New 19 Axes Single-Processor System, for Door Moldings Manufacturing

P. Badescu and N. Mihai

Abstract—**The present paper describes a new technology for the manufacture of interior door moldings, in the spirit of Industry 4.0. A new manufacturing method is presented, using a single processor for all 19 axes numerically controlled. Thus, production costs are reduced, while the productivity and quality of the products increases. All operations are performed automatically, without the intervention of the human factor. Some of the electromechanical devices used are completely original. The data are processed in real time by a software platform, which also performs real-time diagnostics.**

Index Terms—**Door moldings, numerical control, real-time diagnostics, single processor.**

I. Introduction

This innovative system was created following several studies, tests, trials and analyzes in interior doors manufacturing plants from Quebec. The studies were requested by some manufacturers, due to the problems posed by current technology, related to: - the impossibility of supplying on time the quantity of door molds necessary for production; - the large number of rejections; - 45 degree angle errors, due to incorrect placement and fixing in the cutting devices; - sizing errors due to folding of long door frames; - packaging difficulties, every unit being of variable size [1]. We also have analyzed several automated production processes, among which we found the most advanced ones at Norfield and Obel-P Automation companies. They have created automatic production lines for interior doors and door moldings. The following results from the analysis are inadequate: 1) all the machines used in a cell are specialized machines, designed specifically for performing certain operations.

We used universal industrial robots, which we adapted (programmed) specifically for the operations. It results in a lower cost for implementation, and the flexibility of the production processes; 2) the surface developed for the processes is very large. We are small, compact and multi-storey. 3) very high consumption of materials: devices, engines, conveyors, guides, etc., resulting in a huge consumption of electricity; 4) even if the processes are automatic, the presence of people on the production lines has not been eliminated. This means that there is no real-time control and diagnosis as we do. We also studied comparatively the single-processor technology developed by Yaskawa, using the MP3300iec-RBC multi-axis processor. This has the disadvantage that it has a higher cost, and the communication can be done only Ethernet. We use more advanced communication - Ethercat, and the cost of the technology we use is lower. EtherCAT is well-suited for synchronized, multi-axis motion control and doesn't require additional hardware to achieve synchronization between multiple axes.

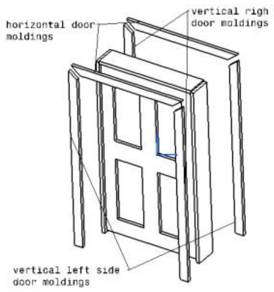

Fig. 1. Doors moldings.

Moldings for interior doors are 6, 3 on one side and 3 on the other, two horizontal above the door, two vertical on the right and two vertical on the left (Fig. 1) The biggest problem is that the dimensions are always variable, there is no series production. Each door spot in a building, even the new ones, must be measured and the door dimensions will be appropriate for this measurement.

Each door has different dimensions; there are no two doors that have the same size. As a result, door moldings will vary in size from door to door. With this problem, we were forced to build a flexible production system that would adapt to the production of unique ones, capable of changing the dimensions of cutting permanently, and even in real time, for priority orders.

II. Description of the System

A. General Description

We designed a flexible robotized production cell, optimized to small dimensions of 33 × 43 square feet (10x13 square meters). Fig. 2 shows the overview of the entire robotic production cell, where the main component parts are highlighted: 1- feed conveyor for loaded pallets; 2 - pallet storage depot; 3 - linear displacement system of the palletizing robot; 4 - deposit of incomplete pallets; 5 - transfer device of door moldings from the pallet to the cutting machine; 6 - packing machine; 7 - carts full of packages; 8 - empty carts; 9 - manipulation robot; 10 - cutting machine; 11 - palletizing robot; 12- evacuation conveyor empty pallets; 13 - empty pallets. [2]

Manuscript received January 23, 2020; revised April 2, 2020.

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DOI: 10.7763/IJMO.2020.V10.755

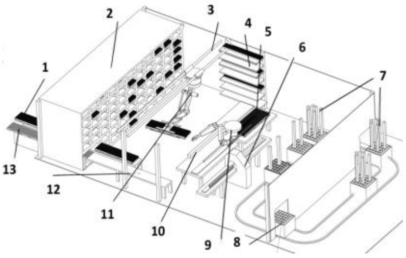

Fig. 2. Overview of the cell.

The operating mode of the system is described below. Behind the pallet storage, the empty pallets are filled with door moldings. Once filled, each pallet is transported by the conveyor to the collection point.

B. Palette Description

The pallet is specially designed to be able to store different types of door moldings. It is equipped with several mechanical systems to allow the 2 functions of the terminal effecter of the palletizing robot: a) the function of gripping and releasing the pallet and b) the pallet transfer function, from the robot to storage, to produce its effect.

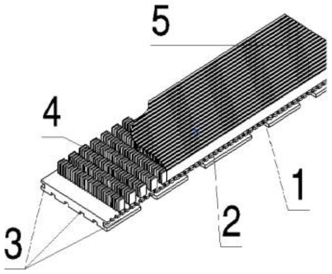

Fig. 3. Description of the palette.

In figure X are presented the main constituent elements of the pallet, which have a good role in the processes of taking, transporting, transferring and storing the palette: 1 - guidance system and transverse positioning; 2 - longitudinal displacement system; 3 - longitudinal guidance system; 4 - systems for fixing door mouldings on the pallet; 5 - door mouldings in stock condition; But the main function of the pallet is to store the door mouldings in the raw state, in special mechanical systems of retaining them in an upright position, and to allow a quick and easy loading of the pallet, as well as the easy removal of the door mouldings.

C. End-Effecter of the Palletizing Robot Description

The pallet transfer system is located in the EE (end effecter) of the palletizing robot. It transfers the pallets, from the robot to the storage, also vice versa, from storage to the robot. EE performs the following functions: a) the function of grabbing and releasing the pallet [3].

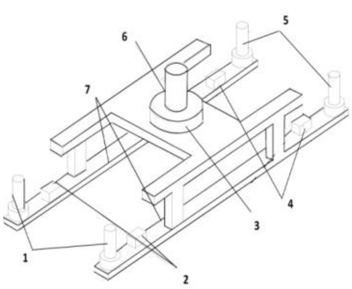

Fig. 4. End-effecter of the palletizing robot.

This is carried out with pneumatic devices and makes it possible to remove the pallet from the feed conveyor or the transfer device and to block the pallet for air transport by the palletizing robot. At the same time, it frees the pallet in places intended for storage. b) the pallet transfer function, from robot to storage, is performed with a complex mechanical system of levers and electric and pneumatic motors. The role of this function is to ensure a correct transfer from the robot to the corresponding compartment in the storage. The movement is done with transfer rollers actuated by electric motors and in one direction and in the other, as in the figures presented in the description: 1 - left system transfer system; 2 - left pallet lock system; 3 - rotary gear reducer; 4 - right pallet lock system; 5 - right system transfer system; 6 – servomotor; 7 - pallet transfer guides.

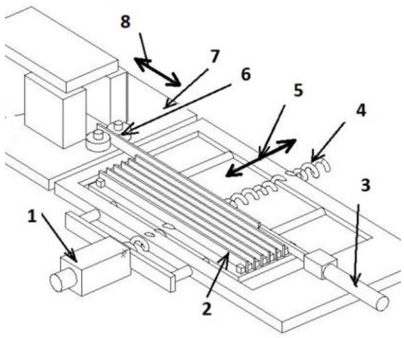

Fig. 5. Transferring device of door mouldings.

D. Description of the Transferring Device

This transferring device has several functions: a) the function of capturing and fixing the pallet; b) the proportional displacement function of the pallet in the direction perpendicular to the axis of the cutting machine; c) the function of pushing the molding from the pallet to the cutting machine; d) transfer function: take the molding and place it on the cutting machine in order to cut to the appropriate size and angle [3].

Fig. 5 shows the components of the transfer device from pallet to cutting machine: 1 – servomotor; 2 – palette; 3 - pneumatic piston; 4 – ball screw; 5 - the direction of movement of the palette; 6 - guide and drive rollers; 7 - the table of the cutting machine; 8 - the direction of movement door mouldings. The purpose of the pallet capture and fixing function is to receive the pallet from the palletizing robot and lock it in special mechanical devices for the guided movement. The proportional displacement function is carried out with a ball screw driven by an electric actuator provided with a high resolution encoder. The displacement steps are proportional to the thickness and dimensions of the moldings in the pallet, so that, at each displacement, the center of the molding is in the direction of the push piston. The thrust function is performed by a pneumatic piston over a distance of 9 to 12 inches. It aims to extract the moldings from the pallet and place them in the transfer rollers. The transfer function is carried out by 2 rollers positioned on one side and the other of the molding, which moves the molding from the pallet on the table of the cutting machine, in the cutting position [4].

E. Description of the Cutting Machine

The cutting machine consists of 3 numerically controlled axes and an axis of rotation from 0 to 45 degrees or 0 minus 45 degrees. The 3 numerically controlled axes are linear and have a role in determining the exact dimensions of the cutting elements. The cutting head makes the two cuts at both ends to avoid positioning errors. It is capable of cutting at very high speeds; successfully cutting up to 20 doors moulders per minute. The cutting head is equipped with a finishing cutting blade, with 40 cutting teeth and a diameter of 10 inches.

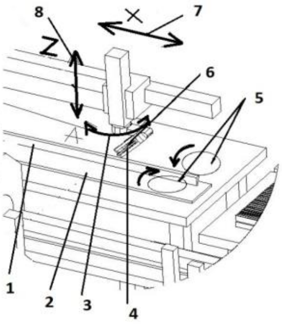

Fig. 6 Cutting machine.

The main components of the cutting machine are shown in figure A.1 - door moulding; 2 - working table of the cutting machine; 3 - Direction of rotation of the cutting head; 4 - cutting head; 5 - door roller drive rollers; 6 - cutting blade; 7 - the direction of travel to determine the length; 8 - input / output from the material.

III. How the Cell Works

A. Description of the Production Flow

The empty pallets are loaded, on models, with 2-8 types of door moldings, of various models, widths and thicknesses, but of standard gross lengths of 8 feet. A pallet can only contain one model, and the number of door moldings in a pallet is determined by its thickness, varying between 24 and 48 pieces. The exterior dimensions of the pallet are the same for all models, as well as the pneumatic-electro-mechanical drive mode. According to figure 1 each pallet is loaded behind the storage, and transported by the feed conveyor, to the point of pick-up by the palletizing robot. The maximum number of door moldings that can be stored in storage is given by relation (1);

$$Nm = \sum_{i=1}^{n} \text{int} \left\lfloor \frac{Lp - li}{li} \right\rfloor ; \qquad (1)$$

where Lp represent the width of palette, li- thickness of each specific moldings and i – the model of moldings. In the first phase, the palletizing robot fills with pallets of various models, all the storage. The pallet storage places are well identified by the data management system. The control system constantly knows how many doors are in the production flow, calculated by formula (1), and uses this information to permanently fill in the remaining empty places in storage. Only full pallets can be found in storage. If fewer door molds have been used for an order than they are in a full pallet, that pallet is stored in a temporary place, and is left waiting for a new order [5].

For the transfer of door moldings from the palace to the cutting machine to be done in good conditions, a new, original design of a transfer device, described in figure 5, was required. This device ensures the transfer of the door moldings on the table of the cutting machine, with an extremely high speed, with high precision. The full pallets are placed in this device by the palletizing robot. When empty, the robot takes them and places them on the exit conveyor, in order to replenish them. Incomplete pallets are also deposited by the palletizing robot in the incomplete pallet deposit, where they are taken as a priority for a new order. The door moldings reach the table of the cutting machine in a vertical position on the side, and are cut by the machine by an original method, by the scissors method. Another originality is that the same cutting head makes both cuts at each end of the door molding. In this way, the cutting errors in length are reduced. Once cut, the door moldings are taken over and stored by the second robot, on the table of the wrapping machine. They are arranged in such a way that they form a package of six, as much as is necessary for the assembly of an interior door. The packaging machine packs the package with plastic foil, and attaches an identification label to the package. The same robot takes the package and puts it in a trolley, in a specially arranged compartment, which, once filled with packages, transports them to the construction site trucks.

B. Description of the Automation System

For the whole cell, a single processor is used for all 19 axes [3], [6].

TABLE I: Several Specifications of System

No crt	Name	Number
1	CPU 32 bit high speed	0,3 ms/1 kstep
2	No. Of axes numerically controlled	19
3	No. Of Digital inputs	32
4	No. Of Digital outputs	32
5	No. Of Analog inputs	12
6	No. Of Analog outputs	5
7	Encoder rosolution	17 -bit
8	Communication	EtherCAT
9	Programmation	FBD, C#, G code

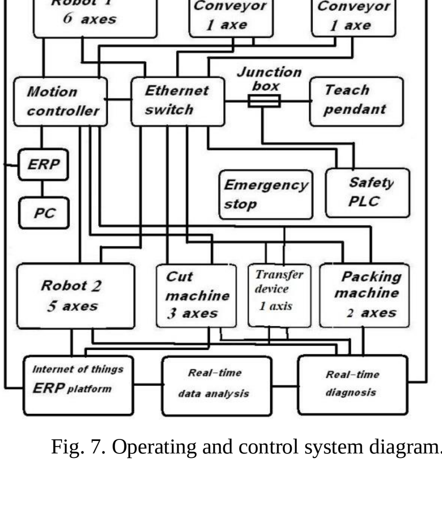

Fig. 7. Operating and control system diagram.

They are distributed as follows: 5 axes for the palletizing robot, one axis for the feed and output conveyors, 5 axes for the handling robot, 3 axes for the cutting machine, one axis for the EE, one axis for the transfer device, two axles for the packing machine. The number of analog and digital outputs and inputs are presented in table 1. The operating and control system operation diagram is presented in figure 7. At the center of the attention of the robotic cell management system is our ERP (Enterprise Resouces Planning). It houses all the command, diagnosis and control platforms, which can be accessed in the form of menus, with individual viewing windows. The information can be displayed on several control screens. The input elements to the system from the human operator are introduced from HMI (Human machine control). The main master processor of the system is 32 bits and has a very high speed of information processing - 0.3 ms / kstep. It directly controls the 19 axes grouped into specific systems for controlling spatial trajectory: 3D functions of linear, circular or hyperbolic interpolation. The same spatial functions normally performed by an individual industrial robot, except that in our case, the same processor manages the functions for 2 robots plus the rest of the axes presented in the diagram (fig 7) [7].

All the components of the system are interconnected by the EtherCAT communication protocol, which allows the real-time control, diagnosis and control implementation with good results. Each element of the system communicates with each other, and with the mother platform that is found in the PC. The entire system is equipped with position, speed, acceleration, vibration, moment, force, current intensities, temperature and pressure sensors.

These sensors allow us to have a good control of the whole cell and to identify the problems that can appear, with great precision, in real time. The manufacturing platform of the ERP program allows taking orders online, temporarily stopping the production and leaving it in stand-by, and introducing new orders, considered priority. Once these are completed, the old production will resume from where it remained [8].

TABLE II: THE AVERAGE OF THE MEASUREMENT RESULTS

No	Length		Angle	
crt	Before	After	Before	After
1	0,03	0,001	45,332	45,025
2	0,02	0,002	44,787	44,998
3	0,04	0,007	45,202	45,012
4	0,07	0,005	44,896	45,041
5	0,025	0,011	44,698	44,948
6	0,035	0,0065	45,025	44,978
7	0,05	0,013	46,580	45,321
8	0,087	0,002	45,980	45,025
9	0,025	0,0015	47,012	44,958
10	0,027	0,004	44,235	44,978
11	0,041	0,0032	43,958	45,352
12	0,065	0,0025	44,358	44,896
13	0,098	0,015	45,215	44,975
14	0,061	0,017	44,687	45,011
15	0,025	0,009	44,357	44,995
16	0,053	0,004	45,369	45,012
17	0,074	0,012	47,010	44,966
18	0,023	0,005	44,899	45,021
19	0,015	0,001	45,325	44,997
20	0,05	0,003	44,541	45,013

IV. EXPERIMENTAL RESULTS

Before designing the new manufacturing cell, we conducted several studies and analyzes in interior door factories. We have made several measurements, repeatedly, to determine the errors of execution of the lengths and cutting angles at 45 degrees. The average of the measurements was presented in table 2, where the average of the measurements is presented on a sample of 20 measurements, before and after the implementation of the new system. The measurements were made on more than 24 models of door mouldings. It was found that the value of the length errors increased as the mouldings were thinner and of a softer material, due to the non-uniformity on the cutting board, and the angle errors were higher for the large width mouldings.

The average of the results of the experimental measurements was also graphically represented in Fig。 8, for both the length errors and the angle errors. In the graphs it is very clear how big the errors before the implementation of the innovative system were and how much they diminished after the implementation. The length errors decreased by about 4 times, while the angle errors by about 5 times.

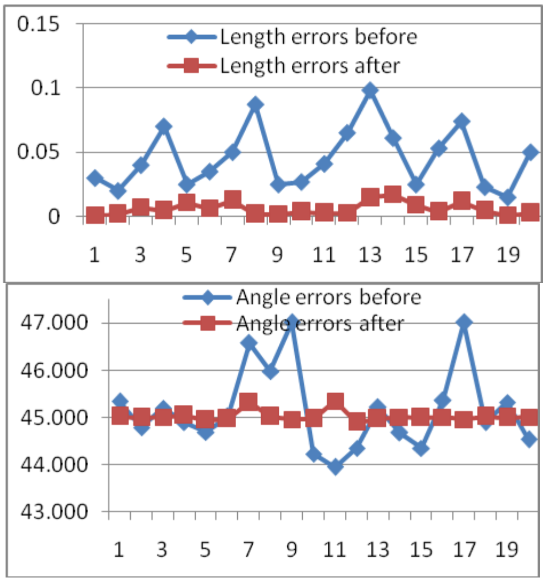

Fig. 8. Graphical representation of cutting errors in length and angle.

The measurements were made with digital measuring instruments, for both angle and length. For angles the encoder was connected directly. For measuring the linear lengths, a 16-bit resolution encoder were used, mechanically connected to a pinion mechanism and toothed belt. The encoder was connected to high-speed counter modules from Delta AHCPU-500 PLC. The software ISP Soft was used to create the conversion program in units of length or angle, and displayed on 7 inch HMI, with a very high resolution of 0.001 mm or degrees.

V. CONCLUSION AND FUTURE WORK

The paper presents an original method of manufacturing interior door moldings, at low costs, and with the simplification of programming algorithms, thanks to the use of function block diagrams (FBD). Connecting the automatic system to an ERP software platform allows us to control, diagnose and control production in real time, in the spirit of the new technological revolution Industry 4.0. With this automatic system it was possible to reduce the errors of length, 4 times and those of angle 5 times, and the productivity increased 4 times. In addition, custom commands can be inserted over the current production, without affecting the proper functioning of the system. What remains to be done is to optimize the processes of handling and transferring the door moldings from the pallet to the cutting machine, where the transfer device requires some adjustments to increase the transfer speed and improve the real-time diagnostic programs for the entire automatic cell. A patent application has been filed with CIPO and the patent is pending.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Paul Badescu led the research activity. He managed the construction activities in the laboratory of the automatic manufacturing cell. Made all the programs to connect the system automatically to ERP. It has improved the diagnostic programs and created the EtherRCAT communication software. Niculae Mihai directed the activities of electro-pneumatic-mechanical implementation, performed the electronic devices and carried out the experimental research. He wrote the paper. All authors had approved the final version.

Acknowledgment

The author thanks the Canadian provincial and federal government for the financial support for this research work, as well as the management of Quebec companies Intermat S.A., ABA Portes et Fenetres and Astra Fenestration, because it allowed us to do studies, analyzes and experimental measurements.

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Dr. Mihai works in collaborations with Prof. Univ. Ph.D. Eng. Adrian Olaru from the "Politehnica" University of Bucharest, Romania. He applied for several invention brevets in the robotics application fields. He is a member of "Ordre des ingenieurs du Quebec" since 2005.