STEPS FOR CREATING AN AUTOMATED SYSTEM, USING THE INTEGRATED AUTOMATION PRINCIPLE

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Integrated automation contains a series of equipments and processes which are designed to make a more efficient production line. In other words, what was done in the past by human operators, now can be done with automated equipments. Offering a clear advantage, automation gained ground in almost all sub-branches of industry, but not only. Integrated automation is seen and considered as a necessity for existence, survival and development of any company that is providing products of superior quality. It combines the interaction between individual components of the industrial field, software and hardware tools and services.

Keywords: Integrated automation, PLC, electric motor, data aquisition.

1. Introduction

Total Integrated Automation (TIA) is a concept in automation technology that began to develop after the mid-'90s, along with the development of technology and the demand for more complex, reliable and flexible systems. This strategy defines the interaction between the individual components of the industrial field (machines, industrial robots, operators), software and hardware tools, services (spare parts, training, marketing, sales, etc.) in order to achieve a complete and optimal automation solution. Interaction is achieved through the connection between the four automation levels of the automation pyramid (Fig.1). TIA concept offers simplification and cost reduction for companies involved in the automation domain [1].

Integrated automation concept occupies an important position in the contemporary scientific and technological environment and it has the purpose to bring closer the domains of technology and management, also leading to a multitude of benefits to the companies that adopt them. At the same time, considerable financial investment is needed for the implementation of the integrated concept [2]. Integrating a constant change of design and manufacturing of technical products is a stunning step made in recent years by any firm that has

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it's core concern the development of new or upgraded products. Machine tools are being annexed to flexible production systems very often, and the prospect of machine tools integration for other activities necessary for the production process is already used by many companies in the construction of integrated production systems. Integrated computer-based design and manufacturing are at this time mandatory for any company, regardless of size, given the complexity of the products to be manufactured, the technology that determines the cost of the product and the need to build a useful database which also includes some management systems [3].

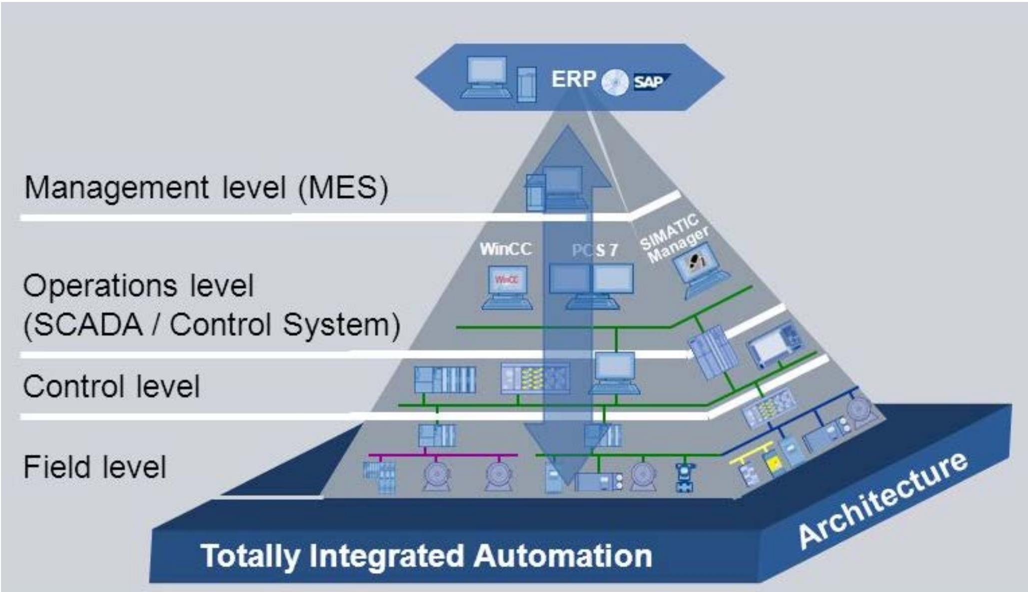

Fig. 1. The TIA concept pyramid.[4]

Companies that manufacture automation systems have implemented the TIA concept by developing a complex software system that allows the virtual creation and control of an automated system [5]. With the help of the platform, the following automation components can be programmed: the PLC, the HMI and the drive system.

An example of a platform used for industrial automation is the TIA Portal platform developed by Siemens. Within this platform are integrated several software that allow the creation of a project in which different types of equipments can interact [6]. The goal of the platform is to be able to carry out an automation project by using a common interface that simplifies data transfer between softwares, dissolving compatibility issues [7]. Also it allows the user to design a project through an intuitive graphical user interface which is easy to use [8].

The main objective of this paper was to create, improve and simplify the control of an automation, using the fully integrated automation concept. This goal has been achieved by creating, improving and simplifying the control of multiple automated processes so that they can be easily used by an engineer who does not have a thorough training in automation and programming. Therefore, various theoretical and experimental studies have been developed focusing on:

- creating an automated system;
- including the concept of fully integrated automation within a system;
- creating an automated program for a system and performing the automatic system configuration;
- presenting the process to improve the performance of an electric motor driven and controlled by means of a static frequency converter.

By creating a methodology which can be followed step by step, a small company who doesn't have the resources to invest in trainings and support from third parties, can develop complex automation systems which can improve productivity.

Considering that the integrated automation is a concept developed and used mostly by private companies, it is a topic that is not dealt with in detail in the literature. Companies that create platforms based on this concept try to sell their product and do not want to present the information regarding the specific configuration settings which can be made in order to improve the automated system's performance.

2. Methodology for creating a system which contains integrated automation

A system is a complex of elements that interact with each other. Its properties depend not only on the properties of the component elements but, more importantly, on the interactions between the elements of the system. Planning and putting into operation of a system containing integrated automation is not an easy process. It is necessary to go through well-established stages and rules of construction of the system. Therefore 14 stages have been proposed in order to simplify the process of building a system that includes integrated automation. They are designed to help an engineer with inadequate automation skills to create, control and monitor an automated system. The 14 stages aim at defining the system, creating a virtual project, configuring and programming the system components and monitoring its operating parameters. Respecting and following this stages ensures the achievement of an integrated automation system, the study of the active control of the parameters of a drive system and the programming of an automated system by using the programmable logic. This stages were conceived because many companies invest in studies regarding integrated systems, but since competition is at the highest level, they do not share the information obtained from experimental research.

The 14 stages for building an integrated automation are:

- Stage 1: Study of the system requirements to carry out the desired process: Before designing any system, a study needs to be made of the system requirements to be able to carry out the desired process. This study must contain calculation of the forces resulting from the process and the forces needed to overcome them. Each device from the automated system has some features that can be found in the product datasheet or in different profile catalogs. These details should be studied carefully, and then choosing elements that have the particularities that are similar to those that are calculated or that have particularities even higher than those calculated. Also, a quality/cost ratio report must be made before the optimal equipment is purchased. If the price difference is very small, equipments must be chose in order to leave room for adding new functions in future processes. In the case of the electric motor, the particularities to be followed are: torque, speed, amount of current consumed and its weight. To select the converter, the following main parameters must be carefully studied: voltage, current, impedance and power consumption. The PLC is the component that unites all other components of an integrated automated system. The following parameters are to be used for selecting this: the number of analogue / digital inputs / outputs, the performance of the PLC for complex operations, the type of communication ports, the type of communication protocols supported, and the type of attachment to match the stand requirements.;

- Stage 2: Creating the physical system: Connecting the system elements is easy according to the instructions received with the automation equipment. In most cases, equipment manufacturers provide installation support to ensure proper functioning. When installing the system, it must be taken into consideration external factors such as temperature and positioning;

- Stage 3: Defining the system within a project: After the system is connected, the automation platform is accessed and a project is made of a virtual system similar to the physical one. This is done by accessing the platform database where all the products of the manufacturer are available. Each component has an identification code and sometimes even the version of it's operating system. With this information, the components can be found in the database of the platform, and using drag and drop option, the elements of the automated system can be entered into the project one by one. If a piece of equipment is not found in the database, it can be searched on the manufacturer's site, downloaded and included into the database. The database of the platform also contains the features of each equipment. Thus, when the virtual system is built, the characteristics of each equipment are introduced into the project, saving the engineer from searching for them and entering them manually;

- Stage 4: Communication protocols: In order for the virtual system to be able to communicate with the real system, the system communication protocols must be determined. The main communication protocols in the industrial environment are Profinet and Profibus. They differ from the TCP/IP protocol used by computers by transmitting information through smaller packets at a higher speed. The Profinet protocol is an improved version of the Profibus protocol and has many features similar to TCP / IP. The main feature of the Profinet protocol is the response time of less than 1 ms;
- Stage 5: Performing automatic system configuration: When a equipment is introduced from the platform database, it retains it's properties. Therefore, the software, depending on the connected equipment, introduces into the operator's program, the operating parameters and the maximum limits allowed in the process;
- Stage 6: Programming each component of the system: The main equipments within the drive system that can be programmed via the programming logic are the PLC and the converter. The most used PLC programming languages are the Ladder Diagram and Function Block Diagram. For these, the TIA Portal platform provides a database from which the necessary instructions can be chosen. Using the "Drag & Drop" option, the instructions can be entered into the program. Using the platform database, an engineer with minimal knowledge and who does not have extensive experience in the field can create a program. With Help feature, it can be observed a description of each instruction, and sometimes there are examples of situations where a particular instruction is used. The PLC and converter programming is done by introducing organizational blocks into a program. The blocks contain instructions that can be defined in the same programming language or in different programming languages. Functioning parameters of the converter can be changed through the use of other software within the platform;
- Stage 7: Programming a human-machine interface: The human-machine interface is designed to help the operator track parameters or alter the process randomly. The HMI (Human Machine Interface) interface has a particular importance, and visual programs are made following certain rules so that the operator does not get tired. HMI panels can be programmed using the platform. Also, it is advisable to compress the information in as few screens as possible, and not to move through the main screen to more than four distinct screens;
- Stage 8: Program compile: After finishing the programs, compiling is required because it identifies mistakes in programming logic. The role of compile is to prevent the process from starting if the program is incorrect;
- Stage 9: Correcting the program: After the compilation, programming errors are highlighted in order to be easily observed and corrected. After the corrections,

the compile is run again until it is indicated that the program doesn't have any errors;
- Stage 10: Testing system operation: Testing the system is done by following the steps you want to be done in the process. The Step 7 software has an option that helps tracking the program during the process. Functions in the program are colored differently depending on their calling during the process;
- Stage 11: Data acquisition: Although the program can work smoothly, data acquisition is required to observe the operating parameters. After adequate numerical processing, the signals acquired can be used to command physical processes, respectively, to store, transmit and reproduce the information thus obtained. The complexity of data acquisition systems has increased considerably, reaching to a structure that contains not only the acquisition part itself, but also a part of process control. Usually, the data acquisition feature is included in the portal;
- Stage 12: Additional configuring of the closed loops that are automatically set: After data acquisition the measured parameters are compared with those established at the time of the process creation study. Attempts are made to change the parameters that were automatically set by the software by modifying certain closed loops. The main closed loops that can be modified are: the current loop, the speed loop, and the positioning loop. The current loop is optimized by the Scout software to automatically adjust the working parameters. Within this loop, "P gain" (p1715) represents the proportional gain of the current controller adaptation, and "Reset time" (p1717) represents the time of the automatic controller in which the error is corrected. The automatic controller has the role of taking over the error signal (obtained from the comparison of the input size and the measured data) and outputting a command signal for the execution element. The shorter the action time, the faster the error is corrected. A lower limit of this time exists because if the time of action is too low, the converter does not have time to correct the electric motor movement with the amount of power required. The loop is represented by the increase in the proportional gain within the reference time. The speed loop is set according to the moment of inertia of the engine when the engine is first set up. The calculated proportional gain is set at about 30% of the maximum possible gain to minimize vibration when the controller is mounted on the machine's mechanical system for the first time. The full speed controller speed is always preset at 10 ms. The positioning loop is the time required to adjust the actual position of the electric motor. This time is experimentally adjusted. If this time is too high, the position error can not be corrected in a timely manner, and if this time is too low, the converter does not have time to correct the engine position;
- Stage 13: System monitoring by data acquisition: SCADA is the acronym for Supervisory Control and Data Acquisition. The term refers to an ample

measurement and control system. The term SCADA usually refers to a control center that monitors and controls an entire production area. The control center's functions are sometimes restricted to decision-making functions or general management functions;

- Stage 14: Observation of maximum limits supported by the system: Since the created system is optimized, different data acquisitions can be made to observe the behavior when maximum limits are reached. Manufacturers offer the maximum limit values of the equipment parameters, but depending on the environment in which the equipment is used, these values may vary.

3. Integrated automation systems

Following the 14 stages, two integrated automation systems were created in order to validate the premise. The purpose of creating these systems is to validate the 14 stages, demonstrating that by following them any kind of integrated automation system can be made from scratch. This demonstrates that the principles can be considered as a basis to be followed for any integrated automation. Tests were made with each system following specific protocols, in order to demonstrate that the automatic tuning of the system is not always optimal and it can be improved. By modifying the closed loops of the system after multiple experimental attempts, better performance can be achieved.

The first system is an automation panel composed of an electric motor that has 0,37 kW power, a nominal speed of 6000 RPM and a torque of 1Nm. It also contains a rectifier and a HMI. When installing an automation, some installation rules should be considered. For example, the buttons and warning lights must be positioned next to the HMI to be observed and operated in a timely manner, depending on the information on the touch panel. The electric motor and the rectifier must be placed distantly from other components because they generate heat.

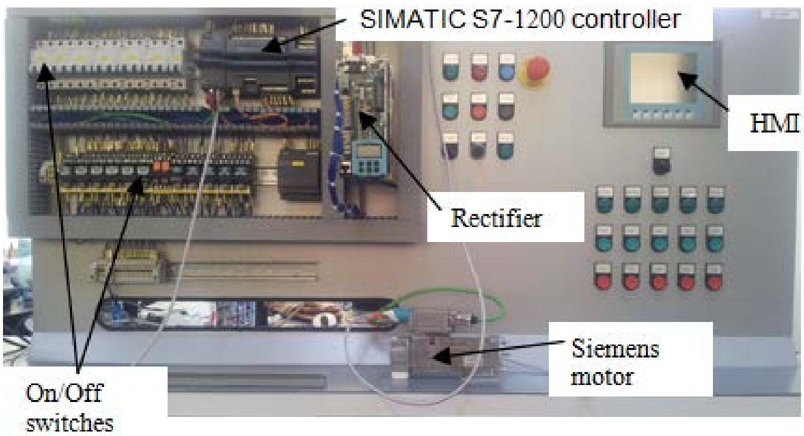

Fig. 2. Automation Panel.

After the tests with the settings made automatically, it was observed that the fastest start of the electric motor was in 1,05 seconds, having a load of 395 g. After changing the current, speed and position loops, the fastest start of the electric motor was done in 0,75 seconds. In figure 4 it can be observed the start of the electric motor, having a load of 395 g attached and the traversing of the range 0-3000 RPM in 0,75 seconds, reaching a maximum torque of 0,98 Nm.

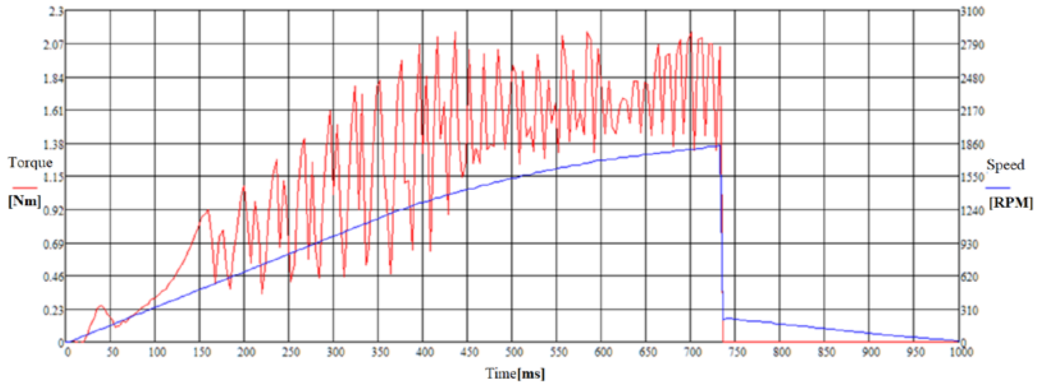

Fig. 3. Starting the electric motor in 0,9 seconds with the closed loops settings made automatically.

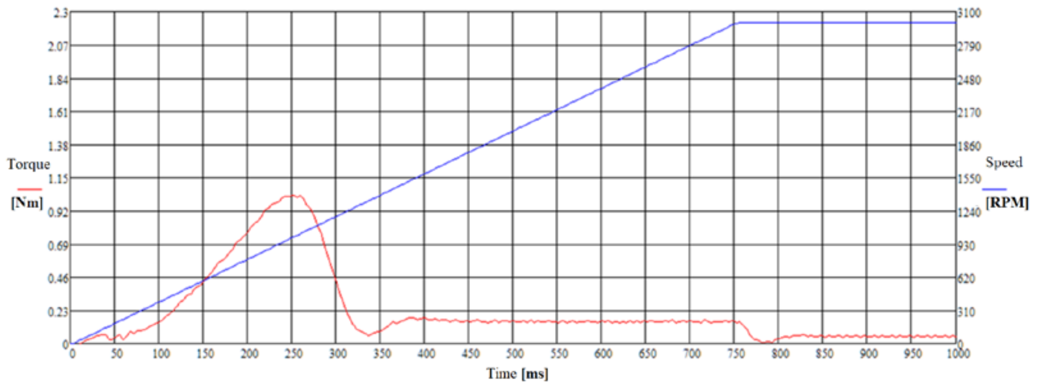

Fig. 4. Starting the electric motor in 0,75 seconds, after changing the closed loops.

The second system (Fig. 4) is an automated rotary table composed of an electric motor that has 0,82 kW power, a nominal speed of 3000 RPM and a torque of 3 Nm. As with the automation panel, the electric motor is connected to the SINAMICS S120 via the "Drive Cliq" system. It consists of a green data cable and an orange power cord. Also with the green cable, the sensors of the electric motor can be accessed . The laptop controls the rectifier and the rectifier operates the electric motor.

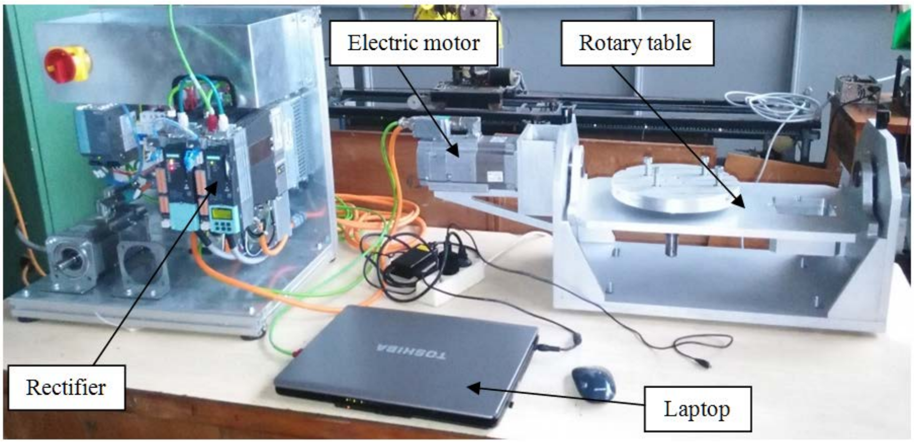

Fig. 5. Rotary Table**.**

Figure 5 shows the rotation table trajectory of 0 °> + 20 °> -20 °> + 20 °, with the configuration of the automatic operation parameters. The rotary table can reach the maximum position of ± 22 °.

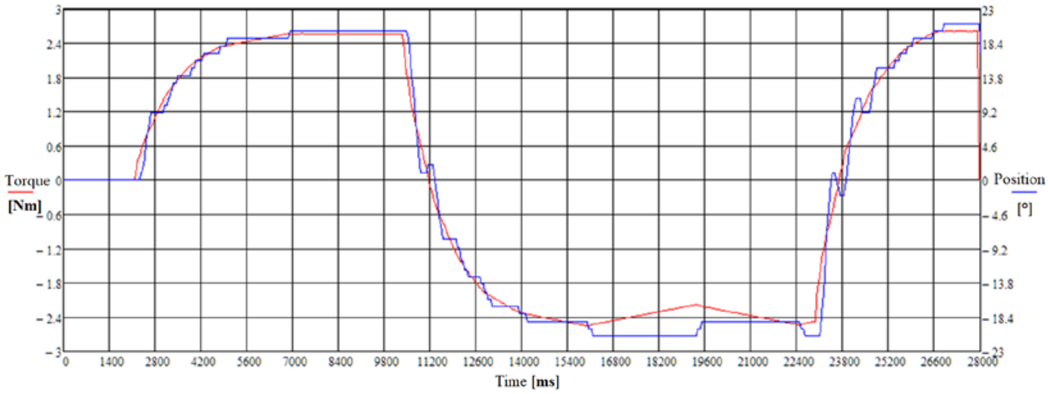

Fig. 6. The torque according to the position, after the configuration was made automatically by Scout software

Figure 7 shows the rotation table trajectory 0 °> + 20 °> -20 °> + 20 ° after changing the closed loops of current, speed and position. After changing the operating parameters, a steady and stable trajectory can be observed and the rotary table can reach ± 22 ° until it reaches the maximum limit of 2.6 Nm of the cup. Also, a significant variation in torque is observed, but this is present due to the very low response time of the electric motor.

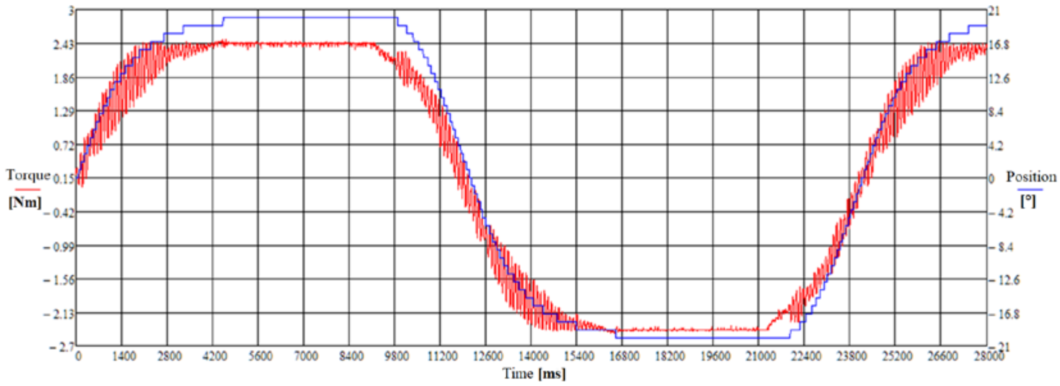

Fig. 7. The torque according to the position, after the closed loops of current, speed and position have been modified.

4. Conclusions and perspectives

The 14 stages were applied in two case studies corresponding to two different automation systems. Only possessing the knowledge of creation and control for an automated system, an optimization can be implemented, in order for the process to have a maximum efficiency. For both automation systems, the loops of current, speed and position were modified. In both cases, after the closed loops modification, the systems had a better performance. By this, the method of modifying the closed loops of current, speed and position was validated.

Within a closed loop, the output signal is monitored continuously and compared to the reference signal. The difference between the two is an error that is ideal to be as small or as zero. In an open loop, the output signal is not compared to the reference signal.

To determine the range of variation of the control loop in the current loop and the adjustment time for the torque value, the current loop has been optimized. This has been modified experimentally with reference to the recommended parameters in the Siemens documentation. In the case of the automation panel, the principle of modifying it was to increase the current control range (p1715) and reduce the torque value adjustment time (p1717). The current control range has been increased because the electric motor requires a higher torque in the event of starting with an attached load and the torque adjustment time has been reduced until the engine has been unable to receive the feedback needed to maintain loop closed. In the case of the rotating table, it was observed that the automatically configured current control range was well chosen and not modified, but the torque value adaptation time was reduced.

In order to determine the variation interval of the speed control parameter and speed controller integration time, the speed loop was optimized experimentally. The speed control parameter (p1460) has been configured according to system requirements. In the case of the automation panel, the speed control parameter has been increased because of the higher speed of the electric motor in a shorter time was needed. In the case of the rotating table, it was reduced because the rotary table needed a slower speed, since the speed was imposed at less than 1 rpm. The time of integration of the speed regulator (p1462) was reduced in both cases because experimentally better performance was observed with less time.

Determination of the variation interval of the recommended time constant for adjusting the actual position of the electric motor shaft was achieved by modifying parameter p1441 within the position loop. The principle of change was to reduce the time constant in various experimental studies to have, as much as possible, a position as close as possible to the desired one. The time has been reduced from the one assigned in the automatic configuration to a time limit in which the engine could no longer position itself.

In table 1 are presented the values of the closed loops parameters, from autotunning and experimental optimization. The perspectives of this paper are to check the results for automation systems that contain more powerful motors.

Table 1.

Parameter's values of closed loops

Current loop				
	P_gain [V/A]		Reset time [ms]	
	Autotunning	Optimization	Autotunning	Optimization
Automation Panel	25.682	30.682	2	1
Rotary Table	77.611	77.611	4	2
Speed loop				
	P_gain [Nms/rad]		Reset time [ms]	
	Autotunning	Optimization	Autotunning	Optimization
Automation Panel	0.0009	0.02	10	1
Rotary Table	1	0.35	12	1
Positioning loop				
	Smoothing [ms]			
	Autotunning	Optimization		
Automation Panel	0.07	0.05		
Rotary Table	1	0.3		

Taking into account the conclusions obtained from the theoretical and applicative contributions, the knowledge gained in this paper is useful to process engineers, technologists and not only so that industrial automation can benefit from continuous improvement and adaptation to the requirements imposed by technological processes. Following the 14 general stages that were designed to create an integrated automation system, a customization can be obtained for processes that have well-defined input data and are commonly found in industrial practice. Also, following the 14 stages set in the paper, the results can be checked for an integrated automation system containing more powerful electric motors.

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R E F E R E N C E S

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