Selected aspects of modular fixtures design for car body production

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Abstract. Nowadays, technical design is supported with a computer hardware and software. In order to ensure proper efficiency and comfort of the designer's work, it is necessary to have hardware with good enough parameters and software able to transform concept into a virtual world. Firts of all, designing modular fixture for car body assembly it is obligate to obtain the necessary input data [2, 4]. It is connected with the close cooperation of designs engineers with the process designer and robotics. The sequence of manual or robotized operations and also the order of putting parts to the station must be clarified. Cooperating devices should be defined to avoid potential collisions. The correctness of this data is necessary for the designer to select the right tooling, and then to project the complete device. After receiving the input data, design engineer has to plan the method of picking up all degrees of freedom of every car’s body part. An important element of constructing the modular fixtures in the automotive industry is design methodology for manufacture and assembly (DFMA). Designing such types of fixtures is time-consuming. Therefore, to make work easier in case of structural changes (face-lifting) compliance with the DFMA principles is indispensable.

1. Introduction
Depending on the company for which the production line project is being designed, the constructors most often use advanced graphic programs (eg. CATIA or NX). The company’s standard determines the version of the software used and additions (eg. macros) that are necessary for correct management and data exchange [2, 4]. An important element in the design of modular fixtures is the fact that in the case of symmetrical to the car's symmetry plane elements, only the components on the left side of the vehicle are constructed. The right ones are a mirror image. In practice, the production line of the left side of the vehicle will be designed. The exceptions are unsymmetrical parts (eg. fuel fill) or situations where the process cannot be symmetrical (eg. no welding robot’s range). After receiving the set of input data, such as the number of joining elements, their orientation, course of the process, cycle time and the placement of cooperating devices proposed by the robotic, designer proceeds to plan the method of taking away all degrees of freedom from the car body parts [3, 5, 8].

2. Taking away degrees of freedom
Only immobilized body parts can be joined with the required accuracy. This is usually done thanks to centering and clamping units. The centering unit accurately positions the element and takes five degrees of freedom at the same time. Apart from a few exceptions for one element, two parallel
Centering pins are used in the technological holes of the part. These are made during pressing body parts with an accuracy of not less than 0.1 mm, figure 1.

![Figure 1. Selected plate with taken away five degrees of freedom. Two technological holes (one circular, the other longitudinal) were made with the process in mind.](image1)

Constructing the centering modules, it must be checked carefully that the pins will not interfere with the parts assembly when departing the station after the process has been completed. For this purpose, the parallelism of the technological openings is checked in all elements of the car body included in the assembly at a given fixture. If these holes are not parallel, this means that when the assembly is leaving from the fixture by hand or through the gripper it will be wedged in the fixture. In order to avoid this situation, the centering pins are placed on the actuators enabling them to be pulled out the hole before the gripper or worker receives the element, figure 2.

![Figure 2. Centring pin on Tünkers pneumatic linear actuator. Open position marked in semi-transparent.](image2)
![Figure 3. Marked plate with taken away six degrees of freedom.](image3)

Centering pins are mainly made of heat-treating steel. This provides an abrasion resistant surface during repeatable contact with the sheet while a core is still flexible. Another important element of the station are clamp units (German: spanneinheit). They are mainly responsible for taking away the last free degree of freedom and for ensuring the required stiffness, figure 3.

![Figure 4. Tünkers clamp unit.](image4)
![Figure 5. Global coordinate system of the vehicle.](image5)
The construction of the clamp unit consists in providing the plate of two supports - fixed and movable. The movable support usually performs its movement on a rotating unit. These are clamping units of manufacturers such as, for example, Tünkers or Destaco dedicated for this application, figure 4.

Each element in contact with the car body is made on a CNC machine to ensure accurate sheet’s shape. Then it is surface hardened on the contact surface, blued, and marked with the number of the element with which it has contact. After mounting, its position is accurately measured using a coordinate measuring machine. The position of measuring holes of all supports must be precisely defined using three total coordinates, figure 5.

If it is not possible to use standard units’ to away all degrees of freedom, in special cases, devices such as magnets or vacuum cups are used.

3. Design for manufacture and assembly

The production process has a significant impact on the of final product costs. Designing in accordance with the guidelines of the design for manufacturing and assembly (DFMA) methodology, a shorter assembly time can be achieved by reducing assembly tasks and unnecessary components necessary to assemble the product. Therefore, the design is done so that the number of elements is as small as possible (as few as possible separable connections), and the assembly operation as simple as possible (eg. good access to screws). In addition, the principle of modular assembly that allows servicing or introducing construction changes for individual units separately.

For this purpose, they are mounted separately on screwed consoles enabling their easy disassembly figure 6. In addition, the construction of assemblies is avoided in a way that enforces sequential assembly. Connecting the body parts with a process requiring very high accuracy and each disassembly of the element responsible for the proper position of the parts makes it necessary to check the correct position of this element before resuming the production process. From the maintenance point of view, elements that are periodically serviced or replaced should be able to be dismounted in the simplest and fastest possible way. Very often, the ease of assembly is associated with a compiled production process. The constructor responsible for the design and documentation of the machine or device should decide whether it would be more reasonable to facilitate assembly or manufacturing. If an element requires complicated machining, it may be wiser to screw or weld it from two simpler ones. It depends of course on the function of the element and the type of material used.
4. The construction form of an exemplary fixture

The considered issue concerns the connection of roof cross members (1) with an evacuation hatch frame (2) figure 7. It was decided to combine them using special adapters figure 8.

The hatch frame will be connected to adapter parts by spot welding. On the other hand, it is problematic to connect adapters with the roof beam. Strength verifications and the multi-criteria optimization carried out that the considered elements will be joined by a riveting method at a manual fixture. As all operations will be carried out by the operator, all the elements it supports must have an ergonomic position.

Occupational safety and health regulations tell that they must be placed at a height of 985 - 1285 mm figure 9, and all handles or switches at a height of 785 - 1485 mm figure 10. In addition, of course, it must be paid attention to the fact that the loading of the sheet was straight (preferably vertically), and access to any switches or levers unhindered.

Another input is orientation of the elements. Taking into account the geometry of the plates, their position will be opposite to the normal one (i.e. the one in which it occurs in the assembly of the entire body). It will also make it easier to add adapters after drilling rivet holes in the roof cross member. Thanks to this, they will be able to be placed in the right position with vertical movement, without complicated activities [9].

A main frame was made of Item company elements figure 11. To ensure the worker’s ergonomics, the frame height from the profiles has been set at 905 mm. As shown in the below model, there is also
a special handle to facilitate the movement of the station. Taking in mind increasing the comfort of work, there is a place for putting away tools, for rivets, and drawers for shavings generated by the drilling figure 12.

![Main frame made with Items elements.](image)

**Figure 11.** Main frame made with Items elements.

Another element of the station is a plate screwed to the frame, and to which also modular groups will be screwed to take away required degrees of freedom. The plate also contains parts positioning elements figure 13. They are adjusted in such a way as to make it easier to place all parts on the fixture figure 14. Such a solution minimizes the risk of positioning elements in wrong technological holes or placing parts in incorrect orientation.

![A - drawers for shavings, B - drawers for rivets, C - shelf for drill and riveter.](image)

**Figure 12.** A - drawers for shavings, B - drawers for rivets, C - shelf for drill and riveter.
The next step in the construction of the device was to take away the roof beam of all degrees of freedom. It is worth mentioning that the element has a symmetrical shape. This made it possible to model the clamp group only on one side and use the "mirror" function. The same was done with the fixed support of the roof beam, which was placed at a height of 1165 mm. The centering modules have not been designed as a mirror image, because the arrangement of the technological holes is not symmetrical. Such a solution also prevents placing the beam in incorrect orientation (poke-yoke). One pin was placed in the round hole, and the long one. This way we can see cross member with taken away five degrees of freedom figure 15.
Clamping unit (movable supports) are placed on Tünkers manual clamps. In the same sub-assembly figure 16, guiding elements for the drill were also designed. A specially milled element was equipped with sockets for drill bushes, which ensured precise location of the drill. Their nominal diameter is equal to the diameter of the drill, however, the dimension is tolerated deep into the material. Such selection of elements will ensure adequate accuracy and eliminate the risk of stuck drill in the guide sleeve figure 17.

Positioning the second element, it must be remembered that it will be riveted with the roof cross member. Therefore, the movement should not be taken away from in the direction of force clamping the two parts by rivets. The position in this direction will be determined after the operation. For the construction of the mobile support, the same clamp was used as for the cross member. The problem was to construct a fixed support. If its position was not moving, it would clash with drilling of the cross member figure 18.
To avoid the situation as in the figure above, a linear actuator with a position block was used. This allows obtaining a fixed support with the exact position while maintaining the possibility of avoiding collisions (lowering the support during drilling). It is particularly important to ensure the adjustment of the position of the supporting elements to ensure alignment for the rivet holes figure 19. Using the fact that the intermediate elements are identical on two sides of the roof beam, and their symmetrical position both groups (similar to the roof beam groups) have been modeled only on the left side and transferred by the "mirror" function figure 20. After correct adjustment of all elements and positioning of the plates on the station, all elements can be riveted with each other. After checking the lack of collision of all modules between each other, the final form appears in the picture below figure 21. The next step after the production of the device must pass quality control in terms of ergonomics, accuracy and repeatability of the process and ease of servicing. When quality control is successful, employees will be trained in the operation of the device.

5. Conclusions
The automotive industry is a perfect example of the concurrent engineering concept. When designing these types of modular fixtures, it is necessary to closely cooperate with the groups of engineers responsible for process planning, construction, process simulation and robot programming. The constructional form of the device depends on many factors. These are, among others, the method of car body joining or the degree of automation \([1, 6, 7]\). In the case of manual or semi-automatic devices, the designer must ensure proper ergonomics, safety and operator working comfort. If the position is at least partially automated, it should be designed as to minimize the possibility of a
collision that can stop production. In both cases the time spent on reliable analysis and elimination of potential construction failures at the design stage is several times cheaper than the costs of losses incurred on account of them. Designing a fixture in a modular way is a facilitation for the constructor who can more easily divide his work into several stages. The division of the fixture into modules is also the making production and maintenance easier at the same time. Assembly or servicing can be limited only to work on specific modules.

6. References

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