



CAD/CAA MODELLING ASSEMBLY OPERATIONS OF TANK WAGGONS

**Arandjel BABIĆ
Aleksandar ŽUKOVSKI
Vladimir JAKOVLJEVIĆ
Marina PLJAKIĆ**

Abstract: Virtual product design represents a technological key for reduction of costs arising from the errors generated in the processes of engineering design during lifetime. It is important to establish a connection between CAD design of products and complex limitations of assembly operations in CAM so that the design process is provided with the conditions for development and modification in a virtual environment before the beginning of production. This integration can be seen on the example of tank waggons. The advantage of this linking in design processes is in overcoming creation of expensive physical production systems so that all variant research could be carried out on a virtual model.

Keywords: CAD, CAM, CAA, assembly, tank wagons

1. INTRODUCTION

Production of wagons, according to the involved resources needed for its realization, belongs to the production of capital goods, such as Architecture, Engineering, Construction (AEC). Designing for this type of industry is characterized by the so-called user design or the design for the known customer and for one from the type of standardized products. Production Technology of the standardized goods is reflected in

- technological processes whose feature is the common content and the sequence of most technological operations,
- groups of workpieces with common structural characteristics.

Research results achieved during many years of working on developing project methodologies, production and verification of the unified and standardized solutions of wagon constructions, first of all wagon tanks, were acquired in activities related to the integration of CAT (Computer Aided Testing), CAD (Computer Aided

Design) and CAE (Computer Aided Engineering) technologies applied within the concept of competitive design. These results are oriented towards the support of: (1) product and technology design process, (2) production and assembly processes and (3) increase in the exploitation security, the so called secondary product safety [1].

In recent years the department of Computer-integrated processes on the Faculty of Mechanical Engineering in Kraljevo we have been working on projects that are based on the integration of engineering design process.

The complexity of assembly processes and technological processes for manufacturing components for the designed product has a huge influence on costs, profit and possibility of recycling. The engineering model of product integrates a large number of DFX approaches, where only after a detailed consideration can it be estimated and adjusted before it is launched into production (the milestone in product development).

1.1. Unification of wagon tanks

The integration of the CAT/CAD/CAE technologies was carried out by teams of specialists in the development of engineering product modelling and the mentioned concept is shown in Fig. 1. The development of new technologies, especially computer technologies, caused the algorithm given in Fig. 1b. to change significantly exactly in terms of greater integration design modules, analysis and testing.

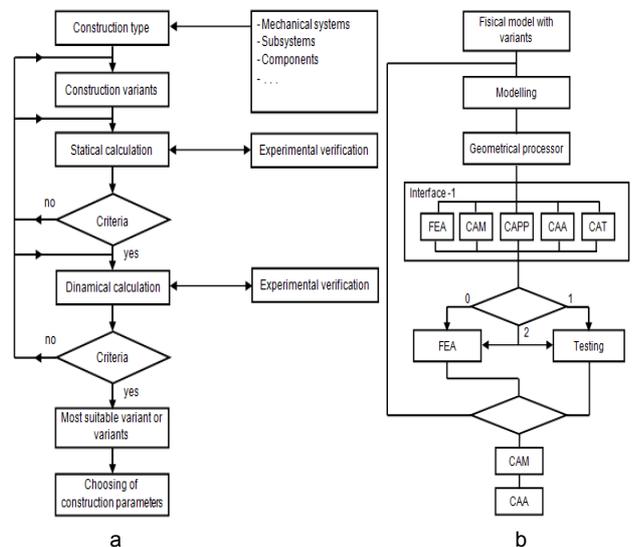


Fig.1. The concept of unification and the theoretical approach to modelling in the wagon design [1]

The identification and classification of the product and its subsystems, or the definition of the natural representative, are the basis of every unification. In the activities that focus on the introduction of CA (Computer Aided) technology in the products and technologies design, and then in the integrated production management, on the level freight cars production (Wagon Factory Kraljevo), we worked out in detail the unification and standardization of tank wagons, as the first step.

In fact, the product model is a transformation in which all geometric and topological, technological and general characteristics are presented in the form of logical data structures or rules.

Bearing in mind that the production of tank wagon containers is done according to RID regulations and the regulations of certain railway administrations, in the case of the tank wagon design (Wagon Factory Kraljevo) priority was given to typification and standardization of the base and supporting structure as a whole. The main sub-assemblies of the supporting structure were implemented and verified to the level of standard solutions, Fig. 2.

1.2. Research in the modeling of the joined tank wagon

The joined solution of the tank wagon, Fig. 2f, is based on the idea to reduce weight of the frontal base by removing the struts, provided that the lateral forces through head-reinforced beams are transferred to the central girders. The role of lateral supports in the frontal part of the supporting structure is also to enable the connection of the vessel with the lower base. The connection of the vessel and the base is performed using rhomboid sheets (adjusted and unadjusted screw linking), firmly attached to the side rails in the frontal part of the stand. The pillar was based on full use of the cross section therefore, in exceptional situations of exploitation, it is a secondary safety element. In this way the vessel is kept from damage at high longitudinal loads, usually in a crash. This limitation in the modelling is important for tanks that are used in the transportation of hazardous materials.

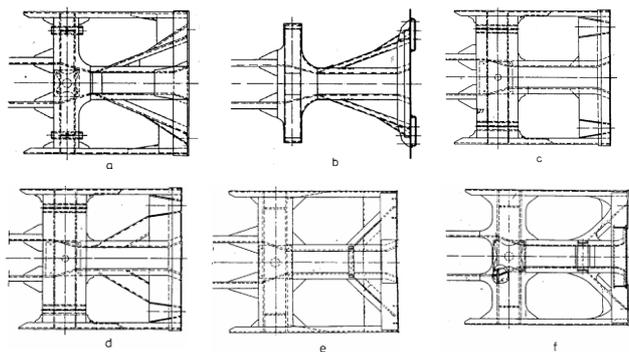


Fig.2. The development of the unified frontal part of the tank base

Torsional rigidity research has shown that a tank wagon must not have rigid supports on the boiler and the stand in the middle of the car. The connection achieved in the case of the joined solution does not allow elastic deformation of the stand in a vertical plane as expressed in the crash of the car. In this way the spiral and longitudinal rigidity of the supporting structure of the car is maintained so that in

a crash it is sufficient to provide the criterion of maximum force (1500 kN/per bumper) at the speed of the car hitting between 12 and 15 km/h. This criterion is met in case of cars which weight 90 t.

It is known that many solutions of the wagon supporting structures with axle load 225 kN per axle do not meet this limitation. Given this, the International Union of Railways UIC was forced to limit the speed of these car hitting to 9 km/h.

1.3. Arithmetic identification of unified tank wagon

In the development of the supporting structures several research projects based on the original product solutions with the use of won and verified methodologies were carried out. Developed and verified methodologies of testing CAT and calculation CAE of the freight wagons with the results obtained in their application form the basis for quality development of automation in the design process through the implementation of the criteria of unification and standardzation elements and the supporting structure as a whole. The calculation of strength of the supporting structure is carried out based on modern methods of applied mechanics and strength of materials. Rating the strength and reliability of the supporting structures is based on the appropriate standards for the calculation of the recommended strength.

The standards include the fulfillment of the following criteria:

- Permitted stress - maximum strain is compared with the allowed one, while static and / or dynamic strength and life are provided by the choice of permitted stress,
- Stability of compressed elements,
- Deflection (deformation),
- Limit load specified by the phenomenon of plastic deformation of the elements
- Empirical rules (for specific elements).

For the evaluation of support structures according to the first three conditions it is necessary to know the stresses under the influence of internal forces. In the process of designing the stress elements are obtained arithmetically, based on the arithmetic model of the supporting structure. Arithmetic model of the supporting structure must provide:

- the highest accuracy of the sizes that are calculated (internal forces, stresses and movements) for adopted approximation on the construction and
- the way how to represent elements of the supporting structure (rods, beams, slabs)

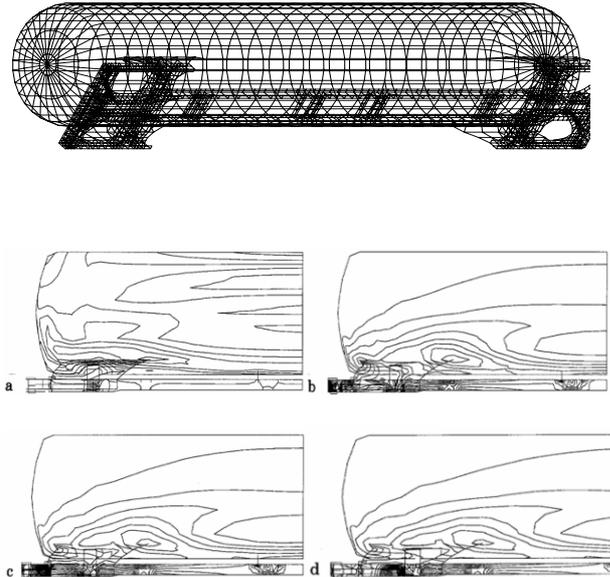


Fig.3. Distribution of stresses on the supporting structure of a tank in case of static load

Fig. 4. shows the dynamic model and the first two major forms of joined tank wagon oscillation. The equivalent rigidity of the finite elements in dynamic model of tank are calculated based on fine-static model and the results of verification of strength of the supporting structure in the static tests.

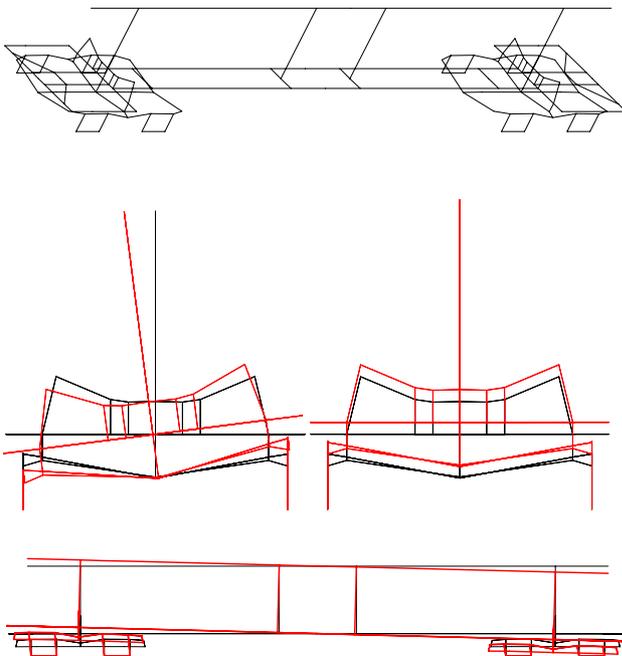


Fig.4. Dynamic model of tank wagon and the first three major forms of the free undamped oscillation of the loaded tank wagon: the first major form: $f_{01} = 1.62 \text{ Hz}$, $f_{02} = 1.65 \text{ Hz}$, $f_{03} = 2.43 \text{ Hz}$

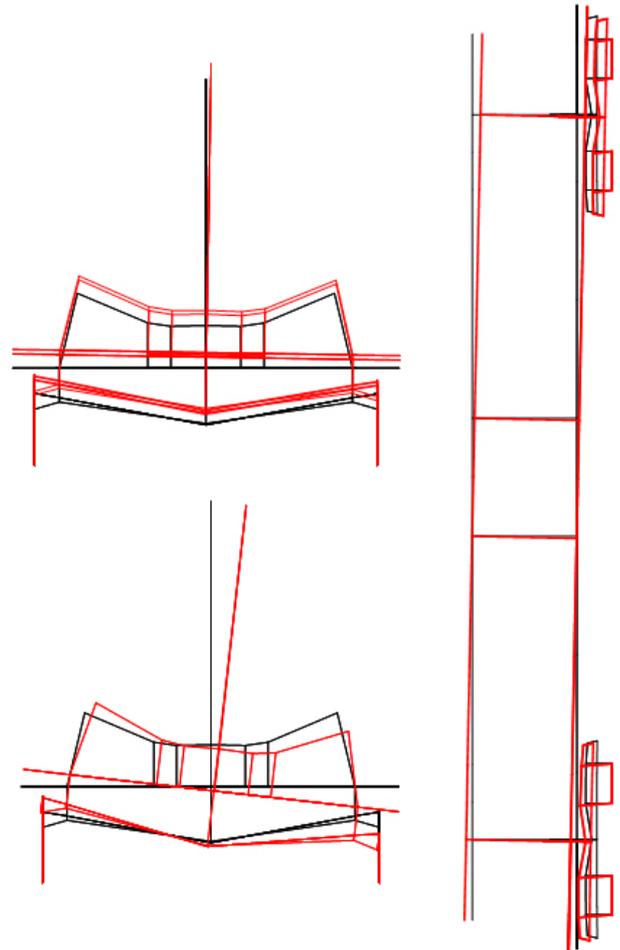


Fig.5. Major forms of the free undamped oscillation of the unloaded tank wagon: the first major form: $f_{01} = 2,69 \text{ Hz}$, $f_{02} = 3,68 \text{ Hz}$, $f_{03} = 4,22 \text{ Hz}$

1.4. Experimental verification of a unified tank wagon

Experimental verification of wagons in Kraljevo Wagon Factory has been running since 1961. In that year Bruel Kjaer's device for registration of stresses in static conditions using strain gauges was obtained. In the same year the device for the simulation of static load was designed. Later a ramp was made to test the wagons by hitting, and also measuring cars were purchased for performing test runs. So in the late 80s at the Research Center of WFK all the tests were performed according to B12/RP17 ORE.

Static and dynamic strength tests were first implemented in Kraljevo and then the tank wagon was subjected to testing in the Centre of French railways SNCF [2]. The test results fully meet the criteria of the ORE B12/RP17, and to illustrate it, Fig. 7. shows the diagram of the dependence of the measured force on the bumper and the speed of hitting.

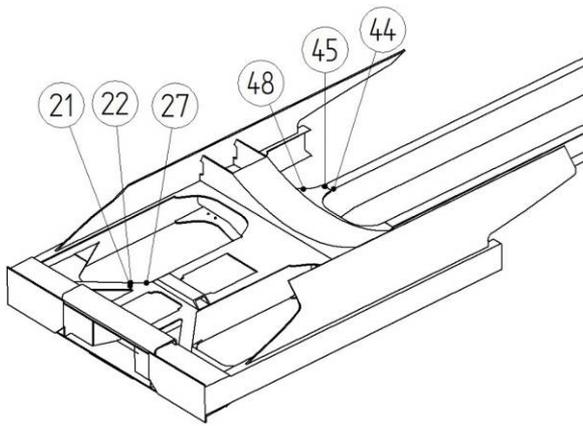


Fig.6. Measurements points in static testing tank wagon[2]

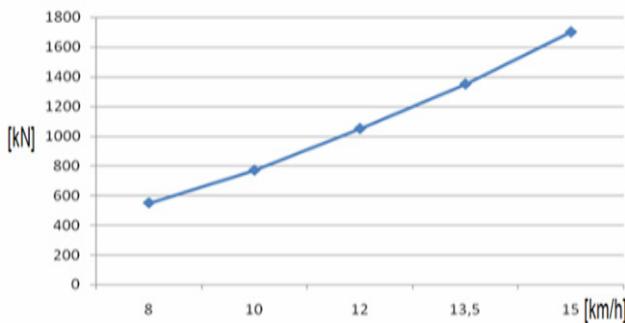


Fig.7. Curve of the dependence of forces/speeds in testing the hitting [2]

2. CAD / CAE MODELLING

Development of software packages in the field of simultaneous product and technology design at the beginning of the third millennium became much more important. This is reflected in the highlighted possibility of exchanging data between models that make simultaneous access to design. Platforms on which software packages have been developed meet the first condition that is defined in the simultaneous modelling, and that is transparency. In this way, it became possible to transfer the information from CAD models directly to the module for CAE, CAM and others. In the process of tank wagon modeling (CAD) the software package Solid Edge was used, and in the strength analysis of the supporting structure (CAE) ANSYS was used. In this way, we wanted to carry out comparative analysis of the strength of the unified tank wagon with the software package KOMIPS [3]. In this case, a comparative analysis is provided without a deeper insight into the results achieved, but only as an entry-level product model that is used in the assembly design.

Solid Edge is a computer supported system for product design (CAD / CAA / CADD) developed based on the so-called Stream technology. Stream technology provides an essential CAD user productivity thanks to newly developed concept of the engineering design the so-called solid modelling, (Parasolid). Through the principles of logical reasoning and decision-making management

stream technology makes Solid Edge easy to use and very productive.

Solid Edge includes unique tools for identifying and eliminating defects in design, thus shortening the time required for product development and reducing costs. The process of product design is not just about making a three-dimensional virtual prototype of products, but it is also about acquiring the knowledge that leads the engineering design process to a precise solution free from errors.

2.1. Modelling on the component level

The above mentioned software package in the modeling on the component level allows the construction of 3D models with real features. The components modelling process begins with the basic form such as a block or cylinder, with a description of the part to create the model. Descriptions include protrusions and the contours (extruded, revolved, swept and lofted), holes, ribs, thin-walled profiles, curves, drawing angles and grooves. It is also possible to create rectangular and circular arrays and copy the primitives symmetricly.

2.2. Modelling of the assembly structures

Solid Edge has a module for designing structures that enables the creation of complex assembly structures that consist of a large number of components and subassemblies. This software package provides a tight integration in the surrounding areas of modelling, visualization devices and appliances for the management of the component – component connection. This makes it easier to manage mounting data from the earliest stages of project planning, through the cycles of re-inspection, production, maintenance, all the way to archives.

The installation environment provides tightening the connection between the parts. These links are automatically supported through the development of design in order to preserve the design intent [4] [5].

2.3. FEM analysis

Software tools FEM are based on the application of the finite elements method, focusing on stress deformation analysis of mechanical characteristics of the product. In this case, the 3D model of the product is modelled in CAD software package (Solid Edge) carries the information that is imported through the interface into the program that is used for simulation of ANSYS. By their use, static deformations under the influence of external loads are simulated, to determine the real conditions of the way the product behaves. In addition to information related to the shape of the model under the influence of the load the information about the forces, bending moments, torsion, etc. may be shown. It is important to emphasize that the product model also contains information about the material necessary for calculations by finite element method.

Integration and use of CAD and FEM software packages allow, through the use of numerical calculation methods,

to perform the optimization of construction forms as well as testing of the behavior of the construction by using other construction materials.

Fig. 8. and Fig. 9. shows a model tank wagon modelled in Solid Edge-in, automatically generated finite element network, and stress state on the product in cases of load over buffers and stretching over traction boundaries.

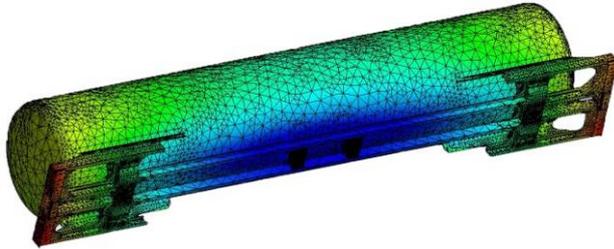


Fig.8. A Model of tank wagon

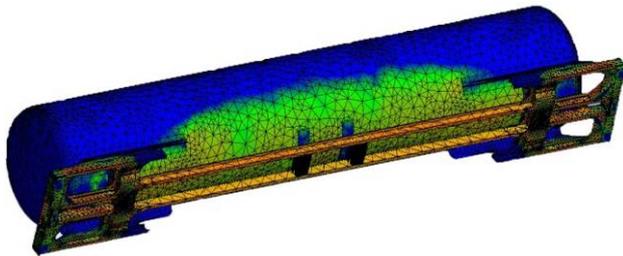


Fig.9. Finite element network and stress state

3. MODELLING OF THE ASSEMBLY STRUCTURE OF THE STAND

Complex assembly operations considerably increase the costs of production of complex products. Also, the products whose dismantling requires complex operations increase the maintenance and recycling costs. Costs for assembling and disassembling significantly influence the costs in product lifetime, which requires the application of design solutions that provide efficient assembling. The complexity of assembling can be defined as the complexity of restriction of mutual motion of the parts which are assembled. In order to prevent problematic assembly operations in the CAM environment, it is necessary to foresee the complexity of mutual assembling of components during product design in the CAD environment by applying virtual tools for assembling [5] [6].

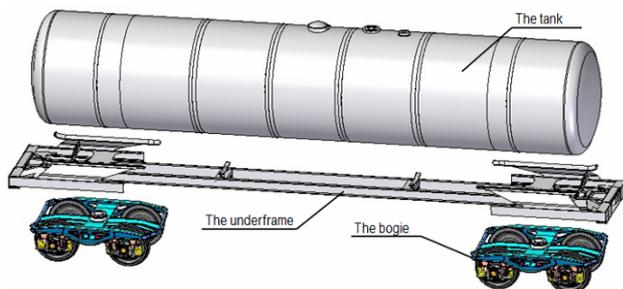


Fig.10. The main elements of the assembly of a tank wagon

3.1. Structural connections at the component level

In the design of assembly processes of underframe (Fig. 11.) which is important in this analysis, a much better effect of assembly rationalization is accomplished by simultaneous analysis of the product structure and the analysis of connections at the component level. It is very important to design components in such a way that their problems in assembly could be solved at the same time. It means that the application of assembly constraints, from the aspect of defined shapes, in well designed parts. The solution of the appropriate assembly process depends on the correct description of these characteristics of the part. From the aspect of assembly, the shape and assembly surfaces have a big influence.

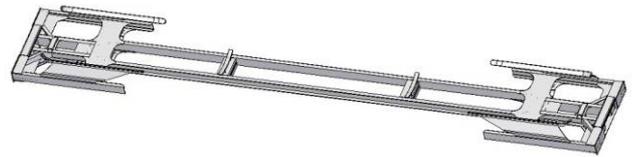


Fig.11. The assembly structure of underframe

The underframe consists of several subassemblies. The main subassemblies are presented in the following fig. 12.

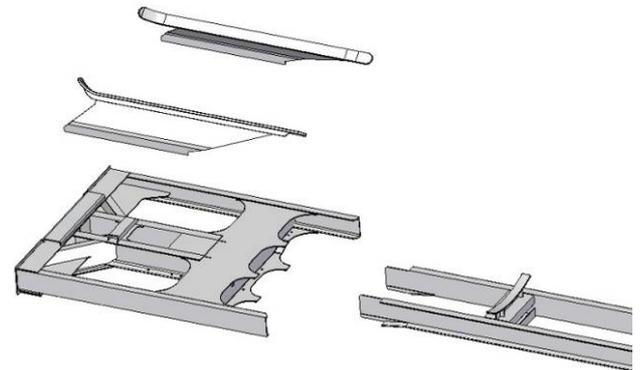


Fig.12. The underframe subassemblies

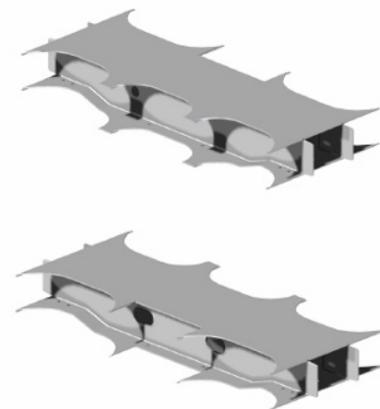


Fig.13. A model of the cross bearer

Detailed analysis of subassembly structures is done based on the example of the cross bearer shown on Fig. 12. The next Fig 14. shows the basic operations of assembly and joining of the cross bearer.

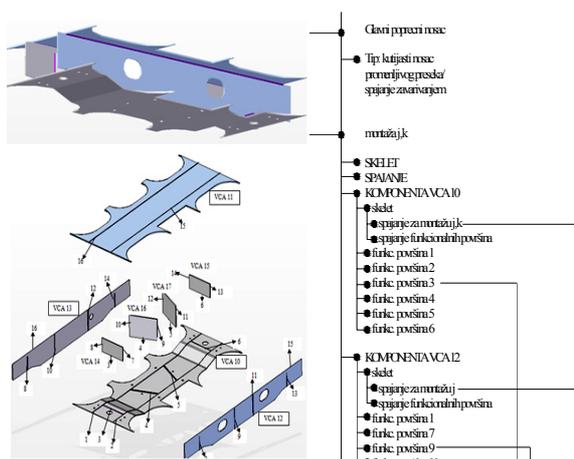


Fig.14. Cross bearer and the operations of assembly and joining [6]

In addition to the orientation of components the figure also shows the connection and joining is done by welding, whereby either functional or free surfaces are chosen to be the mounting surfaces. Functional areas can not be changed in favor assembly ones, but free can. In the design of the assembly process of the projected boom the so called precise assembly is seen with the elements of the assembly process defined to the level of intervention. This means that detailed links between functional and free areas for each component are given, and that the representation of the technological process of assembly designing is complete [6].

Final assembly of the lower base allows the realization of structure construction based on the automated welding process in additional positioning and clamping system whose axis is NC-controlled, Fig. 15. It was designed that the head of the robot that performs the welding is able to NC –control in six axes.

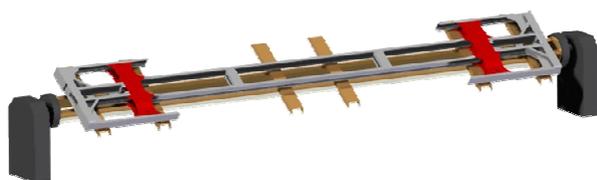


Fig.15. Positioning and clamping system for the process of final assembly of underframe

4. CONCLUSION

The introduction of the concept of integration based on CAx technology in the process of product design and installation technology leads to the improvement in the business results which is reflected in a faster, higher quality and lower cost meeting the demand coming from the market. This integration is given on the example of unified tank wagons that has so far been realized in a few hundred pieces. According to the DFX approach in order to form new models such as the CAM linking assembly operations. This linking allows the creation of higher-level models so that variant research of the production processes are carried out on the virtual model.

REFERENCES

- [1] Babić, A.: *Ca modeliranje u projektovanju teretnih vagona*, Monografija 30., Biblioteka Dissertatio, Zadužbina Andrejević, Beograd, 1997.,
- [2] Departemen des essais et des laboratoires: *Wagon-cisterne a bogies le transport de produits petroliers blancs de construction F.V.K.*, Essais statiques et dynamiques au tamponnement, MEV3 RG91112/91 V3-82, Direction du Materiel SNCF, septembre 1991.,
- [3] Babić, A.: *Modeliranje u integrisanom projektovanju proizvoda, procesa izrade i montaže vagon cisterne*, 13. Simpozijum CAD/CAM, Beograd 2000., str. 2.41-2.47.
- [4] Babić, A.: *Konceptualno modeliranje proizvoda i procesa u projektovanju vagon cisterni*, 28. Savetovanje Proizvodnog mašinstva Jugoslavije sa međunarodnim učešćem, Sekcija CAD/CAM/CAPP/CAE, Kraljevo 2000., str. 6.48-6.52.
- [5] Nemanja ILIĆ, Marina PLJAKIĆ, Arandel BABIĆ, „*Intelligent CAD design and assembly plan of milling heads*“, The 7th International Scientific Conference, Research And Development Of Mechanical Elements And Systems, IRMES 2011 April 27th to 28th, 2011 in Zlatibor, Republic of Serbia, p 109.-112.
- [6] Babić, A.: *Tehnologija montaže*, Udžbenik, Mašinski fakultet Kraljevo, Kraljevo, 2005.

CORRESPONDENCE



Arandjel BABIC, Prof. D.Sc. Eng.
University of Kragujevac
Faculty of Mechanical Engineering
Kraljevo
Dositejeva 19, 36000 Kraljevo, Serbia
babic.a@mfv.kg.ac.rs



Aleksandar ZUKOVSKI, M.Sc. Eng.
University of Kragujevac
Faculty of Mechanical Engineering
Kraljevo
Dositejeva 19
36000 Kraljevo, Serbia
a.zukovski@sbb.rs



Vladimir JAKOVLJEVIC, Ph.-D. Student
University of Kragujevac
Faculty of Mechanical Engineering
Kraljevo
Dositejeva 19
36000 Kraljevo, Serbia
babic.a@mfv.kg.ac.rs



Marina PLJAKIC, Ph.-D. Student
University of Kragujevac
Faculty of Mechanical Engineering
Kraljevo
Dositejeva 19
36000 Kraljevo, Serbia
pljatic.m@mfv.kg.ac.rs