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ADVANCED OFF-LINE PROGRAMMING AND SIMULATION OF A FLEXIBLE ROBOTIC MANUFACTURING CELL USING KAWASAKI PC-ROSET

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Abstract: *This paper will present the development process of a manufacturing cell and the offline programming and simulation of an articulated arm robot with six degrees of freedom included in that cell. The study is made on a Kawasaki robot used in machining applications with self-driven tools, and the program used for this purpose is the PC-Roset software. The development approach deals with aspects ranging from cell layout design and workspace validation using CATIA software to application programming and optimization using the virtual environment and analysis tools offered by Kawasaki PC-Roset.*

Key words: *robotic machining, offline programming, virtual simulation, PC-Roset.*

1. INTRODUCTION

Continuing previously presented papers, the present work highlights third level approach performed by authors in the field of specific research for robotic machining, inside the PhD program for elaboration of the PhD thesis titled "Contribution on robotic machining optimization by flexible manufacturing cell and processes improvement".

First level approach has been related to perform a documentation study to identify state of the art in robotic systems architectures, specific end-effectors and robotic machining processes for complex part processing.

As result of this study, the main approaches and issues regarding robotic machining with self-driven tools have been identified. A systematic synthesis of current research stages has led to specific systems classification with respect to manufacturing cells layout and machining setup. Also, this documentation stage has shown the opportunities and resources offered by offline programming environments and software packages.

Second level approach has been related to virtual prototyping optimized structures of flexible manufacturing cells specially dedicated for robotic machining, by mean of self-driven tool end-effector, including specific devices for supplementary part-orientation during robotic part-processing. Based on the conclusions of the documentation stage and the characteristics observed in the developed virtual manufacturing cells, an analysis has been made regarding the optimization and issue solving possibilities of cell layouts and structures, taking into account specific online and offline programming requirements.

Present work-related to the third level approach in preparing PhD thesis-is directly related to a dedicated approach on specific modeling techniques related to off-line programming and simulation of robotic manufacturing systems using self-driven tools.

For practical illustration of offline modelling and simulation of robotic machining, a flexible cell virtual model has been elaborated. After individually designing each robot's specific parts and partially assemblies in the cinematic modelling, all axes have been reciprocally constrained and specific motion laws defined to allow end-effector trajectory generation and servo-assisted end-effector orientation motions simulation. Complementary works for fully synchronization of robot overall kinematics with the input / output signals used in the manufacturing cell have been performed in order to achieve overall cell functioning simulation. To point out the linear/angular movements executed by the mobile elements of the articulated arm robot, Digital Mock-up menu and the commands related to DMU Kinematics sub-menu of Catia V5 virtual prototyping environment have been used.

2. THE CELL STRUCTURE

The designed robotic cell includes the following elements:

- a Kawasaki FS10E 6-axis articulated arm industrial robot with 10 kg payload equipped with a pneumatical self-driven tool;
- the robot base is mounted on a pedestal in order to enlarge it's workspace and to allow it to work on a suitable level for most commercially available workpiece positioners;
- an ATI RC 340E radially compliant deburring end-effector featuring 40000 rpm spindle and 340 W machining power, which is a dedicated milling tool;
- an automatically tool changing system is used for automated coupling-uncoupling of different tools stored in a tool storage system;

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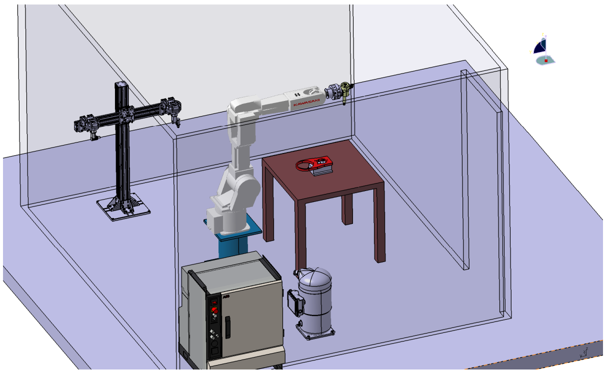

Fig. 1. The manufacturing cell virtual model.

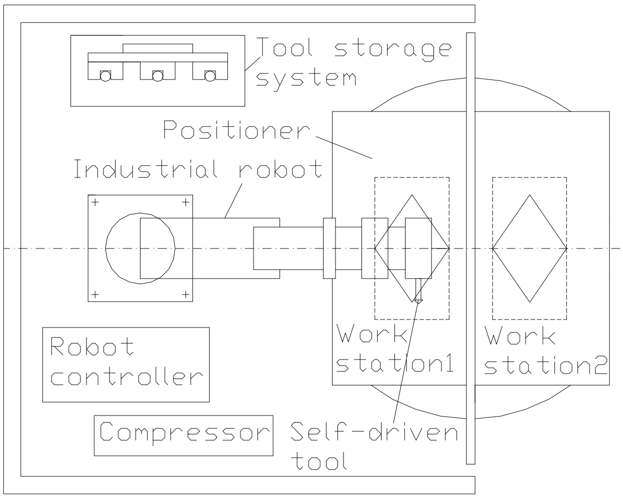

Fig. 2. The general structure of a first principle flexible manufacturing cell.

- a Kistler 9257B dynamometer is mounted between the part and the table, with the purpose of measuring the machining forces and torques.

According with the classifications made in the first research stage of the PhD thesis, the designed manufacturing cell is dedicated for the first class of operating principles - machining made with low-power self-driven cutting tools handled by industrial robots, which includes operations that require small processing forces.

The manufacturing cell virtual model (elaborated in the second stage of PhD thesis development) on which the virtual setup for offline programming is based is illustrated in Fig. 1. The reciprocal position of the main elements – the robot, robot pedestal and processed part – validated using DMU Kinematics, together with the Kawasaki robotic system were kept in the simulation virtual scene and optimized using specific tools offered by PC-Roset software.

The real robotic system on which the virtual cell structure is based is illustrated in Fig. 3. The system includes a Kawasaki FS 10E articulated-arm robot with six degrees of freedom equipped with an ATI automatic tool coupling-decoupling system and ATI RC-340 radially compliant self-driven tool, as well as a Kawasaki D controller. In the next research stage, this system will be used to setup a real manufacturing cell for experimental data output, which will be used together with virtual experimental results for comparison and analysis.

Fig. 3. The Kawasaki FS 10E robotic system.

3. GENERAL PRESENTATION OF THE WORKSCENE

The cell was elaborated with the purpose of performing a simulation of a machining process. The simulated operation is the contour surface finishing of a certain part, with both internal and external contours being processed. The work-scene includes an industrial robot specially designed for part machining, with six numerically controlled axes and equipped with a radially compliant milling end-effector with a tool radius of 2 mm. The tool radius was chosen in order to reduce simultaneous contact between the active part of the tool and two perpendicular surfaces of an inside corner, because the resulting force imbalance in two planes can cause severe tool chatter. As a result, following the recommendation of the producer, the tool radius was chosen 1.5 times smaller than the smallest fillet on the path. The part is placed on a workstation and fixed by a vacuumatic system. In order to simplify the workscene geometrical structure and allow the computer resources to focus on the programming and simulation tasks, the cell layout and component configuration have been simplified to the minimal functional level. The general layout of the works-scene is presented in Fig. 4. The constraints between the cell components were specified after performing a set of preliminary tests including robot motion and simple trajectory generation, and with the help of the Display Model's Minimum Distance and Collision Check Setting tools included in PC-Roset (see Fig. 6).

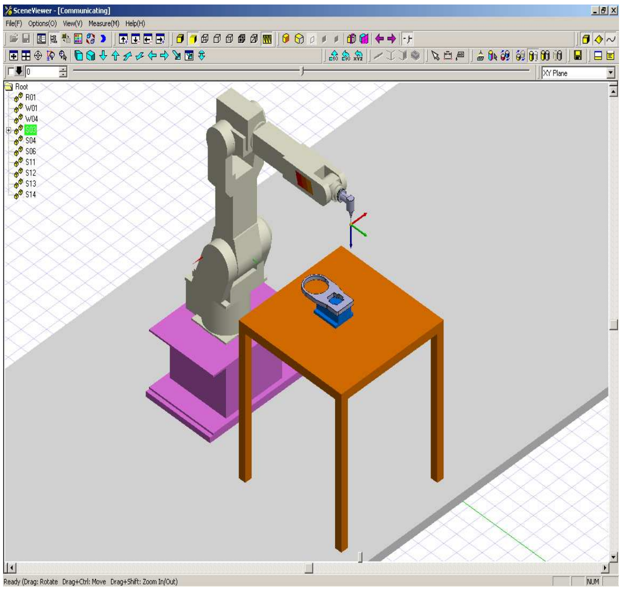

Fig. 4. General layout of the work-scene.

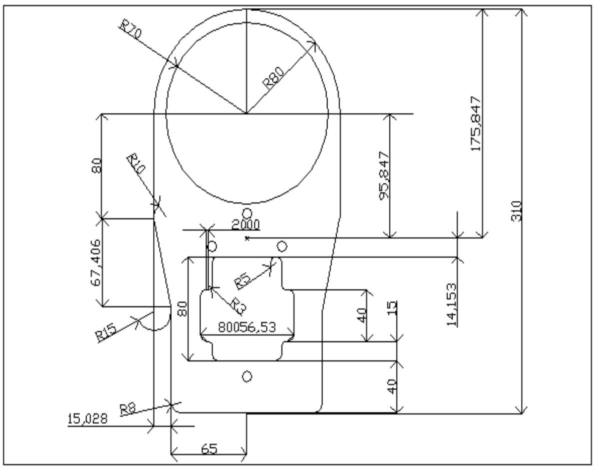

Fig. 5. The dimensions of the processed part.

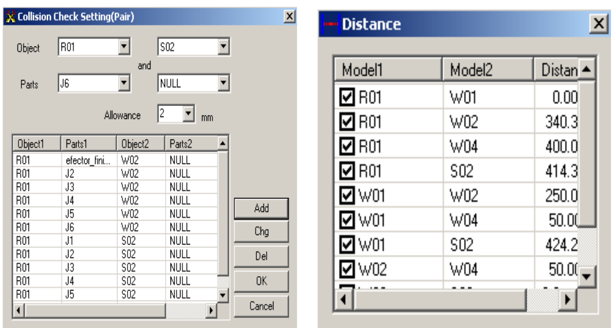

Fig. 6. The constraints between the cell components specified in the Display Model's Minimum Distance and Collision Check Setting tools.

The part on which the machining process was simulated is illustrated in Fig. 5. The part contains both internal and external contours, as well as fillets, circular and plane surfaces, and surfaces that are not parallel with the application's axis system.

4. THE SIMULATED MACHINING PROCESS OF ROBOTIC MANUFACTURING CELL USING PC-ROSET SOFTWARE

The application modeling and simulation was made using the software package PC-Roset developed by Kawasaki Robotics Inc., which is a program dedicated for offline programming and simulation of robotic applications. The operating procedure of PC-Roset is shown in Fig. 9.

The program includes a virtual teach panel that allows four modes to jog the robot: joint mode, base *XYZ* mode, tool *XYZ* mode, and world XYZ mode (see Fig. 7). The mode can be changed from the teach panel. The joint mode allows the individual movement of the axes. In the tool mode, the robot moves along the robot tool coordinates, but the values shown in the edit boxes are expressed in robot coordinate values. In the base mode, the robot moves according to the base coordinates. In the world mode, the robot moves along the robot world coordinates.

The point-by-point instruction method was used for application programming, all the trajectory data being inserted as program lines in the virtual teaching panel. The development of the machining algorithm was made considering a set of general principles:

- the axis system attached to the part was considered to be in its geometrical centre and the axis system attached to the robotic end-effector was considered to be placed on the tool head, with the *Z* axis oriented along the tool's axial direction (as shown in Fig. 8);
- the tool was configured for use in PC-Roset with the Tool Editor module of the software package, specifying the (0,120,75,90,90,90) values set for tool coordinates system position and orientation (see Fig. 10);
- the sequences in which the tool approaches, engages and departs from the part must respect the following pattern: the TCP must be positioned 10 mm above the machining engagement point, with an offset of 5 mm along the direction of the surface normal, after which the tool performs a linear movement along the *Z* axis until it reaches the engagement point plane and moves towards the part until the contact is made;
- also regarding the movement sequences, the pattern is based on the general structure presented in Fig. 11, where "Air" represents the intermediate targets between path sections, "Approach" represents the targets that move the robot to the surface smoothly and safely, "Start" represents the first target that locates on the surface, "Via" represents the targets that locate on the surface, "End" represents the first retract target, and "Departing" represents the targets that leads the robot to withdraw from the surface;
- the movements between two cutting sequences are made using the JOINT interpolating method;
- the movements performed during the cutting sequences are made using either the LINEAR or CIRCULAR interpolating method (depending on the profile geometry);

In order to obtain a complete dynamic model of the system, the tool mass and gravity point position data are introduced in the Auxiliary Settings menu of the virtual teaching panel as shown in Fig. 12.

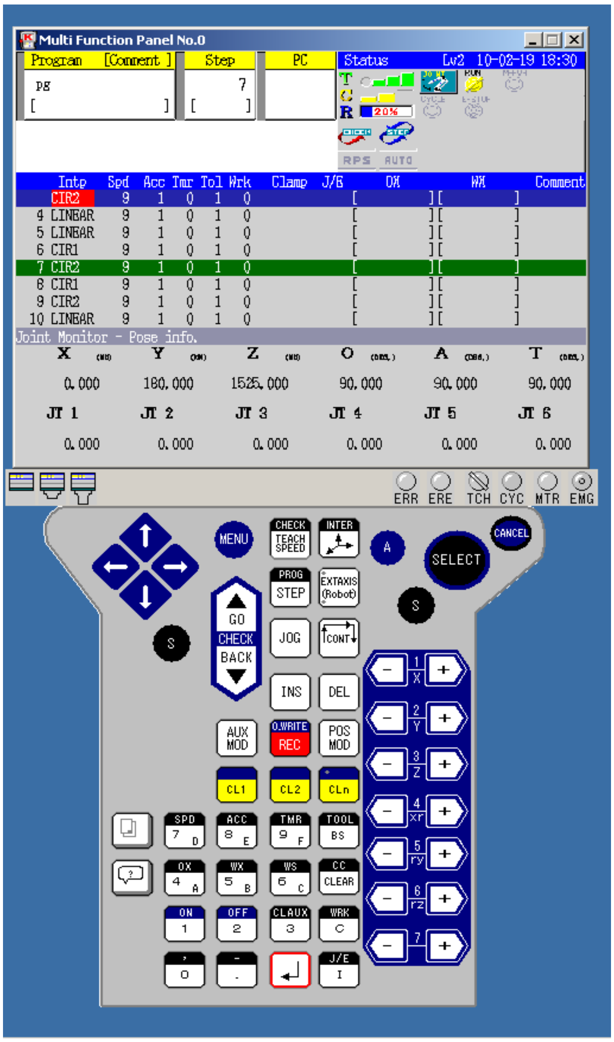

Fig. 7. The virtual teaching panel.

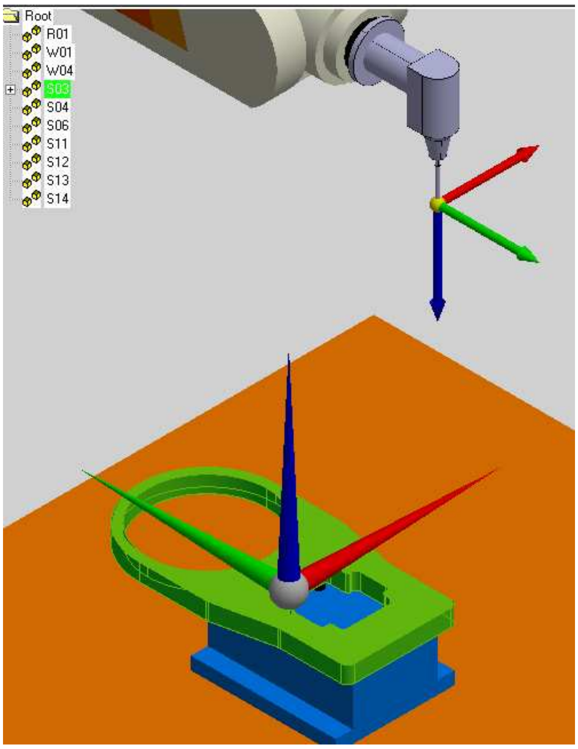

Fig. 8. The positioning of the axis systems attached to the part and to the end-effector.

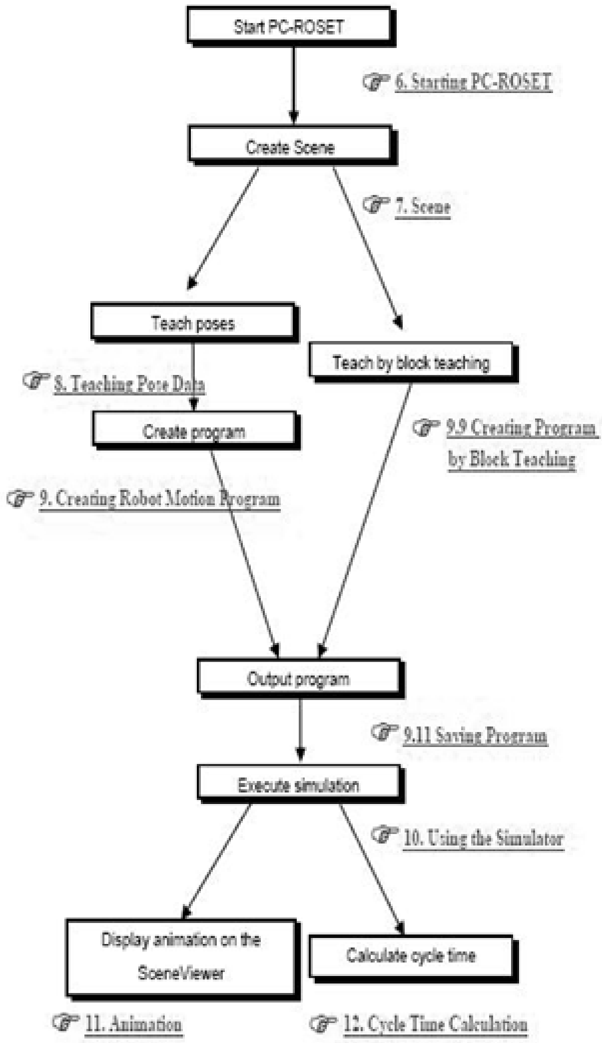

Fig. 9. The operating procedure of PC-ROSET.

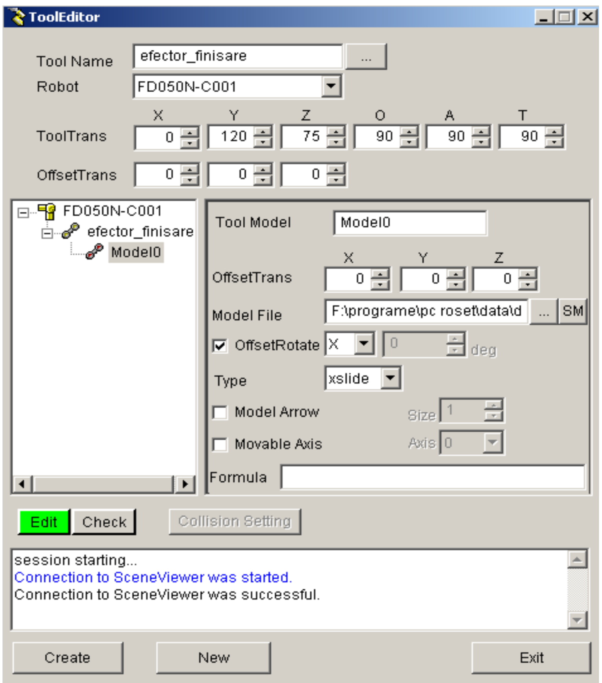

Fig. 10. Tool configuration using the Tool Editor module.

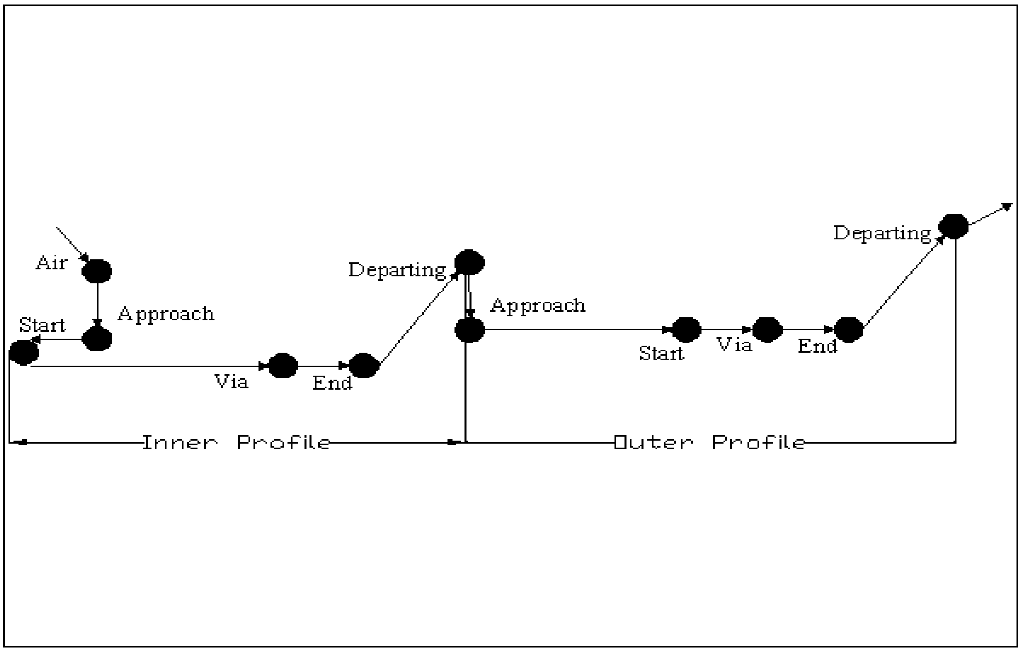

Fig. 11. The path structure.

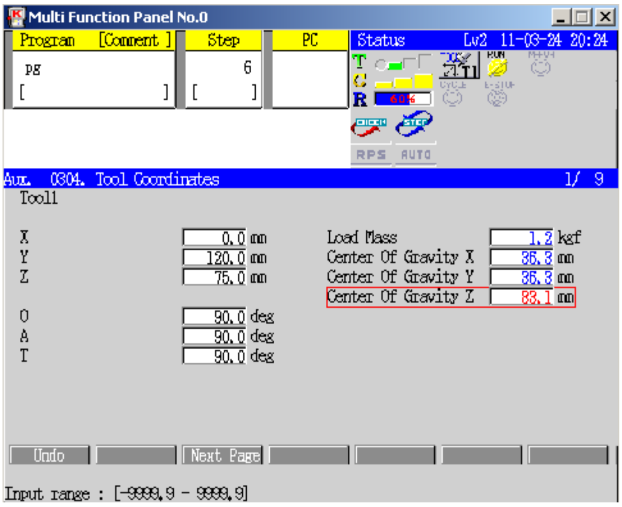

Fig. 12. Tool configuration data introduced in the Auxiliary Settings menu of the virtual teaching panel.

All the points used for the teach-in process were calculated with respect to the center of the axis system attached to the part, which is itself positioned relatively to the application's axis system. The trajectory was configured considering the fact that the centre of the axis system attached to the tool will coincide with the teached points at the end of each movement. Considering this, it must be concluded that, in the stages when the tool is engaged with the part, the trajectory follows exactly the nominal contour of the work-piece with an offset of 2 mm. In order to keep a firm contact between the tool and the part, the cutting parameters were set based on a conservative approach, allowing the system to successfully cut the biggest burr possible considering the specified radial compliance of 7.6 mm. Also, the contact force between the tool and the part is strongly related to the tool's compliance, since this is a passive force control method, regulated by the air pressure in the system. As a result, the air pressure in the compliance system is an important parameter, controlled in each instruction from cutting sequences by a set of I/O signals, depending on the required cutting force (see Fig. 13). Because the program structure was created using the block teaching method, the move instruction is created at the same time with the corresponding trajectory point specification, together with all process parameters and I/O signals.

It can be observed that the robot handles the end-effector along the external and internal contours of the part in order to remove burrs, permanently keeping an appropriate tool orientation. The programming algorithms are mainly oriented towards increasing the precision of the robot during processing phases that require permanent modifications of the tool orientation, especially the round portion of the part.

Fig. 4 shows the scene in which the simulation is performed, with the robot in a cycle start position. The sequences from the robotic manufacturing simulation during the run of the part processing program are shown in Fig. 14.

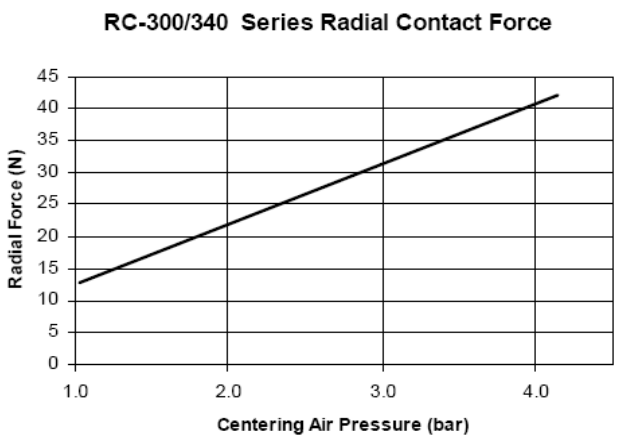

Fig. 13. RC-340 radial contact force-centering air pressure diagram.

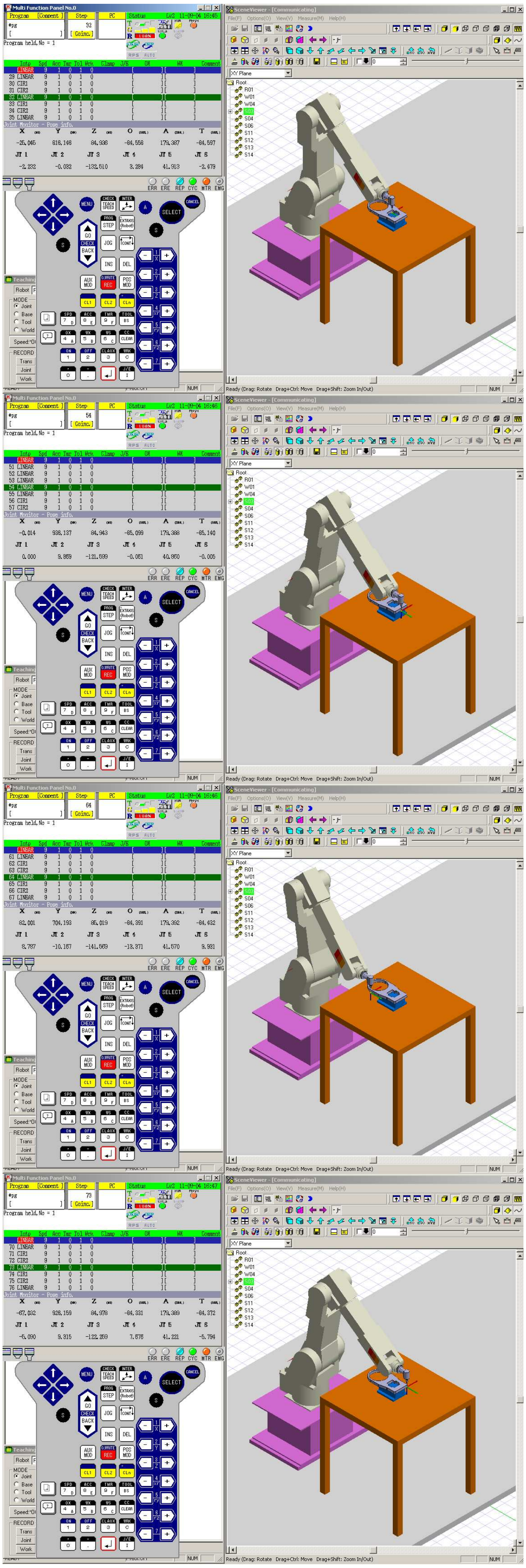

Fig. 14. The sequences from the robotic manufacturing simulation.

5. CONCLUSIONS

The work in this paper is intended to prepare a background for future research conducted by the authors regarding the issues of the robotic machining. The programming techniques used, that involve work transformation values and block teaching, will provide the base for the development of future algorithms used for flexible manufacturing cells simulation.

The main author's achievements in offline programming the above presented machining FMS Cell using Kawasaki PC-Roset are:

- for workspace validation/optimization, along with CATIA specific features, the tools offered by Kawasaki PC-Roset software, such as Display Model's Minimum Distance and Collision Check Setting have been used;
- the Tool Editor module has been used for tool calibration before off-line generating program and (including integrated co-ordinated measurement functionality);
- for application configuration, block programming has been used in order to allow the programmer to combine the different program modules into a nested hierarchy of conditional statements and to call the specific block when a corresponding action is required;
- in order to ensure permanent tool-workpiece contact during the manufacturing process, a conservative approach regarding cutting parameters was used, but also, the passive force control provided by the compliance system was optimized by controlling the air pressure on each trajectory segment by using specific I/O signals.

The next level approach in PhD thesis development will be related to experimental setup of a flexible manufacturing cell specially dedicated for robotic machining by mean of self-driven tool end-effector, shown in Fig. 3. The cell has been specifically designed for experimental results output, in this respect including specific force and torque reading devices. The goal is to compare the results derived from simulations created in virtual environments (Kawasaki PC-Roset and ABB RobotStudio) and the results obtained from experimental machining operations performed with the real flexible manufacturing cell. This analysis will provide the necessary data to support the theoretical considerations regarding robotic machining operations optimization included in the PhD thesis.

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