is activated with heat and the heat front spreads within the part. This heat front is detected by an infrared camera. Errors such as a lack of adhesive can be detected. In order to allow a good view and accessibility a reconfigurable fixture is needed. Thus an adaptive gripper systems has been developed which is explained next.

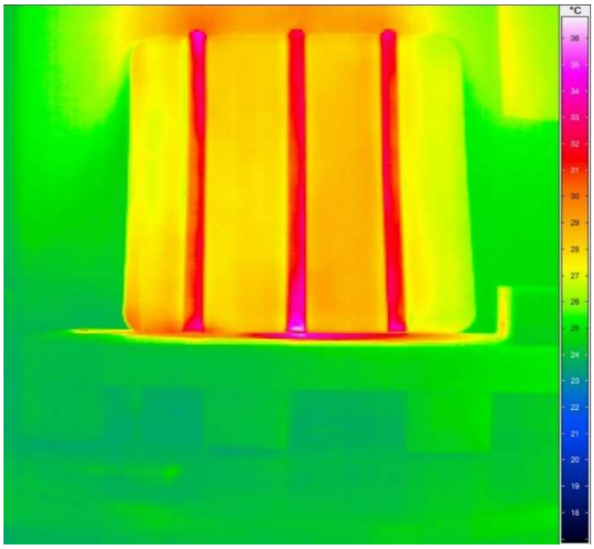

Fig. 8. Thermography example of a CFRP bowl.

6. ADAPTIVE GRIPPER SYSTEM

For surface treatment and assembly of the various large components suitable handling systems are required. Due to the high requirements in terms of the working space, the variety and the accuracy here a novel adaptable handling or gripping system is developed. Nowadays robots are used to deal with the challenges of changing tasks in assembly processes. In the previous production process, a new appropriately configured endeffector is required for a minor alteration to the geometry of the component, which must then be replaced with standing production. In addition to loss of time, a corresponding stockyard for a variety of endeffectors must be provided, which represents a significant cost factor in large components. To significantly minimize these factors in the research project reconfigurable gripper system is developed that can adapt to a wide variety of geometries and thus eliminate the workpiece exchange and storage costs as far as possible. For eliminating this problem a new handing strategy was developed. Four autarkic kinematic units are necessary for this task. They consists of a vertically articulated robot and their own control unit (Fig. 9). Each robot can perform an autarkic movement at the beginning and forms a unit with the other robots, when it is combined with the part. Hence each kinematic unit possesses its own control a global positioning can be performed easily on a support. That allows a quick reconfiguration of the assembly area. The vertical articulated robot conducts a regional positioning, which can be required for an easy accessibility for the worker. [9]

The wrist of the robot (Fig. 10) consists of an endeffector. This endeffector possesses a vacuum cap at the end. Vacuum grippers are widely common in system handling and assembly. Shape memory alloy (SMA) wires make it possible to move the arm. This wires are actuators with a large power/mass ratio. The most popular SMA used is Nickel-Titanium (NiTi) which is known to have a power/mass ratio of 50 kW/kg. This allows for the construction of very light weight and energy efficient systems. The SMA wires contract if a voltage is induced. The shape memory effect involves, after a mechanical

Fig. 9. Kinematic unit.

Fig. 10. Photograph of the manufactured and assembled prototype.

deformation, a return to an undeformed state when heated. The NiTi wires strains of more than 4% [10]. Due to these wires expansive servo motors can be economized. Production can react on changing tasks quickly without additional manufacturing resources.

7. DEMONSTRATION AREA

The compiled results of this project are to be modeled and demonstrated in an advanced development environment (Fig. 11). The improvement of the assembly system

Fig. 11. Demonstration area of the research project IproGro.

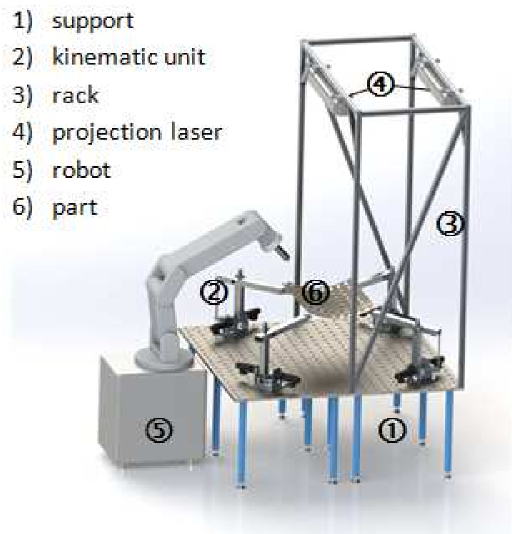

Fig. 12. Set-up of the Demonstration area.

is reached by an intelligent combination of all systems. In order to test the capability of the assembly site all systems are implemented and tested within a demonstration environment which is described next.

8. SET-UP

Fig. 12 shows the set-up of the demonstration area of the research project IProGro. The assembly site consists of a support (1). On this support the four kinematic units (2) can be adjusted and fixed for a quick global positioning. The kinematic units itself consists of a vertically articulated robot, which performs regional positioning. The local positioning takes place with an adaptive gripping technology. The adaptive grippers can be configured by the use of SMA-wires. A rack (3) mounts two projection lasers (4) which indicate an assembly site for a part. A lightweight robot (5) enables a human-robot-collaboration and activates the surface of the part (6) with atmospheric plasma. In addition to that the robot performs inspection tasks with an infrared camera.

9. WORK CYCLE

Fig. 13 shows the flow diagram of the work cycle. The work cycle starts with the sign-up process. A worker has to sign up at the assembly site. This can be done for example with an RFID chip. The registration is necessary for the system to identify the worker. So the system can provide an optimal work environment for the worker such as the height adjustment of the operation position, input devices, placing material at disposal and tool ready position. After that the user chooses a part that they want to put in hand. This component is identified with RFID for quality control. Following an industrial computer loads data and transmits it to the projection laser. At first time the projection laser shows the worker where they have to adjust the kinematic units, so that they can perform global positioning easily. The worker calibrates each kinematic unit for the first time. This calibration is necessary to set up the base coordinate system for each unit. With this input the vertically articulated robots can move to the right position which is transmitted by a supe-

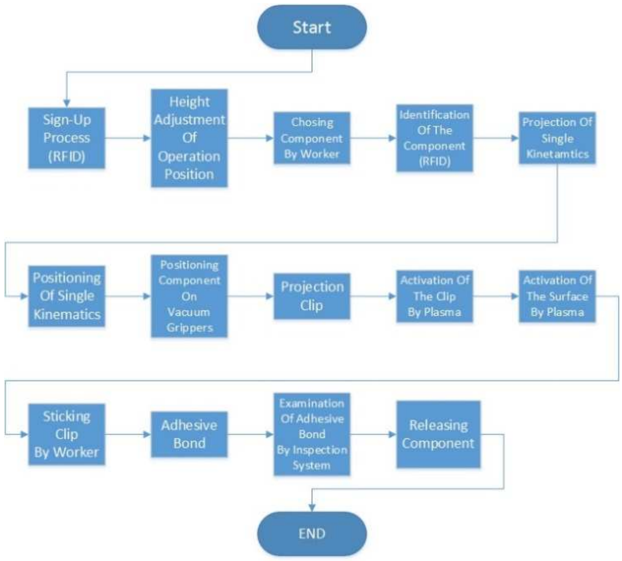

Fig. 13. Flow diagram of the work cycle.

rior control unit. In second the projection lasers indicate the position of the part so that the user can place it on the vacuum grippers. Next steps can be only performed if the part is precisely positioned. Due to the projection the workers has an immediate visual inspection of the position. The grippers themselves perform a local positioning by adding a voltage to the SMA-wires. When the kinematic units reach their position, a lightweight robot can start to measure its base coordinate system that is essential for path planning later on. With this data the robot can perform different tasks like inspection tasks, a surface treatment or simple positioning tasks. Activation can be performed with atmospheric plasma with a lightweight robot. At first the robot activates the clips, which are provided in a station. After that the robot executes the activation of the shell. The assembly site of the clips is indicated by projection lasers, so the worker can see whether the lightweight robot activates the shell on the right position. If the robot is finished, a worker can stick the clip to the shell with the help of the projection. After curing the inspection system examines the adhesive bond. If no errors are detected, the part can be released.

10. SUMMARY/ CONCLUSIONS

In conclusion it can be said that the system developed in the research project IProGro provides innovative production technologies for large components. On one hand the flexibility is reached by a reconfigurable fixture for the components on the other hand it is achieved by assistance systems. The assistance systems provide information and take into account the level of education. This is one possibility to face skill shortage. Additionally, cycle times can be shortened and quality improved. Lightweight robots and adaptive gripper systems open up new possibilities for inner automation that is used for completing the inner structure of the fuselage. Although plasma activation serves as a demonstration case here the principle can be transferred easily to other areas of operation like welding, painting and so on. The key is to use the specific skills of humans and workers to reach an optimum to fulfill the work task.

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