Automation from an automotive perspective

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ABSTRACT

The use of composite materials has increased in recent years and one of the most expansive user is the aerospace industry. Aerospace industry has experienced a combination of market growth at the same time as the share of composite materials in the designs has increased significantly, forcing the aerospace industry and its sub suppliers to seek new ways to increase productivity e.g. by an increased level of automation.

By introducing production technology and production strategies used in automotive industry a significant potential is created for aerospace industry and especially the composite manufacture to be more competitive. Automotive industry has been the leading industry for many years in respect of assembling and manufacturing fairly complex products in large scale. In addition, automotive industry has developed towards more flexible production technology allowing shorter series and more specialized vehicles to be built on the same production line, closing up the gap with aerospace industry in terms of batch sizes and flexibility.

This paper introduce lightweight assembly- fixtures and –grippers manufactured in composite materials to significantly improve the mechanical performance, weight and structural rigidity as well as the flexibility of production. In addition, the composite concept has successfully been used for replacing heavy manual equipment in steel where the mechanical properties improve production quality and ergonomics in the assembly lines.

1. Introduction

Introduction of the generic robot in the 70´s started a new industrial era. The generic robot allowed a new order of complexity and functionality having a large impact on the degree of automation. As the robot became more common and price and functionality improved, the complexity of the production system increased and so did the cost. The next great challenge for the industry is to combine a high degree of automation and a high degree of flexibility, ultimately utilizing the full potential of the generic robot and form a generic production plant suitable for a wide range of products and products not yet developed.

Figure 1 CuC production cell

AB VOLVO and ABB contacted FlexProp AB in 1999 to investigate the possibilities to reduce weight and improve functionality and mechanical performance on grippers/fixtures. The industry could foresee new innovative ways to plan production resulting in reduced costs and increased flexibility if the weight and performance of the grippers/fixtures improved significantly. It was also obvious to the industry that conventional materials such as steel and aluminium did not supply the necessary properties to fulfil the criteria's. FlexProp had at the time shown it feasible to significantly reduce weight on production equipment by introducing large C-frames for self pricing riveting made out of composite material. Since then FlexProp have worked closely with industry to developed, manufactured and tested numerous different equipments, materials and principal designs in a wide variety of applications.

The cooperation has been successful, the technology is running since 2004 and the first full scale plant is under construction utilizing the full benefit of a lightweight fixture system.

The idea

The idea required robot-manoeuvred fixtures of large dimensions, lightweight equipment beyond anything available at the time. It was indeed challenging to transform large grippers into geometric setting tools and judging from the knowledge available, not feasible. It was also obvious that the lighter the system could be made, the more accurate, faster and simpler the system would be. The success of the idea required a new innovative system of lightweight and rigid fixtures. Optimizing existing technology would not solve the problem.

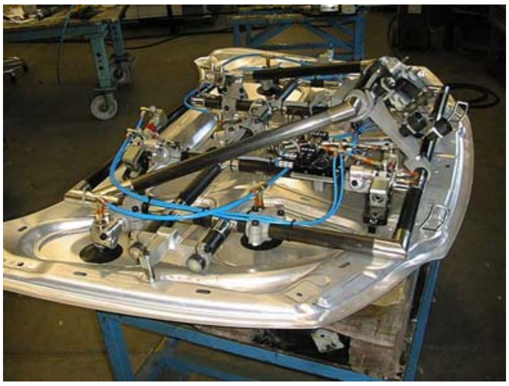

Figure 3 The very first gripper manufactured by FlexProp in composite material, in the late 90 s.

The lightweight rigid fixtures have a significant impact on how production can be planned but we are still far from understanding the full potential of the technology. Some of the more obvious advantages are;

- Logistics is reduced due to denser planning of the production line.
- Flexibility is improved in many respects as lightweight equipment is easier to handle.
- A larger proportion of the reconfigurable production system could be regarded as infrastructure and used to its full technical lifetime instead of being exchanged when a new model is introduced.
- The start-up time is shorter as a large proportion of the investments are standard equipment and each unique part normally could be tested in advance before being introduced on the line.
- Geometrical accuracy and off-line programming will be more accurate as the mechanical performance in terms of temperature-, geometry-, and dynamic stability is improved.
- Energy consumption is reduced due to less payload and there is a potential to use smaller robots.
- Lightweight fixtures allow production planning in a more efficient way, reducing investments and improve productivity.

- Production, people and knowledge could be exchanged in-between different plants as the production system is based on the same principles even if the products are different. The fixture itself is easily transported as the weight, fully equipped, is well within handling weight.

2. MATERIALS

In addition to toughness, a gripper is designed for stiffness - fundamental knowledge to understand to improve performance on grippers/fixtures, strength is normally not a problem. By comparing specific stiffness and allowable yield stress/deformation between different materials it is shown that composite material has significant potential to improve performance on gripper / fixture systems, table 1. A high specific stiffness allows lightweight stiff designs and high elongation to yield point / remaining deformation improves toughness.

Material	Yield stress MPa	Elongation %	E modulus GPa	Density kg/m^3	Specific Stiffness E/б
Steel	250-350	0,1-0,15	210	7800	26,9
Aluminium	200-300	0,28-0,43	70	2700	25,9
Composite	800-1000	0,8-1,0	100	1500	66

Table 1

The material used for the composite gripper system is developed and manufactured by FlexProp. The composition of the material is unique but in standardized dimensions. A material mix combining mechanical properties, toughness, machine ability and chemical resistance. The base structure is manufactured at room temperature and thereby minimizing internal stresses. The material is temperature stable; elongation due to temperature is close to zero and the material is resistant to weld spotting, oil, water and all chemicals normally found in a body-in-white shop.

3. DESIGN CRITERIA

Any equipment mounted on a robot forms a dynamic system with the robot. To fully understand the design criteria both the gripper/fixture and the robot has to be studied and the natural frequency of the system is of great importance for the performance of the production cell. To reduce design criteria to a question of moment of inertia and weight is a dangerous simplification of the problem, which could result in restrictions on how the robot can be operated. If the system does not have the necessary natural frequency it is likely to have a conflict between productivity and accuracy. Off-line programming and simulation will also agree better with reality if the system has the necessary natural frequency.

Studies of the systems´ and its components´ natural frequencies has been an important part of the research in addition to robustness, accuracy, service, economy and long term properties.

4. PRINCIPAL DESIGN

The research has up until recently focused mainly on the particular demands truck industry and especially cab production have. In 2006 AB VOLVO, Volvo Car Corporation and FlexProp launched a development program, within the MERA project, focusing on two issues.

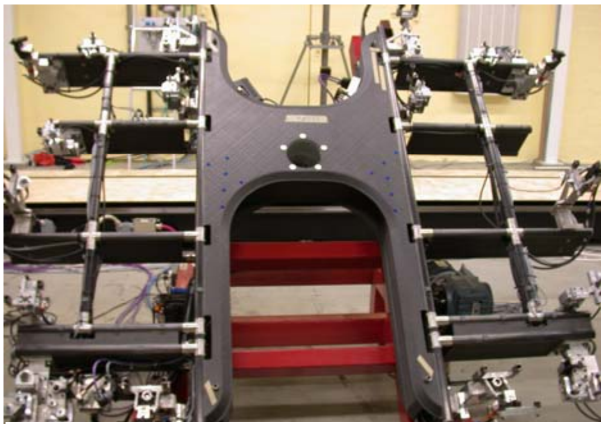

Figure 4 *An early generation of the CuC system, combining both pipes and box structure.*

- To broaden and adapt the technology for new applications, especially car manufacturing.

- The industrialize the manufacturing and design methods of the truck cab gripper / fixture system, the Cubic Composite Fixture System, CuC – Fixture System. [1]

The CuC system is normally but not solely a geometrical setting tool; optimized to handle large structures. Each CuC fixture is a unique fixture designed for a particular component, optimized for ultimate mechanical properties. The CuC Fixture System is used in demanding applications and it has become obvious that the CuC Fixture System is to complex where the demands are more moderate.

Figure 5 Principal design

The demand for a complementary technology resulted in further development and the CiC Circular Composite Gripper System was developed. The Circular Composite gripper system, CiC system adds flexibility to the CuC system and form a modular system of its own with similar functionality as the modular aluminium systems available on the market. In addition to flexibility and excellent mechanical properties the cost for a CiC system is competitive compared to conventional aluminium system. The CuC system and CiC system are compatible and both systems could be integrated with conventional aluminium and steel systems.

5. DESIGN PROCESS

The CuC system is best described as a box with standardised interface surfaces - surfaces where clamps and various equipments are attached. These interface surfaces are made out of steel or aluminium up to customer specifications and are mounted on the base structure within high tolerances. The outline of the base structure, the positioning of the interface surfaces and robot attachment is decided by the line builder.

6. INDUSTRIAL APPLICATIONS

For eight years AB VOLVO, ABB and FlexProp has built and evaluated several different principal designs. All equipment manufactured has been fully functional and is still in service with exception for the first demonstrator. Today, a significant amount of equipment are used in industry, some of the equipments have been used for as much as 4 years in full production.

All experience is unanimous, composite material is an excellent material - it combines weight, strength and robustness, making it a perfect light-weight material for equipment used in automotive industry.

7. WEIGHT AND PERFORMANCE

The CuC system is a geometrical setting tool and it is unfair to compare it with conventional grippers as the functionality of the CuC Fixture is quite different to a gripper. But there are some examples used in industry were the fixture is made mobile but manufactured in steel. The base structure of these steel fixtures weights approximately 850 kg compared to 55 kg for a similar CuC system. The steel alternative is carefully handled by a special gantry the composite alternative is handled by the same robot used for welding. Both productivity and investment cost are in favour for the composite alternative.

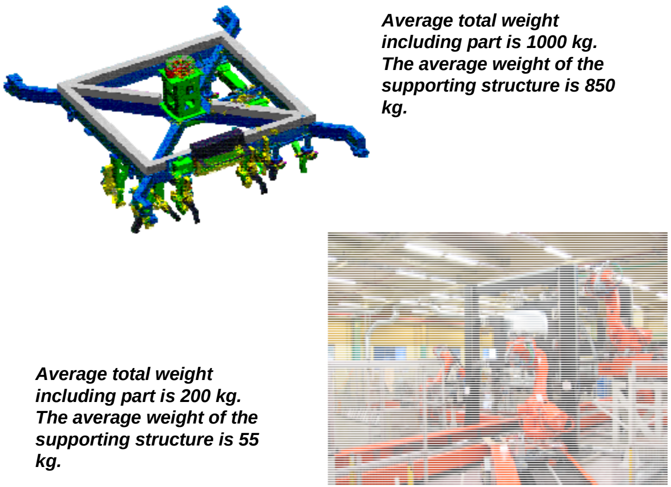

Figure 6 CuC fixture system compared to a conventional steel design with similar functionality.

Evaluation

To be able to evaluate mechanical performance a "standard beam" was designed in steel and two generations of composite designs. The beam was loaded with 160 kg, equivalent to normal service load in a typical truck cab application.

Figure 8.0 shows a steel beam. 8.1 the 5th generation of composite technology. 8.3 the 6th generation of composite technology with the same dimensions as the two above. 8.4 is the 6th generation of composite technology but with approximately 20% smaller dimensions.

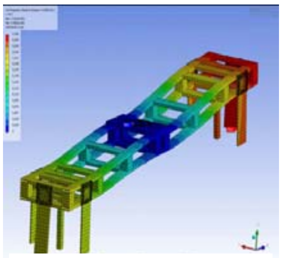

Figure 8.0 14 Hz / 86 kg

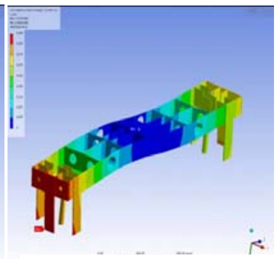

Figure 8.1 16 Hz / 41 kg

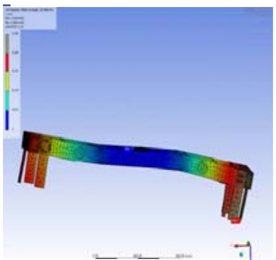

Figure 8.3 25 Hz / 26 kg

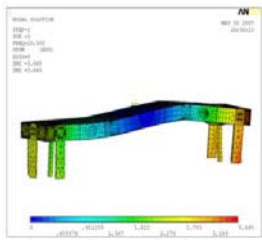

Figure 8.4 20.5 Hz / 21 kg

8. QUALITY

To design and manufacture a fixture/gripper involves a number of steps;

- Positioning clamps, locating points and robot attachment
- Principal outline
- Verifying functionality
- Final design
- Manufacturing
- Geometry assurance
- Documentation

The process above look somewhat different depending on customer and type of project but the process often involves many people and there is a risk for misunderstandings throughout the process. To minimize the possibilities for mistakes FlexProp has developed a quality assurance protocol and methodology for the most frequent situations. In the process of verifying the geometrical control procedures a number of different measuring systems have been evaluated to accurately verify geometry and performance.

9. ROBUSTNESS

For obvious reasons robustness has been in focus since the start and robustness has been tested in numerous ways in addition to full scale tests in production. One of the more spectacular tests was performed using a standard 200 kg robot to see if the robot was strong enough to cause any damage to a "standard beam". The beam was thrown towards a welding bench and towards the floor with full power available. The beam was inspected and measured and no deformation or damage was registered. It is our conclusion is that the composite technology shows robustness not yet experienced in grippers used in automotive industry.

Figure 7 Test of robustness

10. MAINTENANCE

Figure 8 Service personnel at training

All experience so far is unanimous - the CuC system requires minimal maintenance. The only experience so far from structural damage has been due to a collision with a truck. The damages caused by the collision were repaired by service personal while participating in a training course. The fact that all wiring is protected inside the base structure also reduces risk for wear of the pneumatic or electric equipment.

To work with carbon composite material requires somewhat different skills, compared to steel and aluminium. It also requires some new hand tooling, compared to what normal is found in a body in white shop. A selected number of service personnel was trained in a three days course, after this class the personnel made some serious redesign of two fixtures. With a short introduction, the right set of materials and tooling, existing personnel can do the necessary maintenance and in most cases even redesign without involving external expertise.

11. REDESIGN

The CuC, Cubic Composite Fixture system, has some unique qualities that allow extensive rebuilding of the equipment. The principal design in combination with a stress-free design and glued structure makes it possible to do complex redesigns without loosing mechanical performance or tolerance.

Figure 9 Left picture show the gripper before redesign and the right picture show the gripper when the new outline is built on top the original design

Due to a most unfortunate series of misunderstandings a gripper made for AB VOLVO had to be redesigned. Approximately 1/3 of the structure, including three interface surfaces was affected by the redesign.

Principal methodology

The methodology is based upon the fact that the original design is stress free and that the redesign it self does not introduce any stresses.

Figure 10 Finished gripper

- The new outline is specified
- New plates are machined as top, bottom cover and sides.
- In this particular case some interface-plates were required to reinforce the connection in-between the original design and the new design.
- The new design is build on top of the original design.
- The superfluous is separated from the new design.
- Finish and reinforcements

Results

Geometric tolerance, mechanical properties and weight is equivalent as prior to the redesign.

12. CiC GRIPPER SYSTEM

The CuC system is an exclusive mobile fixture system with excellent mechanical properties.

To take full advantage of the CuC system it is essential that the process is planned accordingly. As a complement to the CuC system the CiC system was developed,

focusing on competitive price, modularity and mechanical properties.

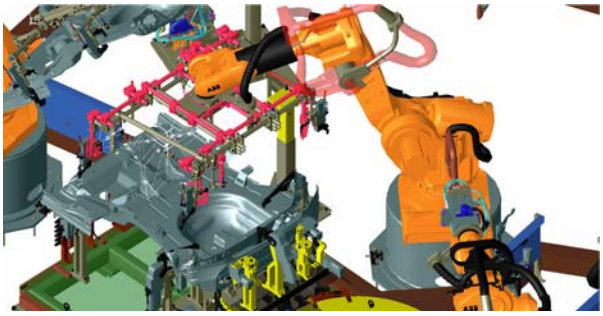

Figure 12 Simulation of a CiC gripper

Figure 11 CiC Gripper

The development work resulted in a fully modular building system made out of carbon composite material. The first CiC system is built around 38 and 23 mm pipes and couplings in carbon fibre and some aluminium parts for robot attachment and clamp attachments. The couplings are made out of plate material, machined to sharp tolerance and glued together to form a three dimensional structure - a coupling. This method minimizes investment cost and allows a wide range of different coupling to be developed without requiring large investments.

The example, figure 12, will be the first CiC system used in full production. The complete gripper weights 37.3 kg. The base structure without clamps, robot exchanger and valve block weights 20.5 kg and this should be compared to approximately 75 kg for the equivalent aluminium design, figure 14. The overall dimensions are, 1700 x 1274 x 630 mm. The CiC gripper will be installed by the end of week 18 2008.

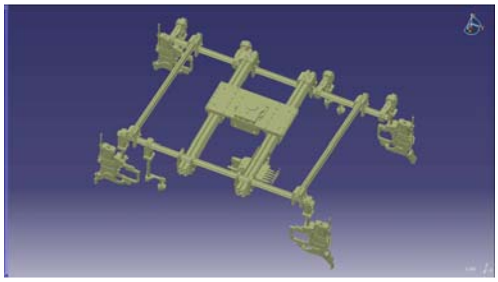

Figure 13 Aluminium alternative

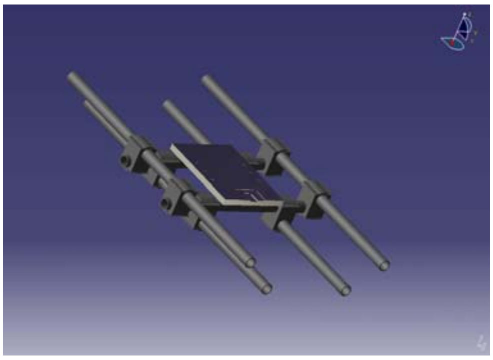

Figure 14 Central beam

The principal design for the particular CiC gripper is built around a “beam” consisting of four members. This principal design is very efficient both from a performance- and a cost-perspective and will most likely form a standard for future designs.

If everything is excluded from the gripper, figure 15, except for the central beam the weight is reduced to 10 kg. For each new cross member we have to add four 38/38 cross couplings in total 1 kg, the 38 mm pipe adds 0.5 kg/m.

13. MANUAL EQUIPMENT

In addition to study robot manoeuvred fixtures/grippers the research program has just briefly looked into manual equipment.

Weight and robustness is always an issue when designing manual equipment. Composite material allows significant weight reduction and excellent robustness. The work has resulted in a method of designing and manufacturing manual equipment based on a combination of the CuC and CiC technologies. Even if most of the manual equipments are unique it is in many cases quite feasible to design and manufacture manual tools with standardised materials and manufacturing methods, reducing development cost and lead-time.

Figure 15 A manual fixture designed in composite material

A case study

This particular manual equipment is used to assembly a hatch. By designing the fixture in lightweight composite materials quality and ergonomics have improved. The cost for the second generation steel fixture is equal to the composite design. The new lightweight fixture is for obvious reasons easier to handle and the toughness in combination to the lightweight design make the fixture significantly more robust and thereby geometrical stable. The weight was reduced from 5 kg to 2 kg.

Figure 17 First generation steel fixture

Figure 16 Second generation steel fixture

ACKNOWLEDGMENTS

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[1] CuC Fixture System and CiC Gripper System are registered trademarks by FlexProp AB and both systems are patented.