

Automation and electrical control of a mortising machine with 12 synchronous perforations in the manufacture of stairs

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ABSTRACT

With the constant technological development, industries have been incorporating technologies into their manufacturing processes, which generate benefits in the productive field. In the manufacturing process of wooden stairs, the faults of the products, generates that an adequate homogeneity is not achieved, often because the manual operation is carried out without having established parameters in the handling of the mortiser. In this sense, the present article develops an automatism and electrical control of a 12 synchronous perforation mortiser, in order to improve the productivity of the perforation stage in the manufacture of wooden stairs. As part of the development, the electrical, pneumatic and mechanical control system is carried out using Autodesk Inventor software, while the KOP programming is carried out in Tía Portal V14 with connection to S7 PLCSIM V14 using the programmable logic controller (PLC) 1214C. Once the automation has been implemented, a reduction in the processing time per wooden strip of 74.68% is obtained. Likewise, with the automatic process, it is possible to produce 2,460 units of slats, that is, the monthly production increases by 294.9%, in other words, the productivity is 58 units of slats manufactured per hour.

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1. INTRODUCTION

Currently, manufacturing companies face a changing environment, above all, they experience pressure in terms of time to market new products, where technology is increasing and competition is increasing [1], [2]. Current production cycles are mainly characterized by their efficient execution with exponential increases in production, and by the competition that these generate in organizations; situation that helps to identify the importance of the processes implemented in the industries and how they must respond to the demands of the market and the effectiveness that the environment demands, always keeping as the main premise the cost-benefit balance of the solution in the industrial environment of the projects [3]-[5]. For this reason, industries are forced to use new systems that support the dynamics that organizations face, however, current systems lack this dynamism, which often makes it impossible to implement new functionalities to the processes of autonomous production, due to the lack of flexibility and agility to respond to the dynamics of production styles that are experienced today [6], [7]. Therefore, one of the strategies that should be proposed

within companies should focus on how to maintain this competitive momentum, in order to become highly productive businesses [8]. The need to have an improvement in the quality of production, as well as its increase, made many of the companies invest in processes that allowed them to have an improvement in terms of manufacturing processes, since they went from being a simple production line to a complete communication between the processes of field and administrative levels [9], [10].

The main challenge of modern industry is to integrate the needs of customers with the different automation technologies used in industrial processes [11], these technologies allow having effective, robust, and autonomous systems of the tasks that are executed in the internal processes of the industries. For decades, automation has been a pillar of the industrial development of humanity, generating employment and taking the system to levels of production never before imagined, in the field of industry, automation contributes to improving the production and efficiency of the different processes that are handled in the market [12], [13]. There are different types of elements that allow us to perform automation, elements such as programmable logic controllers, frequency inverters, servomotors, sensors and others have emerged in this optimization process as the ideal tool to improve production levels [14], [15], in the industry the most used are programmable logic controllers (PLCs) due to their great coupling with human-machine interfaces (HMI) [16], also the PLC allows us to carry out supervisory control and data acquisition (SCADA) systems, which is a system that It is based on computers which allows us to supervise and control process variables remotely, communicating with field devices (autonomous controllers) and controlling the process automatically through specialized software [17]-[20]. In pointed out that automated companies must provide reliability, efficiency and flexibility in their systems, which satisfy the market demand, demanding that they have competitive machines with a high technological degree [21]-[23]. One of the main bases is the control, monitoring and analysis of production processes in a sequential manner. Having described the previous paragraphs, it can be indicated that the company's problems arise from product failures in the manufacturing process of wooden stairs, because the drilling stage is often carried out depending on the criteria of each operator without having established parameters in the handling of the mortiser, which is why an adequate homogeneity in the product is not achieved. In this sense, this article develops an automatism and electrical control of a 12 synchronous perforation slotting machine to improve the productivity of the perforation stage in the manufacture of wooden stairs. The research aims to generate a greater knowledge of the automation area, taking into account that the vast majority of industrial processes are being carried out automatically, for which the company, where the research is carried out, sees the need to update its equipment to improve the quality of its products, reducing time and costs, through efficient, accurate automation, which improves productivity.

2. LITERARY REVIEW

As indicated in [24], [25] the evolution of information technologies has increased the possibility of having a new vision about manufacturing processes in the area of industrial automation, whose challenge focuses on flexibility and their reconfiguration. The trend in industrial environments is to create systems intelligence from a large population of small, networked devices with a high level of detail in terms of intelligence levels, facilitating the adaptability and reconfiguration of systems, for which allows to satisfy the unforeseen business needs during the design stage, thus granting real benefits at the business level [26]. The new technologies and the demand in the organizational environments, allowed the birth of new solutions that allow the integration of other systems for the acquisition and processing of information [27], [28]. Similarly, in [29]-[31] it is pointed out that industrial automation allows us to control machines, its main objective being to reduce the time of the process. Today it is possible to automate practically any industrial production process through the design and implementation of automation and any other element necessary to achieve respectability of a process with cycle times much lower than those that would be achieved manually or semi-automatically. Through the adoption of electro-mechanical automation and comprehensive industrial automation systems of the industry, a substantial improvement of all its production processes will be achieved, thus making companies much more competitive [32]. As indicated in [33], although the automotive sector is the pioneer in terms of process automation, today, thanks to the presence of sophisticated systems within production processes, several sectors are applying their knowledge, with the in order to improve the quality of its products. Finding the companies in the wood sector, in the need to automate the control, displacement and coupling of their machines, in order to optimize the manufacturing processes to improve the quality of the finished product and therefore not only satisfy the needs of the customers, but rather improve their productivity in relation to quantity, cost and time [34].

3. DESCRIPTION AND DEVELOPMENT

As part of the automatism of the synchronous mortising machine, the mechanical, pneumatic and electrical system is established to be used. Taking into account that, for the manufacture of wooden stairs, 2 elements are necessary, the steps and the uprights. The steps are milled, and the uprights are mortised with holes for the steps to fit.

3.1. Description of the mechanical system

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The mechanical system consists of 2 displacement axes and 1 slat handling axis. The first displacement axis (X) is horizontal, and the second axis (Z) is vertical, the manipulation axis (Y) will place and remove the slats automatically. In the X axis, a linear and continuous back and forth movement has been determined, which moves the wooden slat fixed hydraulically on chassis 1. Chassis 1 is subordinated in the amount of displacement, in order to carry out the graduation required by the mortising machine, likewise, the distance of the mortising in the wood, it is coupled to a reducer from 30 to 1, that is, for every 30 turns of the motor, the reducer will make 1 turn. In the Z axis, there are 12 bits or milling cutters, which individually have: (A chup that adjusts the bit, 2 1-inch wall bearings and a pulley for the transmission of movement), thus having 12 groups of these components, which will be mounted on chassis 2, which in its rear part has 4 motors (every 3 axes with their pulleys are linked to 1 motor), thus having 4 groups. The chassis have a vertical travel restriction, which is driven by a 3-inch screw, with an orange gear on top, which is coupled to a motor. In this system there are 6 total motors used: M1=M5=M6=M7= High-speed motor, 2HP, 60Hz, 3φ Three-phase (For the movement of the 12 blades that mortise the wood), M2= ½HP motor, 60Hz, 3φ Three-phase, with clockwise and anti-clockwise rotation (Used to control the vertical axis) and M3=Low speed motor, clockwise rotation, 2 Hp, 60 Hz, 3φ Three-phase (Control of the horizontal axis). The mechanical system for the mortising of the slats was developed with the Autodesk Inventor software, and is shown in Figure 1.

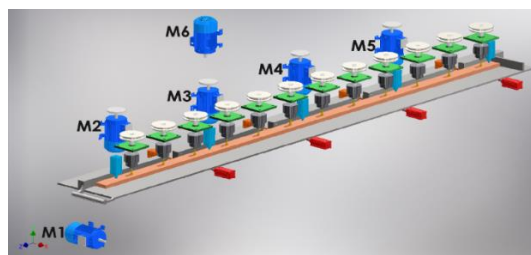


Figure 1. Mechanical system of the mortising machine with 12 synchronous perforations

3.2. Description of the pneumatic system

The pneumatic system has 12 solenoids (P1-P12), which are controlled by solenoids, which are pistons that are grouped into 3 groups (A, B and C) with their respective characteristics. Group A is made up of 4 solenoids (P1-P4) that control the advance and placement of the wooden strip; group B is made up of 4 solenoids (P5-P9) that control the adjustment, from the slat to the chassis 1; group C is made up of 4 solenoids (P10-P13) that have control over the withdrawal of the strip, after mortising. The pneumatic system for the mortising of the battens is shown in Figure 2.

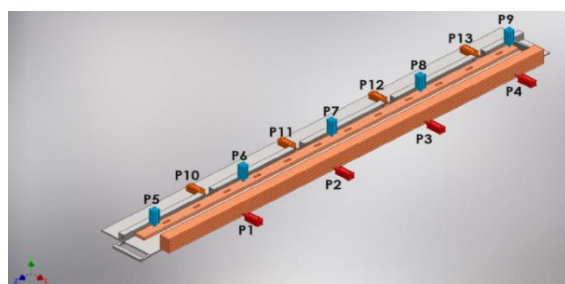


Figure 2. Synchronous 12-hole pneumatic mortising machine system

3.3. Description of the electrical system

The electrical system circuit is divided into 3 axes (X, Z and Y). In the "X axis", the motor M1 is used, which is coupled to the speed reducer. In the "Z axis", 4 motors are used (M2, M3, M4 and M5), which move the axes, towards the blades, while the M6 motor controls the vertical displacement of chassis 2. Regarding the "Y axis", it has 12 solenoids (S1-S12), which are coils that will control the passage of air to the pistons 3 groups of solenoids will be used, all 24 volts for their activation and displacement and 0V for their deactivation and return, these solenoids will be energized or de-energized according to the time line, exposed in Table 1. In the first column of Table 1, the company's current batten mortising processes are shown

(place, fasten, mortise, loosen and remove the batten), in column 2, the line of action is observed, which is in descending order, in column 3, is the name of each term, exposed in the line of action, in column 4, the names of the drive components are shown, described in the mechanical and pneumatic system. Column 5 shows the drive groups with respect to the axes, column 6 shows the time of each action, of automation and the last column shows the progressively accumulated times, being the total time for the mortising of 1 strip of 33 seconds.

Figure 3 shows the automatic circuit elaborated using the CADe Simu software, which allows the sequential process of Table 1 to take place. For the batten to be mortised, the circuit begins at the top, with the relays of protection for each motor, then there is the stop button (PP), which deactivates the energy, when it is open, turning off the circuit, followed by the start button (PM), which starts the cycle of the mortising process of a list Wiring logic is shown below with markings, open and closed contactors, for the actuation sequence of the pneumatic and motor components. Likewise, on the right side a limit switch is shown that closes the circuit, terminating the process. The second important component is a relay, on the “axis Z”, that turns off the rotation of the motor 6. Finally, there is a 4 Hz fixed frequency variator, whose function is that the motor goes up and down, on average at about 33RPM, with the purpose of gently mortising.

Table 1. Synchronous 12-hole pneumatic mortising machine system

Processes	Line of action	Name	Pneumatic components and motors	Displacement axis	Time of each action	Accumulated time
	PM				0	0
Place ribbon	A+	Group 1	S1,S2,S3,S4	Axis Y	1.5	1.5
Hold ribbon	B+	Group 2	S5,S6,S7,S8,S9	Axis Z	1.5	3
Mortise	M1+	X-axis motor	M1+	Axis X	2	5
	M(2-5)+	drill motors	M2,M3,M4,M5	Axis Z		
	M6 +/-	Z-axis motor	M6 +		20	25
		M6 timetable end of race	M6 H			
		M6 anti-clockwise end of race	F1			
		Z-axis motor	M6-			
	M(2-5)-	drill motors	M2,M3,M4,M5		2	27
Loosen slat	M1-	X-axis motor	M1-	Axis X		
	B-	Group 2	S1,S2,S3,S4	Axis Z	1.5	28.5
Remove ribbon	A-	Group 1	S5,S6,S7,S8,S9	Axis Y	1.5	30
	C+	Group 3	S10,S11,S12,S13	Axis Y	1.5	31.5
	C-		S10,S11,S12,S13	Axis Y	1.5	33

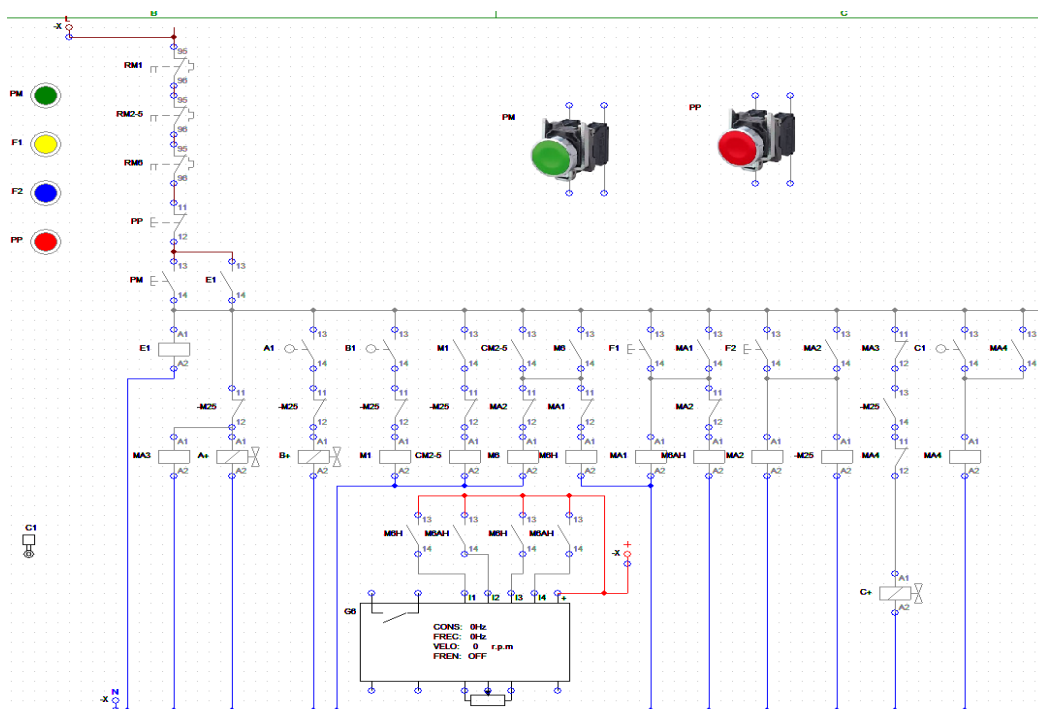


Figure 3. Electric system of the synchronous 12-hole mortise

3.4. Development

Figure 4 shows the LAD programming in tía portal V14 with connection to the S7 PLCSIM V14 of the PLC 1214C. Pressing the start button (PM) starts the process, since the circuit will be normally open and when it changes state, the mortising stage will begin, in the event of any unforeseen event or risk, the stop button (PP) will be pressed, which will de-energize the entire process. Once the PM is in logical state 1, the valve solenoid "pistons (A+)" gives way to the pistons of group 1, after 1.5 seconds the timer 1 activates the solenoid of the "pistons (B+)", which, when extended, hold the strip with the solenoids of group 2 (axis Z), leaving the entire hold of the wooden strip, ready for the mortising process.

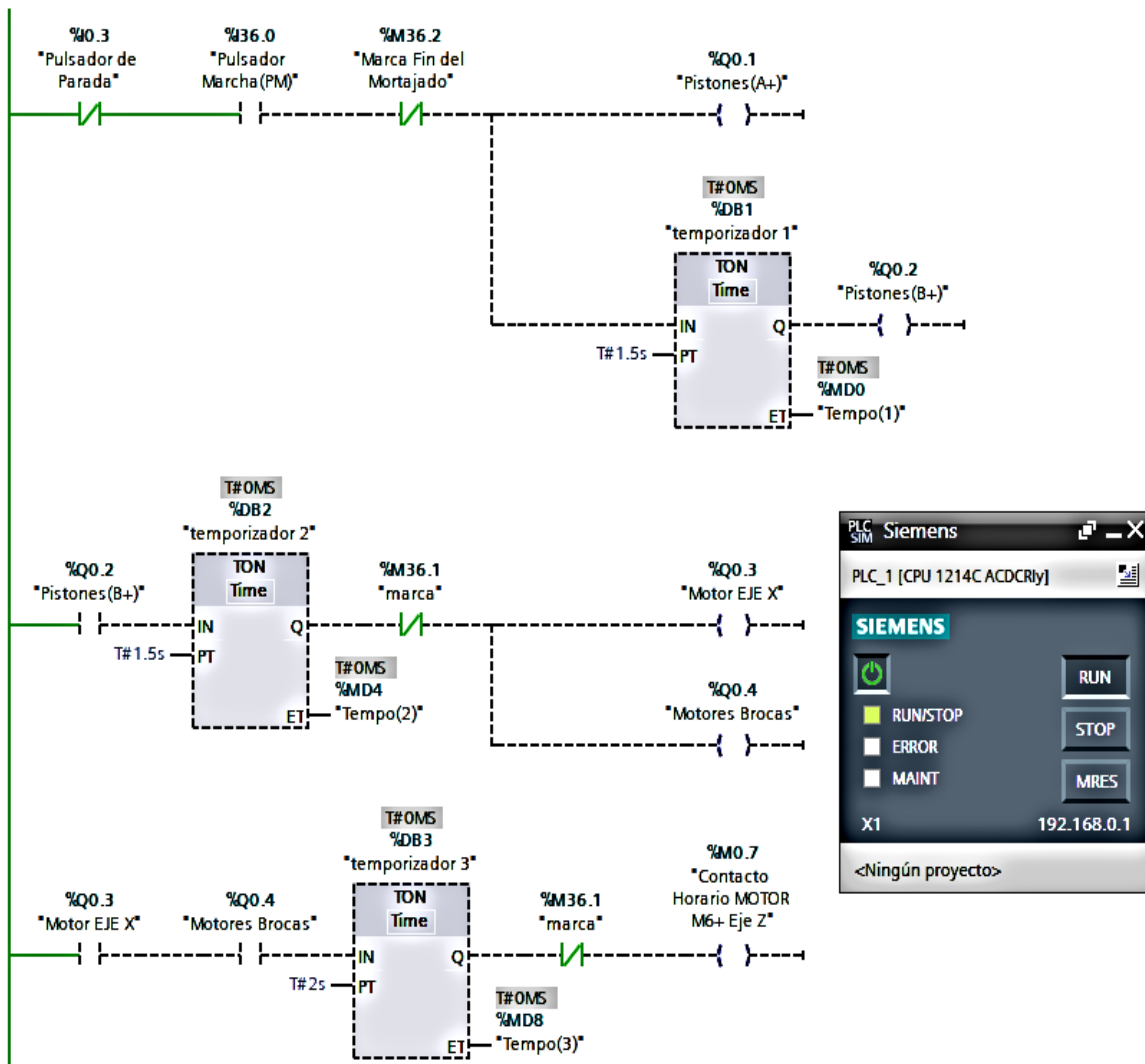


Figure 4. Programming and simulation of segment 1

In Figure 5, timer 2 is shown, which is in the second line of the KOP code, which after 1.5 seconds, activates the X axis motor and the drill motors, which through an independent relay activates the group of engines from the third line of the LAD code. Likewise, once the connection delay timer (timer 3 of 2 seconds) reaches 0, the "M6 motor time contact + Z axis" is turned on, which lowers the bits to start the mortising process. Going down about 3cm, there is a "limit switch F1", which is the mechanical limit in which the Z axis will go down, and de-energize with a "Mark" the clockwise direction of the motor as seen in Line 4 of the code KOP. At this stage, 1 sec will be given, so that there are no crossovers in the M6 motor, thus protecting it from the clockwise and counterclockwise contacts, on the other hand, once the timer 4 (1 sec), arrives at 0 sec, the "counterclockwise motor contact M6- Z axis" is energized, which will make the drills go up to their original location, finishing mortising the strip, thus waiting for the limit switch F2.

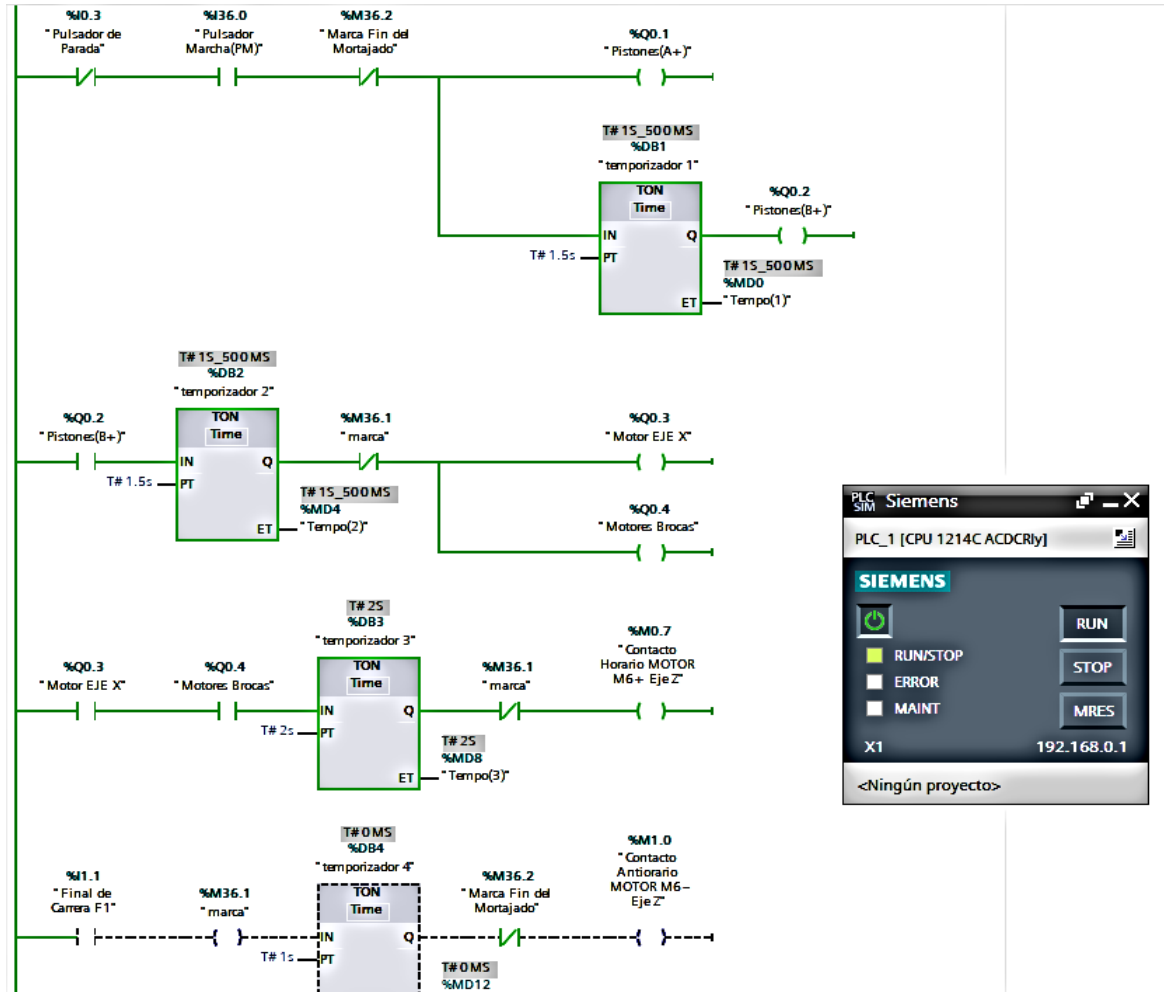


Figure 5. Programming and simulation of segment 2

In Figure 6, the operation of the "limit switch F2" is shown, which will de-energize all the motors, with the "End of Grooving Mark". In line 6, the logic of the circuit causes the piston C to unfold, and after 1.5 seconds and through the "Retract Mark (C-)" the entire cycle is started in a continuous loop until the operator. You want and stop the operation with the stop button (PP).

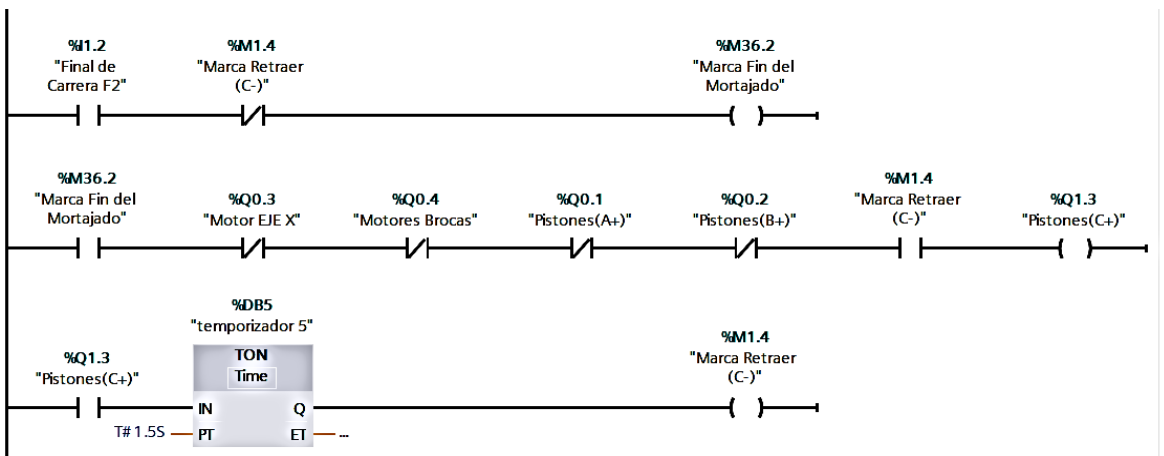


Figure 6. Programming and simulation of segment 3

4. RESULTS AND DISCUSSION

4.1. Results

In order to determine the benefits generated by the automation of the mortising process in the manufacture of wooden stairs. Table 2 shows a comparative analysis of the results. It should be noted that, in the processing time per strip, the speed of the pistons and the ignition time of each motor are being considered.

Table 2. Comparative results

	Manual process		Automatic process	
Total manufacturing time per strip	235	seg	59.9	seg
	3.91	min	0.99	min
Total time for 623 ribbons	2435.93	min	610.54	min
	40.60	hrs	10.18	hrs
Monthly mortise slats	623	und	2460	und
Monthly time of produced quantity	2430	min	2430	min
	40.5	hrs	40.5	hrs

According to the results of Table 2, the elaboration time of each strip has been reduced by 74.68%, that is, 175.1 seconds less, compared to that obtained in the manual process. In addition, it is shown that monthly in the manual process, 623 slats were made in a time of 40.50 hours, if we consider the same number of slats made, in the automatic process, it can be determined that this would only take 10.18 hours. In the same way, if we consider as a base, the monthly time it took to produce the number of ribbons, it is calculated that in the same time (40.5 hrs), with the automatic process, it is possible to produce 2460 units of ribbons, that is, the monthly production increases by 294.9%. With this result it can be interpreted that the productivity with the automatic process is 58 units of strips manufactured per hour.

4.2. Discussions

In relation to the results obtained in the previous paragraph, it can be pointed out that the implementation of new technologies in industrial environments brings great benefits in the productivity of the processes; Likewise, with the inclusion of this automated control system, the production process will go from being centralized, to decentralized and intelligent, in this way, the machine adapts to changes through automation and optimization of functions and resources according to commands from the programmable environment. Likewise, the technological updating and automation works, such as the present case, help to mitigate and avoid risks, through a correct selection of the programmable automaton that best suits the characteristics and requirements of the process, and detailed engineering with operational tests of the implemented system. Authors such as [35] presented an analytical model in order to estimate the performance of automated systems in order to increase productivity in delivery and decrease response times, as a result they obtained that the production time in the preparation of orders is achieved reduce by up to one third of its initial value.

In the investigation of [29] when performing the automation for an industrial thermoforming machine through a PLC, an increase in production (30%) was obtained, in addition to the same consumption under the production cost per unit. In the same way in [17] the realization of the project allowed him to increase 40% of productivity. Of the same, automation generated great benefits, as indicated in [36] productivity indicators improved significantly, labor productivity increased by 217.39 kg/hour - man and machine productivity to 200 kg/hour machine. On the other hand, machine utilization and production output increased by 100%. Vizcaíno [33] the automation of the process reduces times by 46%. In relation to the reduction of time in [18], the production process was optimized with the reduction of time. Cevallos *et al.* [19] the design of an automated system through a PLC introduced advantages to industrial production such as increased efficiency and quality, production homogeneity, reduced physical effort of plant operators and increased productivity functional safety in it.

As indicated in Acharya *et al.* [28], the design of the automated system was able to reduce the process time from 13 seconds to 11 seconds and the reduction in bottling time was 36%, in addition, the return of bottles by 90% was reduced part of the final consumer and production is increased by 36%, the prototype has been developed with pneumatic actuators, sensors, solenoid valves, solenoids, motors and a programmable logic controller (PLC S7-1200). Likewise, in the scientific article of [25], automation achieves a more agile and efficient distribution of the finished product, obtaining that operators have adequate ergonomics in the performance of their work and do not perform routine, inadequate and exhausting movements. Morel *et al.* [12], the result achieved was the integration of process control systems, which generate the feasibility of manufacturing functional devices with a small installation space, easy operation of the automatic control software, and an integration between the connection of the control systems for each process. Mejía-Neira *et al.* [8], productivity is increased through the implementation of an automated system, which reduces response times for the supply of raw material and guarantees customer satisfaction with optimal delivery times.

5. CONCLUSION

Industrial automation offers competitive advantages, ensuring its permanence and prevalence in the market, maintaining excellence in production processes, guaranteeing fast response times, and also reducing risks to employees. The present investigation incorporates a programmable automaton to the manufacturing process of wooden stairs, which allowed a greater control of the synchronous 12-perforation mortiser used in the perforation stage. The main benefit, derived from the implementation of the automation through a programmable logic controller (PLC), is the reduction of the time to mortise the wooden slats, resulting in an increase in production, compared to the manual way. With this automation, the quality of the drilling stage was improved, making the process in the manufacture of wooden stairs safer. Given this, it is recommended to provide prior training to the operators, so that they know how to properly use the automated synchronous 12-perforation mortiser and what measures to adopt in the event of any inconvenience, likewise, it is suggested to carry out a continuous verification and monitoring of the updates as soon as possible to the software used for the development of programming.

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