Studies Regarding the Design of Spray-Painting Robotized Cells

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Abstract – **The applied research regarding the spray-painting robotized cell starts from the industrial demands, namely the furniture companies.**

The most common reasons for using robots in spray-painting operations is to reduce labour requirements, removing the operator from potentially hazardous environments, reducing the coating material and the energy consumption, reducing the number of rejected parts, improve the quality and consistency and assure repeatability of the process.

In spite of the presented tasks, the spray-painting robots should not be viewed as complete solvers of all painting problems but as an integral parts of an automated system.

I. INTRODUCTION

Robotized lines are so seldom engaged in furniture dyeing and coating that engineers don't really have the chance to inspire themselves from existing solutions. The majority of developed variants are still in experimental form. It is evident that the design of a new processing line requires laborious researches and work before the elaboration of a work plan.But, robotized spray painting is used very efficiently in car industry, which will be considered a strong strategic point in the followings.

For the selection and successful implementation of a spray painting robot, it is necessary to establish a set of selected criteria that enables the decision for the robotized spray-painting implementation.

The painting robots can consistently duplicate the best work performed by skilled spray painters, providing in the same time enough time to adjust and refine the programming. Once the robot is programmed, it will execute the exact motion of the sprayer providing quality results including the colour change and the interface capability with turntables, conveyors, lift and transfer tables and other supportive equipment of the painting system.

Automation comprising robots, in the case of spray painting, has to face a series of obstacles difficult to be performed even for a skilled worker. The amount of process parameters and restrictions which ought to be taken into account is large. The implementation without previous comparative studies or simulation would be a risky and expensive action.

A. Why using a spray painting robot?

The answer is relatively simple and comprises all the reasons to reduce the operating costs and increase the return of investment. Underutilization of a programmable robot is as unprofitable as adapting limited automation to a task requiring a high degree of flexibility.

B. When to implement a spray painting robot?

The moment of implementation of a spray painting robot is strongly dependent on the company technological stage, and the specific tasks that are performed within the company. The selected factors which define when to implement a spray painting robot include: the status of the market, the type of product manufactured, economically and technologically conditions of the plant and production line, the level of the labour costs, applicability of government health and safety regulations, material and energy costs and some other factors that represents particular cases to each specific manufacturer or a particular manufacturing environment.

For example, as not recommended situation, it would be inefficient and not very cost-effective to install a spray-painting robot capable of "handling" 20% more then the regular situation in the case where the other components of the production line can increase with no more than a 5%.

C. Where could a spray painting robot being used?

Considering the most general case, a robot for spray-painting can be used for painting cases of cars, trucks bodies and accessories, strain and wood furniture, porcelain coating, kitchen and bathroom fixtures and appliances, enamel on lightning fixtures, etc.

Painting robots have not been successful when implemented as "stand-alone" robots. The interfaces between the robot and the transfer system are essential for system success. A robot can be made into a movable item by mounting it on a turntable, lift table or transverse table or in connection with conveyors, turntables and lift tables that are transporting the parts or products and can rotated or indexed them continuously or by indexing position.

Rarely a painting system used to paint a single product, therefore the connection between the robot conveyor and the product identification are other important considerations for the robot implementation. In the same manner for existing or new processing lines sensing system are required for position and configuration identification and the colour changing.

D. How to select a spray painting robot?

The selection of a spray-painting robot requires the coordination of robots data with information about the robot manufacturer's facilities. One of the most effective methods of obtaining robotic information is by describing the actual application to allow one or more robot manufacturers to prepare system versions based on company specifications and company products.

The number of degree of freedom (DOF) is the next characteristic for the spray-painting robots. For this application normally the robot has to have 6 DOF with the orientation mechanism having 3 DOF as the human wrist and possibility to rotate with infinite angles.

II. SPRAY-PAINTING CELL

The existing process analyzis is a main concern in the design of robotized spray-painting cell. In many companies is a gap between the technologic, economic and operating departments in seeing the process like a whole. Therefore is necessary to identify the flows, the connections and hierarchy within the process operations.

In our study we start with the painting shop general modelling, on the model being possible to add the particular characteristics of each company.

In figure 1 is the graphical representation of the spray-painting cell and in figure 2, the analyze of the operator essential skills. Within this modelling is considered the working space, painting devices operation requirements, placement and manipulation of the paint store [1], [2] (that can be centralized or distributed along the paint shop), the parts orientation and storing devices, compressed air facilities (if any), the number and placement of the human operators, the environment protections devices and human operators protection and ergonomic rules and facilities (filters, water or air curtains, lighting facilities, fire escape, fire extinguisher facilities, first aid and safety equipment placement etc.).

All these elements can be modelled and place in the paint shop area. From these elements is the start, usually any existing company would like to made the minimal change, minimal investment and minimal production time cutting by introducing new (robotized) technology.

Beside the list of elements that will be eliminated form the paint shop endowment the fluid and under pressure air store and control units are of major concern in any painting system. The control of these functions is the key for obtaining a quality paint and efficient use of painting materials.

There are numbers of methods available to achieve this control. Most automate and manual spray guns are

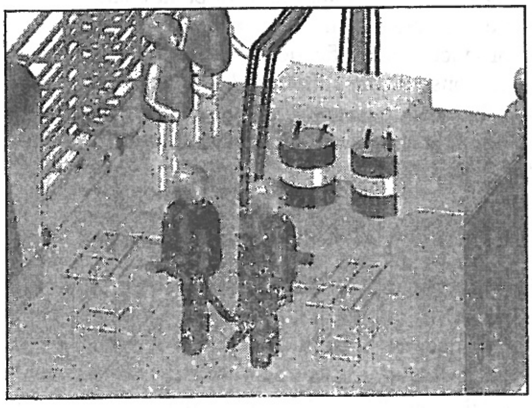

Fig. 1. The analyze of the human operator essential skills

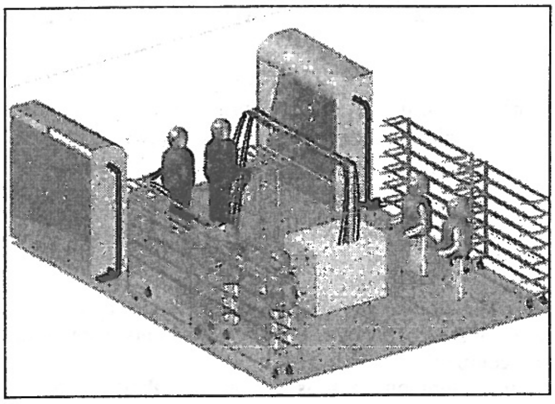

Fig. 2. The model for the general representation of the spray-painting cell

equipped with manual adjustments to perform these functions. Normally, these controls are presated by the operator. By taking advantage of the programmable output functions of the robot controller, it is possible to have fully automatic control over fluid flow and pattern size. In this respect, a standard automatic type spray gun is modified to allow remote and separate control.

In the case of spray-painting, automation comprising robots, the amount of parameters and restrictions which ought to be taken into account is high. Without a preliminary study, would be very risky and expensive to implement the robotized solution thus is recommended to made a preliminary analyze of the existing endowment and the needs of elements that worth to be changed.

III. ROBOTIZED SPRAY-PAINTING CELL

A. General considerations

Considering an existing situation, as depicted in figure 1, the proper time for upgrading a manufacturing system is when one or more essential machines or processes are to old (slow, high energy consumption, low accuracy, etc.) and the quality management standards oblige the manufacturers to implement equipments that correspond to a series of requirements that improve the quality of the product, the environment protection and the lifestandard of the company personnel.

The robot system provides more versatility and flexibility than automated systems. However, because robots are limited to their work envelopes, it is necessary to increase their spatial coverage. This is accomplished using positioning axes, which can be programmed to reposition the robot manipulator to gain the optimum working position during the painting process.

Positioning axes can be designed to elevate the robot manipulator to increase its vertical reach or to enable tracking of a moving conveyor. Also, the wrist driving system has to be placed faraway of the arm end. In addition, the robot arm has to be easily fitted with paint and air hosing and covered for an ease cleanup and protect the equipment from overspraying.

With this additional elements the robot degrees of freedom could be increased to 7 DOF (4 DOF additional to the wrist) that will also increase the gun's mobility and permit spraying the backside and underside and hard-to-reach areas of the parts.

By equipping the spray gun with a multiple rotation capability that will enable the rolling of the gun to paint also the interior surfaces.

During the teach cycle, the spray gun control functions are programmed by the robot operator through a series of air-piloted and shuttle valves, remote-control regulators and fluid and air pressure monitoring devices. By taking advantage of the programmable output functions of the robot controller, it is possible to have fully automatic control over fluid flow and pattern size. In this case, a standard automatic type spray gun is modified to allow remote and separate control.

In most cases, the required cleanup of an automated system consists in cleaning or changing the retaining ring and spray cap of the gun. If the gun is mounted on an automatic machine, the system may have to be shut down.

In the case of a robot, a spray-cleaning nozzle is mounted at a convenient location and the robot is programmed to move and position the spray gun in front of the nozzle. At this time the programmable output function controls the spray-cleaning jets for the proper duration.

B. The robot type selection

The spray painting robots have to be able to be programmed on continuous path and to store multiple-programs with random access. Such a robot the one depicted in figure 3., was modelled at a 1:1 scale in order to be used within the virtual reality definition of the spray-painting process. The latest developments allow an off-line programming with a preliminary 3D graphic computer simulation [3] of the process.

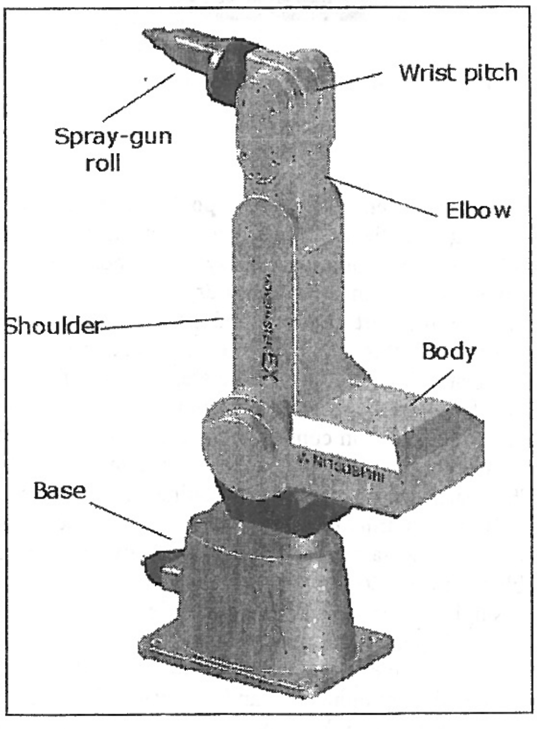

Fig. 3. Robot model applicable for spray-painting process

Between the main goals of the computer simulation is the definition of the working space considering the inverse and direct kinematic model of the mechanical structure and the graphical representation of the robot motion based on the joints travel limits.

The working space is generated [4] starting from the structural cinematic and the inverse kinematical model. figure 4.

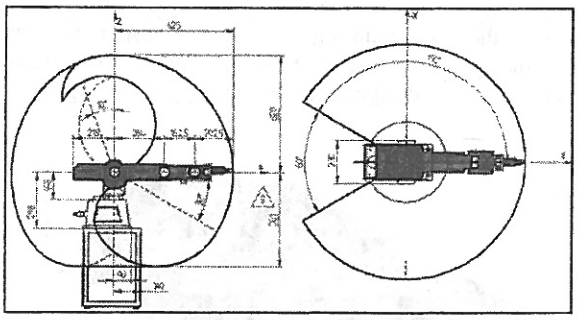

Fig. 4. The cinematic structure of the selected serial robot

Generally, in a wood furniture company the wood parts are split into three families: big flat parts, small flat parts and parts with sophisticated geometry. In the studied case the first category of parts is processed in a separate room by a very efficient curtain coating machine. The other two groups of parts are lacquered by human operators. The implementation of robot supposes the replacement of the personnel from the human lacquering room.

Starting from the actual situation by modelling the spray-gun and the spray-painting robot may be defined the maximal covering area that can be processed by this type of robot. Considering the specific robot model the size of the maximum part that can be lacquered is defined by the maximum possible rectangle drawn by the robot in the maximum cross section of his working envelope.

Experimentally determined, the dimensions are: maxX=177 mm, maxY=358 mm. Considering the spraying cone (specific parameter for each spraying gun) with a covering diameter of 150 mm that can be moved along the contour of the small rectangle from fig.5, the dimensions will grow with the half of the diameter resulting the maxX=252 mm and maxY= 433 mm.

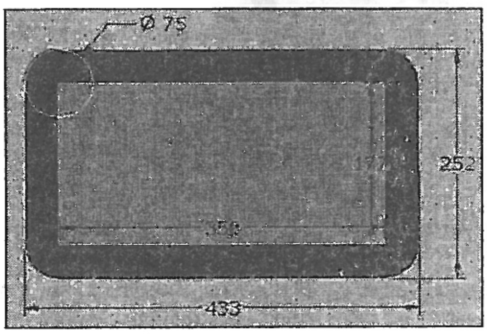

Fig. 5. Maximum covering area definition

Having already defined the maximum part that can be lacquered, the next robotized cell elements can be designed.

The feeding conveyor: transports the selected parts from a distribution point to the lift table. Only parts smaller than the maximum allowed dimensions are accessing this conveyor. For the designed system are two conveyors, one next to the robot, equipped with an optional cleaning device, which removes the substance deposited during spray-painting, figure 6 and another curved or straight conveyor, that could be in a passive or active version, that is transporting the parts form a general store to the spray-painting position or transport the parts from the spray-painting position to an intermediate storing device specially designed for the drying process, figure 7.

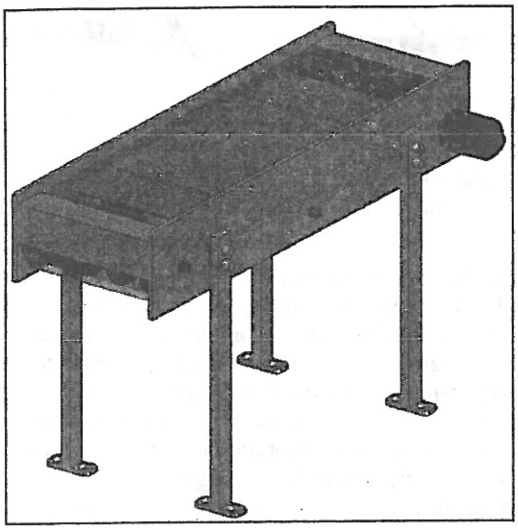

Fig. 6. Conveyor equipped with cleaning device

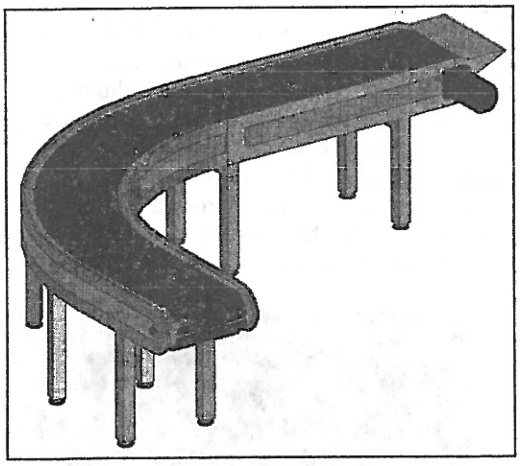

Fig. 7. The curve feeding conveyor

The evacuation conveyor: is suspended on the ceiling and it has the base construction similar with the construction as the feed conveyor figure 8. The parts are pushed from the paint table on the belted conveyor by a sensored arm which is installed on a frame right next to the lift table.

The lifting table: In the designed solution has been considered two levels of the process: the feeding level and the evacuation level. The link between the two process levels is ensured by an auxiliary device "the lift table". The devices ensure not only the lifting between the levels but the lifting mechanism having placed on it a rotational table is increasing the number of robot DOF to 6, figure 9.

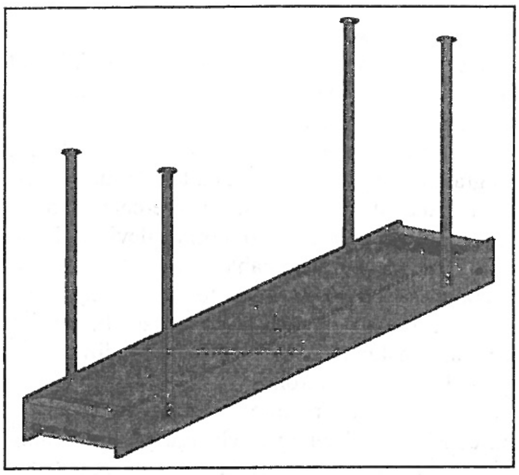

Fig. 8. The suspended evacuation conveyor

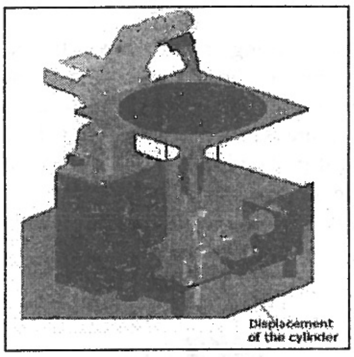

Fig. 9. Standby position for the robot and the lift table

The part centring and positioning arm: for completing the feeding conveyors system to ensure a complete functionability of the system a positioning and centring mechanism was necessary to be design. This consists of the part centring and positioning arm and a push-arm. All this auxiliary elements are ensuring the direct positioning and the part transfer in front of the robot being placed in between the feeding conveyor and the suspended evacuation conveyor together with the lift table that place the parts in between the two conveyors levels.

The part centring and positioning arm [5] consist actually in two arms installed on the same frame with the evacuation push-arm, their mirroring mounting solution enables the arms to move in opposite directions, actuated by a single motor placed in the middle, according to the applied rack-pinion mechanism, figure 10.

The lifting table is placed in the middle of the group of centring and positioning arm and the evacuation push arm, in the front of the robot, the part that must be finished (paint, lacquered) being placed and process on the lifting table.

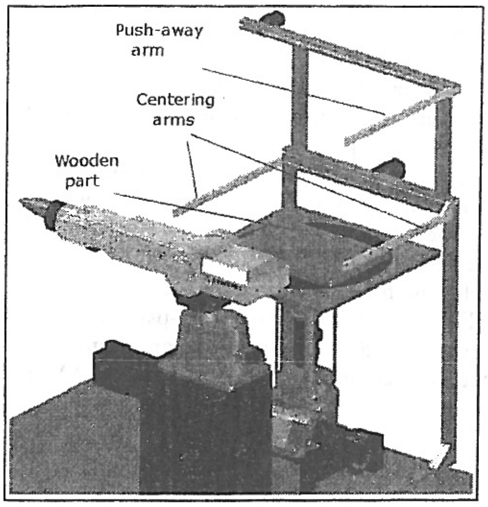

Fig. 10.The part centering and positioning arm and the evacuation push arm

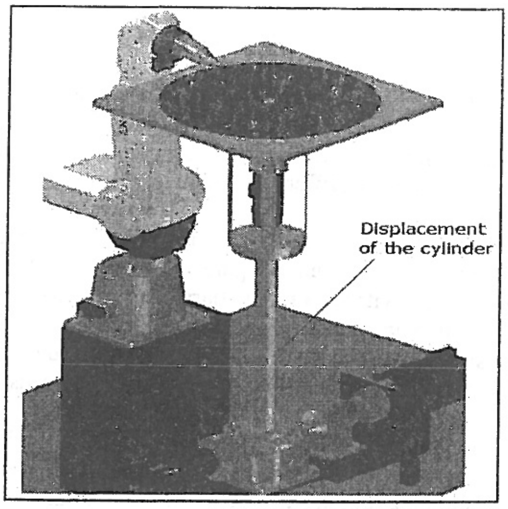

Fig. 11. DOF extension by using a lifting table in association with the robot

In figure 11 is represented an example how the system serial robot lifting table works, illustrating the possibility to increase the number of DOF if the industrial process requires such an extension. In the spray-painting case the restrictions imposed by the robot number of DOF and the robot working space (the maximum covering area from figure 5) are surpassed with the help of the lifting table motions that ensure in the painting of the apart lateral sides considering different part thickness.

By composing the elements represented in figures 3, 6, 7, 8, 9 and 10 in a logical order [6] dictated by the spray-painting process, results the entire structure of the robotized spray-painting cell, represented in figure 12.

Starting form the fact that the representation of the spray-painting robotized cell in figure 12 is the virtual reality of the cell, all part being the simplified design at the 1:1 scale, that ensure the possibility to add changes any time, considering any further requirements. This is a very powerful and necessary option, in the spray-painting robots design and activity that includes also the auxiliary equipment, all the components must be designed and built for reliable operation in a dirty, solvent-filled atmosphere.

Beside the design of the process cell, the maintenance system must also be designed, the equipment used in a robot painting process must be clean, otherwise the equipment could cause production downtime and losses.

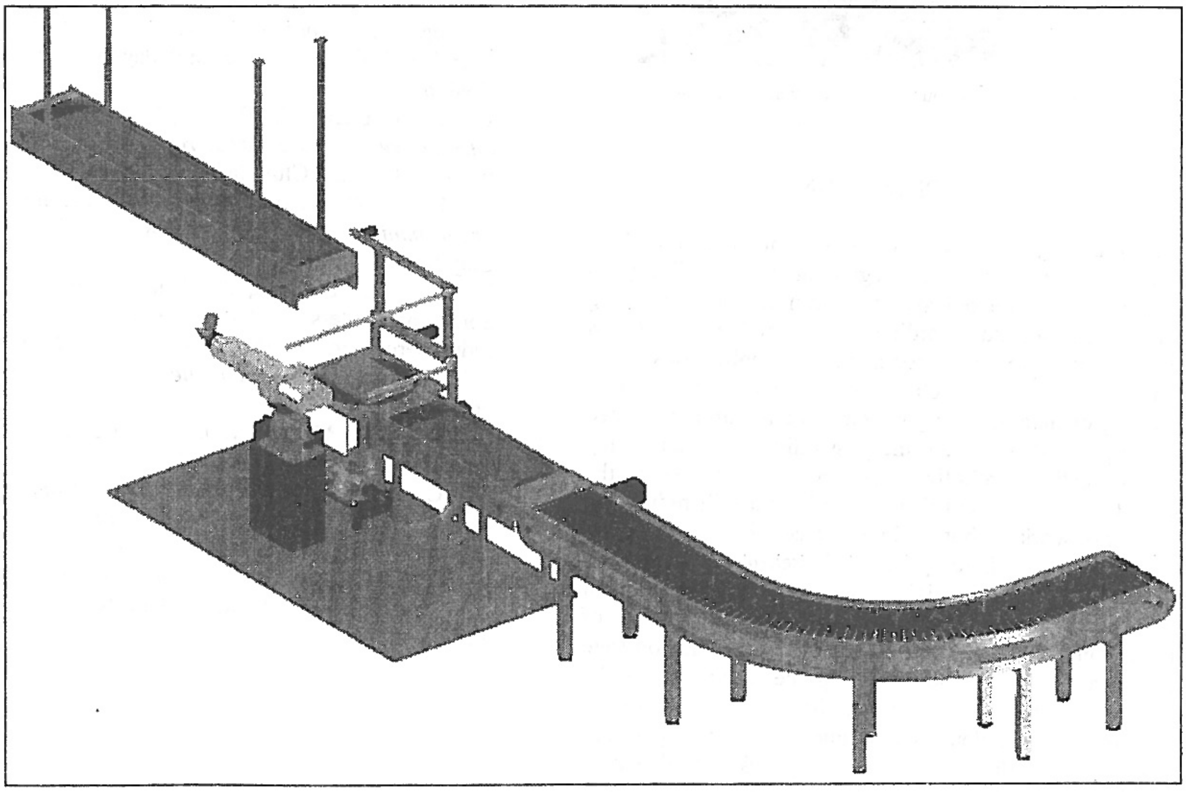

Fig. 11. The robotized spray-painting cell

IV. CELL CONTROL

Automation comprising robots in the case of spray painting has to face a series of extra tasks due to the particular aspects regarding the spray-painting process that sometimes can be difficult to perform even for a skilled worker.

The amount of parameters and restrictions which ought to be taken into account is quite large [7], [8], [9], [10]. Implementing without a preliminary study, simulating or at least creating an animated model would be a very risky and expensive move, so it is recommended to make careful research about the existing equipment, what needs to be changed and what worth to be changed.

In the presented system, the robot is the master element for the system [1]. The lifting table and the part centring and positioning arm are considered to be auxiliary or slave elements.

For the entire system was used the PC control for the off line programming[11], dry run and data and signal transfer between the PC and the robot specialized controller. The parameters setting interface being represented in figure 13.

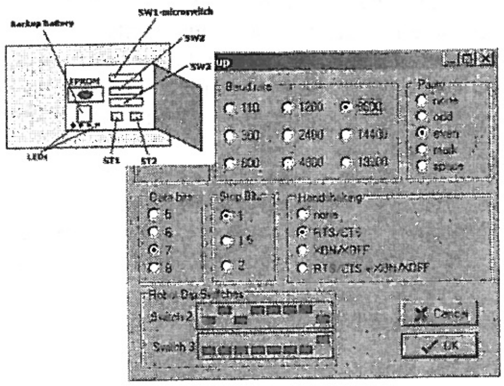

Fig. 13. PC serial communication parameters setting interface

V. CONCLUSIONS

At this stage, two types of conclusions may be taken. First are the conclusions regarding the possibility to implement a robotized system within the spray-painting process and second regarding the use of the CAD-CAM software packages in a larger number of applications.

Concerning to the robots implementation into spray-painting or manufacturing systems, the research presented in the paper demonstrate the possibility of implementing robots creating a robotized spray-painting process. In the same time is imminent that primarily that will reduce the number of workers, but workers of a certain type, in reality the number of gathered people is increasing but also their specialization must be higher. What is considered to be an important element is that with the virtual representation of a new conceived cell is easier and eloquent to demonstrate the advantages of robotizing a process, which are the changes and the actions that must be made, the amount of investment, the implementation time and pay back period.

In respect with the investment payback period, which usually takes about 3- 5 years, the presented concept shows a complete feasibility and economic justification with a payback period shorter then 2 years.

Regarding the usage of some software packages may be concluded that the CAD-CAM software (i.e. from the Unigraphics family of software) is given an enormous help in modelling a desired industrial environment. It shows also that with adequate knowledge and modelling functions is an easy way to materialize ideas without wasting much time and money, inverse proportionally with the skills level of the user.

As a general life concept conclusion for the mechanical and automation engineers, beside the conclusion regarding the validity of robotizing the spray-painting activities it is also recommended for any designer and mechanical engineer to acquire one or more CAD-CAM software, learn them well, and use them.

V. REFERENCES

[1] A. Pisla, T. Antal, D. L. Pisla, "Programarea asistata de calculator a robotilor destinati acoperirilor prin proiectare termica de pulberi," in *Proceedings of the 1995 The days of the Romanian Academy, Science Technology and Industry Symposium*, 95RO400020, pp. 101-105.

[2] G. S. Georgescu, *Îndrumător pentru ateliere mecanice,* Editura Tehnică, Bucureşti: 1978, p. 35.

[3] D. L. Pisla, *Simularea Grafică a Roboţilor Industriali*, TODESCO, Cluj-Napoca: 2001, p. 129.

[4] D. L. Pisla, A. Pisla, "Interfata grafica de vizualizare a spatiului de lucru pentru un robot industrial serial," in *Proceedings of the 1996 ACTA UNIVERSITATIS CIBINIENSIS, Series B Mechanical Technologies and technological installations,* 96RO—ISSN 1221, pp. 91-96.

[5] I. Negrean, *Robotics, Kinematic and Dynamic Modeling,* Editura Didactică şi Pedagogică, Bucureşti: 1998, p. 35.

[6] V. Handra-Luca, C. Brişan, M. Bara, S. Brad, *Introducere în modelarea roboţilor cu topologie specială*, DACIA, Cluj-Napoca: 2003, p. 43.

[7] A. Pisla, *Numerical control Equipement and Programming of the Industrial Robots*, TODESCO, Cluj-Napoca: 2002, p. 35.

[8] L. Morar, D. L. Pisla, A. Pisla, "Erstellung eines Sprachinterpreters fuer einen Mitsubishi Industrieroboter," in *Proceedings of the 1996 micro CAD'96 International Computer Science Conference*, 96H, pp. 25-28.

[9] R. C. Dorf, *Modern Control Systems*, Addison-Weseley, New-York: 1992, p. 658.

[10] M. C. Wanner, *Rechnergestützte Verfahren zur Auslegung der Mechanik von Industrieroboter*, Springer-Verlag, Stuttgart: 1998, p. 77.

[11] D. L. Pisla, *Utilizarea Calculatoarelor Compatibile IBM-PC*, Casa Cărţii de Ştiinţă, Cluj-Napoca: 2003, p. 35.