

Use of articulated arm robots and parallel acting in flexible manufacturing cells

M. Costea^{(*)1}, A. Ancuța⁽²⁾, and G. Jiga⁽²⁾

(1) University POLITEHNICA of Bucharest, Splaiul Independenței, 313, Department of Robots and Manufacturing Systems, RO 060042, Bucharest, Romania

(2) University POLITEHNICA of Bucharest, Splaiul Independenței, 313, Department of Strength of Materials, RO 060042, Bucharest, Romania

Abstract— In this paper the authors followed the conception of a flexible manufacturing cell where robots with parallel acting, articulated arm and transportation systems have been integrated. In this study the behavior of industrial robots as well as the designed mounting solutions are analyzed. The functional role of these manufacturing cells is to achieve electronic components assembly for mobile phones. In order to manipulate the electronic component boxes, the authors conceived a modular effector equipped with vacuum gripping systems. For this assembly application there were selected two parallel acting robots (DELTA type) since their acceleration permits the achievement of working cycles in a minimum period of time. For the proposed structure a transient structural FEM analysis was carried using the ANSYS code.

Index Terms—Structural elements, articulated arm robots, DELTA type robots, robots programming.

I. INTRODUCTION

For the designed cell, in this paper the authors analyzed the behavior of parallel acting robots and the articulated arm robots with serial architecture and close kinematic chain. These robots are produced by the ABB Robotics being used in assembly or pick and place operations. Due to the high values of velocities and accelerations during the working cycles the authors used the most appropriate DELTA robot [1, 2], IRB 360-3/ 1130. This robot has a payload of 3 [kg] and a maximum action radius of 565 [mm]. The typology of the analyzed robot was conceived in a way to be suspended on a mounting structure. The second variant of robot used in our analysis was an articulated arm robot used to manipulate the components boxes. There are also other important components which have been used in the study such conveyor belts, IRC5 robot controllers etc.

II. STRUCTURAL COMPONENTS DESIGN

For the structure sizing, an isometric view of the final assembly has been plotted as one can see in Figure 1. For the upper part, a structural steel plate with a thickness of 15 [mm] is fixed, serving to the robot mounting. To establish the height of the structure, but also the distance between the aluminum profiles, an important role is given by the positioning of the robot, since, in the case of DELTA robot, the calibration procedure is different from that of articulated

arm robots. Calibration consists in placing each robot segment on the rubber markings located at the base.

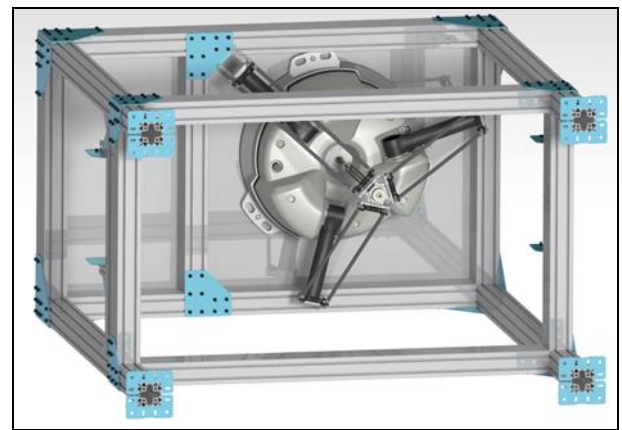


Fig. 1. Bottom view of the final assembly

After the 3D model of mounting solution in CATIA the authors extract the 2D sketches of the final assembly, as one can see in Figure 2.

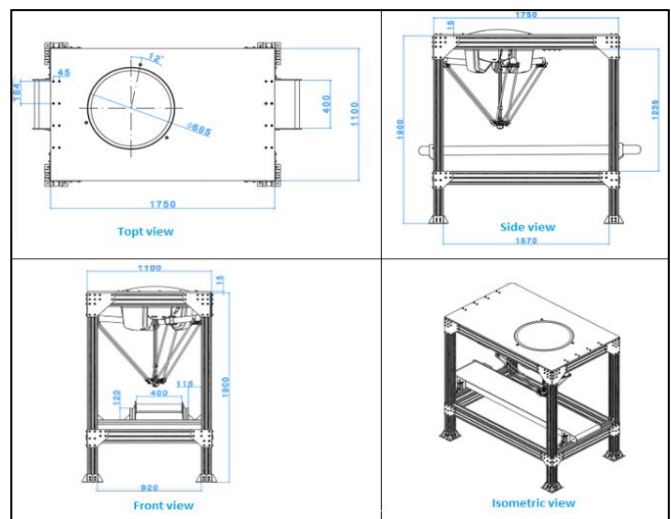


Fig.2 2D technical drawings of the modular structure

III. PHYSICAL ASSEMBLY OF THE MOUNTING SOLUTION

For the final mounting solution of IRB360 DELTA type robot it was necessary to use the 2D technical drawings plotted in Figure 2.

In Figure 3 the final assembly structure was depicted. It includes three different Aluminum profiles (45x45, 90x135 and 90x90), stiffeners, the upper steel plate necessary for the robot base mounting. The last but not the least, a conveyor

used for the mobile smart devices' transportation was added to the structure.

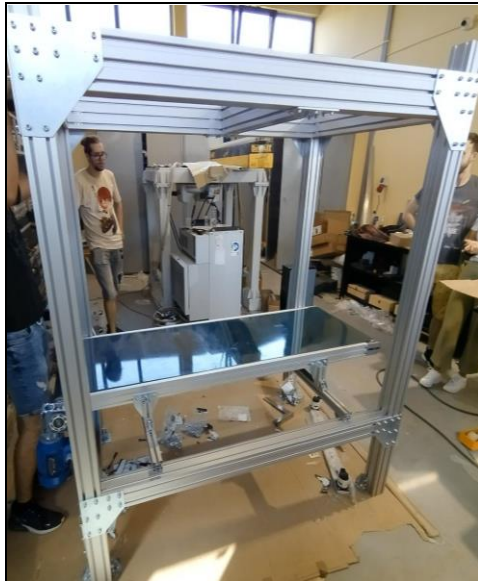


Fig.3 Final assembly of the IRB360 mounting solution

In the case of the analyzed robotic cell, the authors used a numerically controlled axis, synchronized with the articulated arm robot. This axis has a load capacity of 250 [kg] and its purpose is to carry the boxes with electronic compounds into a favorable position.

For the mobile part of the previous axis, a plate is designed to support the boxes handled by the IRB-2400. This component is attached to the axle by means of 12 screws. The size of the component is chosen depending on the working points where the DELTA robots are present. Two pneumatic cylinders with double action having a length of 400 [mm] will be mounted on the surface of this component. These pneumatic cylinders are needed to bring the boxes into the position where the IRB360 robot can act. Figure 4 provides an overview of these components.

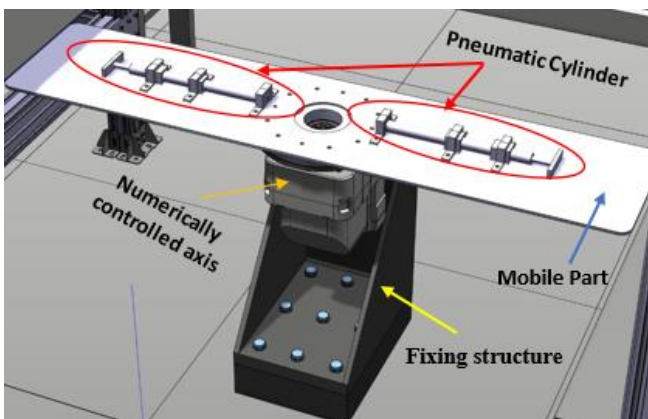


Fig.4. Numerically controlled axis

For the handling application but also for the assembly one where articulated arm robots and with parallel actuation were used, it is necessary to design an effector equipped with vacuum prehension systems. In case of ABB IRB 2400 robot for the support structure the authors designed a vacuum end effector realized of Aluminum components. Also, suction

cups and ejectors were included to obtain vacuum. In Figure 5 is presented a 3D model of the effector conceived for boxes handling operation.

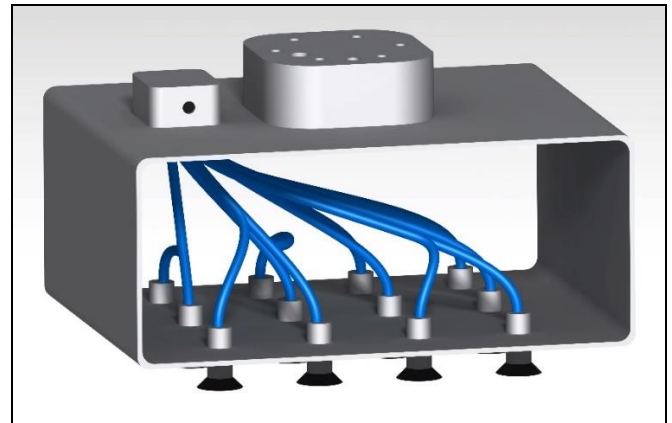


Fig. 5 Vacuumatic end effector for box handling

IV. DESIGN OF A FLEXIBLE ASSEMBLY MANUFACTURING CELL

A flexible manufacturing cell could be adapted to changes in the material flow. This includes transfer-transport systems with the role of supplying working points. In this case the manufacturing cell is equipped with three entries and one exit if we refer to the number of objects entering in the manufacturing system, respectively to the number of objects leaving the manufacturing system. In this case, the number of entries is given by the elements circulating on the entry conveyor (mobile phones), the number of boxes with the first and second type of electronic components (speakers and batteries). The industrial cell contains two DELTA type robots playing the role of assembling the electronic components entering in the flexible manufacturing cell. To transport the boxes with electronic components to the working points of the robots with parallel acting, the IRB 2400 robot was used, as well as an additional numerically controlled axis.

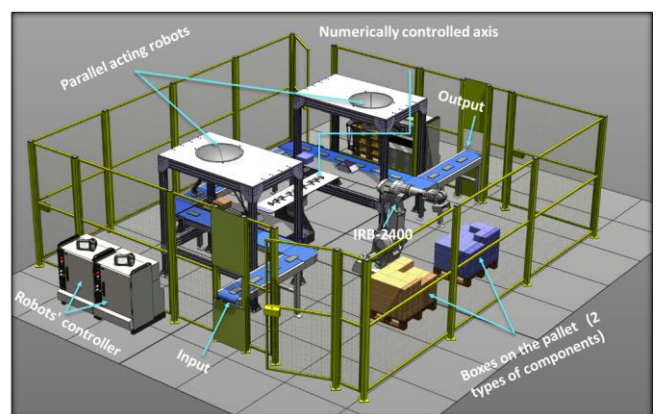


Fig. 6 Isometric view of the assembly cell

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V. ROBOTS PROGRAMMING AND OFFLINE SIMULATION

The three ABB robots can be programmed using their specific programming language, namely the RAPID programming language. For any robotic application as a pre-programming stage, it is necessary to perform the effector parameterization, more precisely the definition of a characteristic point attached to this one (called TCP - tool center point). Without this feature point, basically, the robot can operate only through a coordinate system attached to the robot base or flange, since they are the only defined elements. In the usual way, the effector parameterization can be performed in several ways, either by defining the TCP in Robot Studio (simulation software provided by ABB), or by defining it manually using the Teach Pendant (this method is more complicated because the following parameters should be defined: the mass of the effector, the center of gravity coordinates, the moments of inertia, but also the orientation quaternions). The quaternions represent the quotient of two directed lines in a three-dimensional space. Also, a characteristic point of the industrial robot end-effector could be defined using an automatic method through the Teach Pendant (method requiring the movement and orientation of the robot with respect to a fixed point). In this paper, the authors used the TCP definition in Robot Studio, as one can see in Figure 7 a and b. Following the steps presented in this figure, the coordinate system Z axis is normal to the flat surface. In the central part of Figure 8, the center of gravity coordinates (taken from CATIA) is depicted.

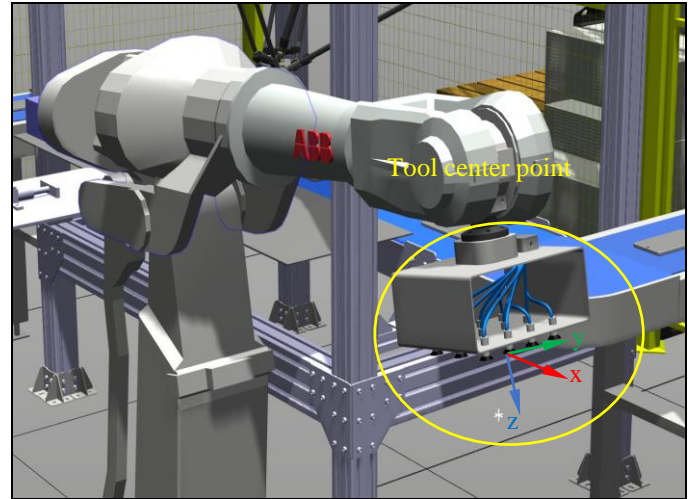


Fig. 8 Tool Center Point

For the safe exploitation of the robot, its working space, depicted in Figure 9, must be evaluated.

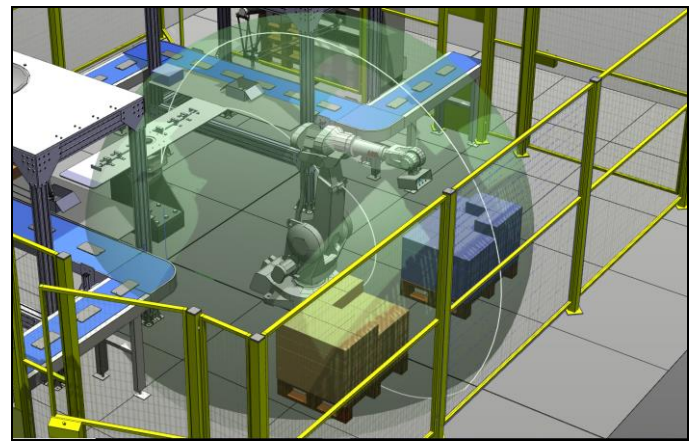


Fig. 9 Articulated spherical working space

The operations that the articulated arm robot [3, 4] should perform are represented by the handling boxes operations as well as their transfer to the numerically controlled axis.

To simulate vacuum generation, an input signal (I/O) must be used and managed, this fact being possible by using a block diagram (Fig. 10) or managing the signals using the training terminal.

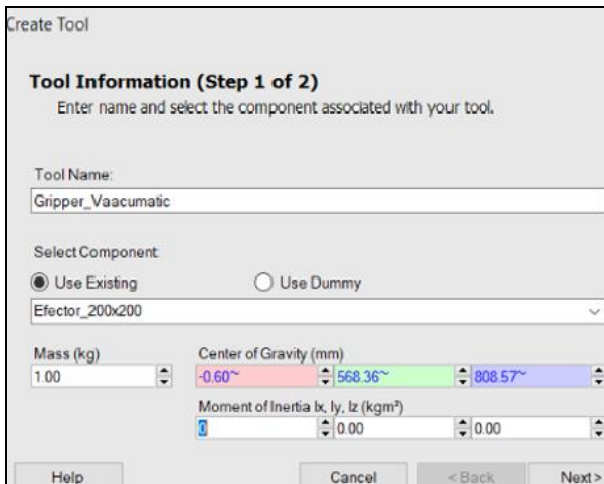


Fig. 7.a Characteristic point parametrization step 1

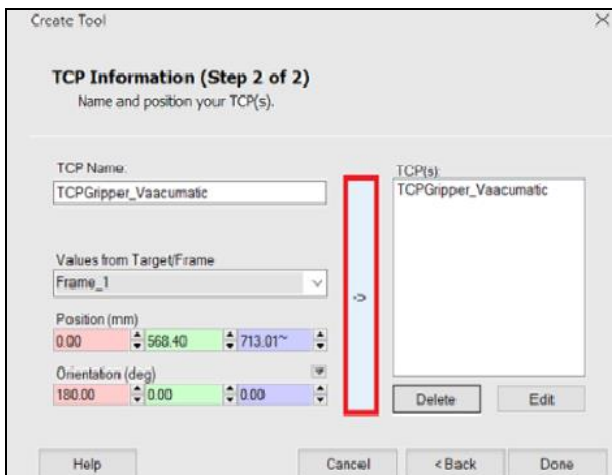


Fig. 7.b Characteristic point parametrization step 2

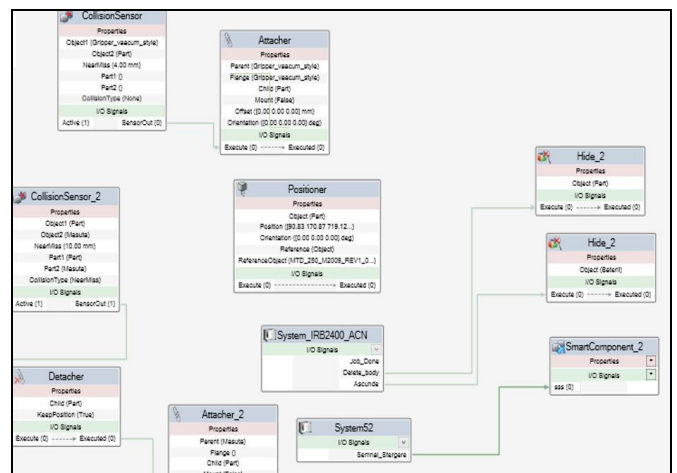


Fig. 10 Articulated arm block diagram of signal managing

These signals will be taken over by the control of the robot and managed by it, through the I/O Systems module. This allows access to all the signals necessary to perform certain operations. For example, in the present case the capacitive sensor integrated in the effector generates a logical 1 signal when the box with electronic components is detected. Thus, this signal must be managed and processed by the controller (IRC5 Single Cabinet) through the input-output module.

Following the sequential execution of the commands within the routines, as well as the use of some signals, the pick and place operation will be able to be performed in an optimal way. In Figure 11 one can see the result of the created routines.

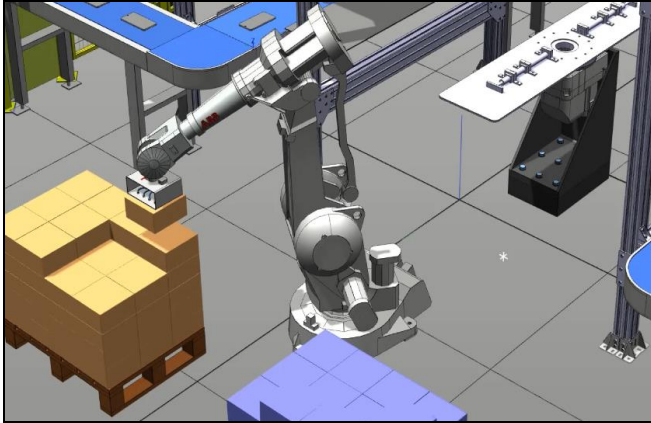


Fig. 11. a. Box handling

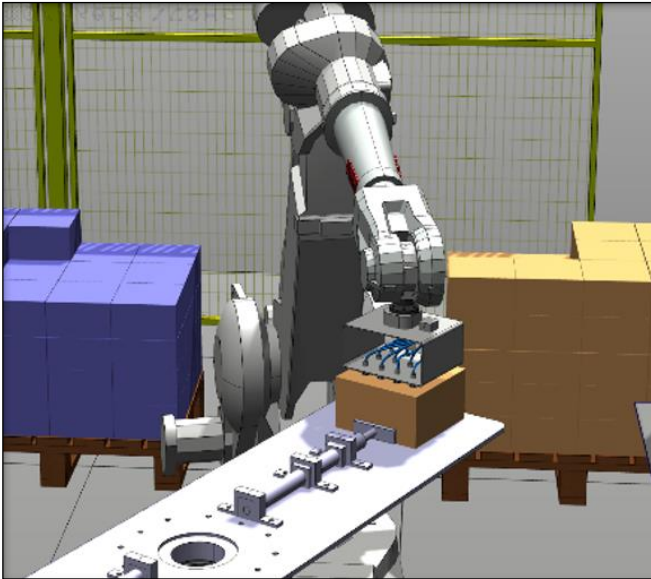


Fig. 11. b. Box positioning on numerically controlled axis

VI. TRANSIENT ANALYSIS

To evaluate the efficiency of the industrial cell, it is necessary to obtain the movement signals of the elements in motion. This is possible through the robot controller, which holds all this information. Execution times per work cycle can be obtained from the post-processed data using an Excel document (Figure 12).

The working cycle processing signals shown in Figure 12 will be used as input data for the definition of kinematic couples within the structural analysis in the transient analysis

module. The signal obtained for axis 1 (J1) is depicted in blue, the signal for axis 2 (J2) in red, whereas the signal for axis 3 (J3) in green.

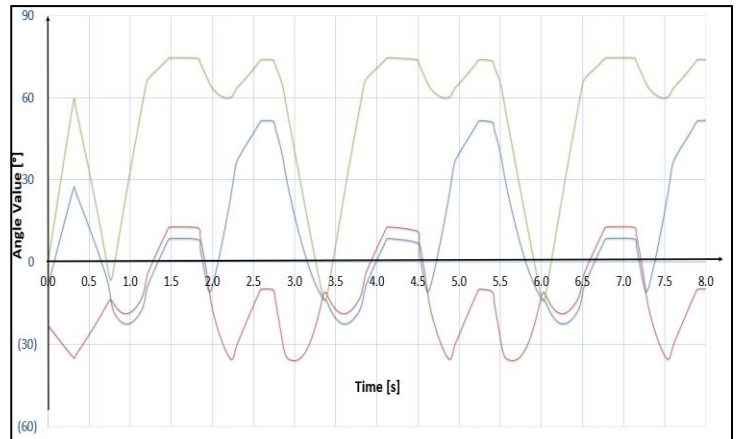


Fig. 12. Axis movement signals

In the present paper the authors performed a transient analysis whose purpose is the checking of the structural integrity of the IRB360 designed mounting solution. In this case the authors used a 3D model imported from CATIA V5 to be used in ANSYS code to determine the stress and strain state. This basic model was simplified since certain elements in the original model have a negative influence on the analysis (screws, washers, nut holes etc.).

In Figure 13 is depicted the simplified geometry of the mounting solution.

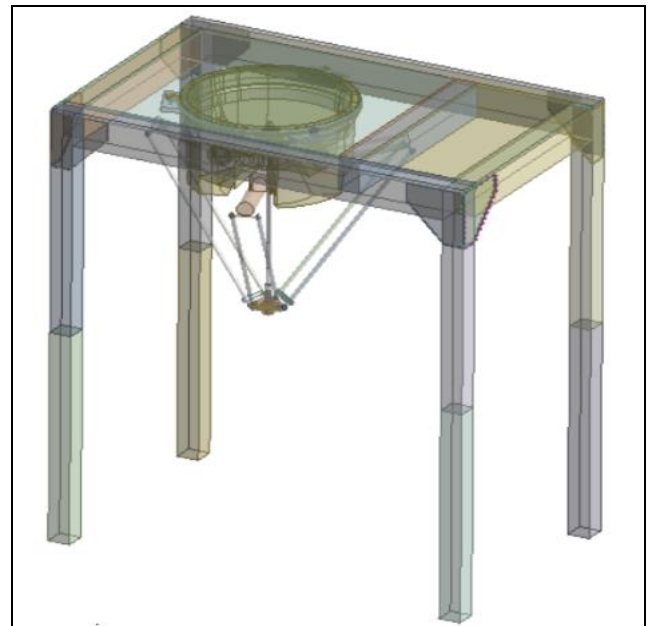


Fig. 13 Simplified geometry of the final assembly

The next step was to recreate robot kinematics, this objective being possible through the declaration of the 15 kinematics joints [5, 6].

This robot has 4 degrees of freedom (DOF) – 3 cylindrical joints and 12 spherical joints. The main degrees of freedom are given by the cylindrical joints for 1, 2 and 3 axis control. For the 4th axis a telescopic shaft will be used, being connected to an electric motor. For each jointed quadrilateral element there are 4 spherical joints, two of them being

connected to the upper arm of each segment and the other two will be connected to the actuated mobile element.

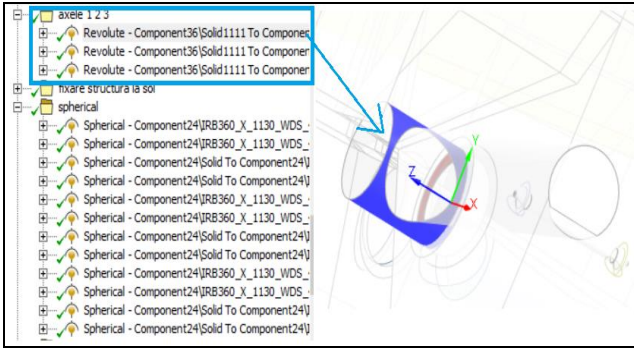


Fig. 14 Joints declaration in ANSYS

In case of transient analysis, the authors defined the materials corresponding to the assembly component elements.

For rigid parts, only densities are considered, while for deformable materials the following data is taken into account: density, Poisson's ratio, and Young's modulus. Figure 15 shows the characteristics of two materials used in this study (Aluminum and Structural steel).

Structural Steel	
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	2e+11 Pa
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+11 Pa
Shear Modulus	7.6923e+10 Pa
Isotropic Secant Coefficient of Thermal Expansion	1.2e-05 1/°C
Compressive Ultimate Strength	0 Pa
Compressive Yield Strength	2.5e+08 Pa

Fig. 15 Definition of Structural Steel properties

Aluminum Alloy	
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	7.1e+10 Pa
Poisson's Ratio	0.33
Bulk Modulus	6.9608e+10 Pa
Shear Modulus	2.6692e+10 Pa
Isotropic Secant Coefficient of Thermal Expansion	2.3e-05 1/°C
Compressive Ultimate Strength	0 Pa
Compressive Yield Strength	2.8e+08 Pa

Fig. 16 Definition of Aluminium Alloy properties

The top plate was made of Structural steel whereas the robot arms were performed of aluminum. The material selected for the robot segments are those presented in the product specification, where it is specified that the segments of the three-robot axis must generate small moments of inertia. The meshing was controlled as well at a global level, as at a local level. Globally, the meshing type elements has been set to be of second order, with a size of 40 mm. At a local level, the authors imposed a size of 20 mm for the meshing elements, the discretization being refined around the robot fixing holes. Simultaneously the authors used the

sweep method with two elements, these settings having the role to ensure correct results in the shortest time. Discretization of DELTA type robot is depicted in figure 17.

Based on the previous geometry simplification and robot kinematics definition, the work cycle performed by the robot during the assembly operation can be recreated, using the motion signals extracted from the Robot-Studio simulation software. Thus, the base plate to which the base of the robot is fixed will be loaded depending on the movements during the robot working cycle with parallel acting.

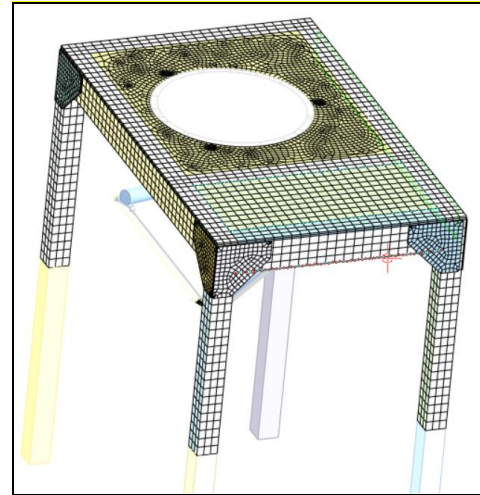


Fig. 17 Geometry Meshing

After recreating the work cycle in Ansys, based on the motion signals taken from the robot simulation software, it will be possible to evaluate the von-Mises stress distribution at the level of the upper plate on which the robot with parallel acting is mounted. In figure 18 is depicted the von-Mises stress distribution.

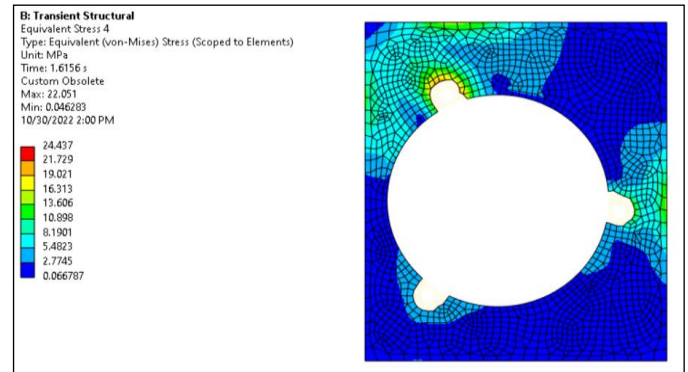


Fig. 18 von-Mises stress distribution

The maximum stress value of 24,437 MPa can be identified in Figure 18. Figure 19 shows a graph containing all the elastic strain values during the work cycle of the parallel acting robot.

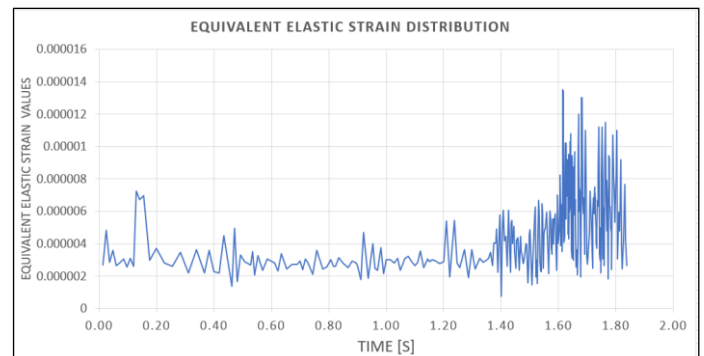


Fig. 19 Equivalent elastic strain distribution

VII. CONCLUSION

Due to its high precision and work rate the IRB 360 parallel acting robot described in this paper is the most appropriate robot for the assembly operation of electronic components. In order to bring the electronic components in a favorable position the articulated arm robot IRB2400 as well as all automatized components are used, leading to a complete automatized cell.

The cell presented in this study has a multifunctional character; it could be also used in other automatized applications.

The offline programming of robots was achieved using RAPID language, being specific to ABB robots. The offline simulation for the created cell was achieved through ABB-Robot Studio. This code folds perfectly on the offline simulation of an industrial cell including ABB robots.

For the stress and strain state determination of the robotic cell elements, an important parameter was the signal determination during the working cycle.

In this study the authors used the transient structural module from ANSYS code.

Through the robot moving signals, the robot kinematics was rebuilt being an extremely important factor since during the robot movements all forces occurring in the system will appear.

Using the post-processing results obtained following the FEM analysis in the transitory regime the most important structural element of the assembly was detected in the upper part, the most relevant stress distribution being obtained at this level.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

M. Costea has performed the design and assembly of the IRB360 mounting solution. He was also involved in robot programming and off-line simulation. A. Ancuta realized the simplification of the structural model geometry and performed the transient analysis. G. Jiga check the final paper content. All authors had approved the final version.

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M. Costea born in Câmpulung Muscel, Argeş County, on October 22, 2001, graduated the "Dinicu Golescu National College", currently studying at the Faculty of Industrial Engineering and Robotics of POLITEHNICA University in Bucharest. His research interests include Engineering, Mathematics, Robotics and at least but not last, special issues in the Strength of materials domain.



A.A. Ancuta born in Târgovişte, Dâmboviţa County, on October 22, 1998, graduated (bachelor degree) and currently studying (master degree) at the Faculty of Industrial Engineering and Robotics of POLITEHNICA University in Bucharest. His research interests include Mathematics, Engineering, FEM Analysis (static, transient, explicit dynamics, stability, thermal, frequency and vibrations) and also FEM optimisations (parametric, of topology, with lattice structures).



G. Jiga (born in Bucharest, August 02, 1961) obtained his PhD Degree in Civil Engineering (1997) and Bachelor of Science Degree in Machine Building Technology (1986) - Faculty of Machine Building Technology, Bucharest Polytechnic Institute, (Romania). At present he is full professor at the Strength of Materials Department and PhD supervisor. His field of interest is linked to the experimental stress analysis, numerical methods, finite element modelling applied on different metallic, polymeric and composite structures, sandwich materials, low velocity impact modelling etc.