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MODELING AND SIMULATION OF A CAPACITOR PRODUCTION LINE

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Abstract. *The purpose of this research is to develop an automatic process based on simulation of productivity and project developments using results in the automation of a production process of electronic products. This process was performed manually and it was modified so that this work could be done by an industrial robot. The effectiveness of the methods used will be measured according to the following purposes: to increase productivity, reduce time used in the production process, reduce the number of operators and improve the process used. The modeling of production process is performed with a proper simulation tool. Project development is done using CAD software, as well as the definition of the type of robot to be used and the peripherals to be employed to meet the needs of the idealized project. Also to improve performance the system is upgraded by a vision system and the increase in the assembly cycle time is evaluated.*

Keywords: *Automatic process for capacitor line, performance evaluation of process, development of automated assembly.*

1. INTRODUCTION

This paper describes a real case of automation process in an electronics factory; it is motivated by a problem in productivity that occurs when there is a large demand for products. By detailing the actual situation, one analyzes the way to solve this problem by using methods of development of product design, productivity studies and simulations of the developed solution. The plant where such work is performed produces electrolytic capacitors. Capacitors are circuit elements used in electronic devices. An electrolytic capacitor, unlike the others, has polarity, that is, it does not work properly if reversed. The product that one assessed in this study is a component of the capacitor; it is an item that must be produced before the capacitor. This product is composed by a ring and a gasket as Fig. 1.

Currently the product is manufactured manually, the steps are the following: (i) The gasket is placed on a conveyor belt located in the center of a working bench; (ii) then two droplets of an adhesive are applied; (iii) finally the ring is assembled in the gasket as Fig. 2.

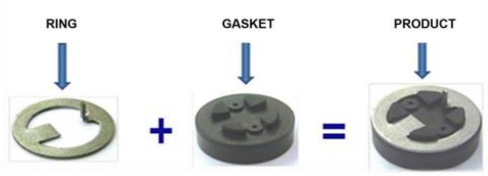

Figure 1. Product.

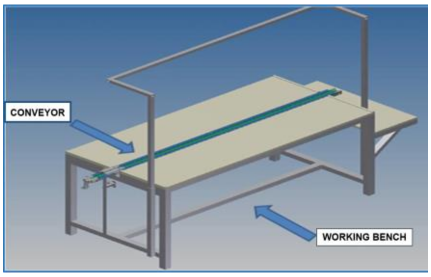

Figure 2. Working bench and conveyor

I. MODELING OF THE CURRENT PRODUCTION CAPACITY.

The first action is to collect data about the production capacity of the manual process. This analysis is performed with the aid of a simulation tool on the computer: ProModel. One of the most widely used simulation software on the market as Doloi et alii (2003), ProModel does the actual simulation of the production process on the computer; the advantages are that this system can be viewed and evaluated. This software uses several basic parameters so that the simulation model can be as close to reality as possible (Torga, 2007). The sequence used to perform the simulation with ProModel is as follows:

• Analyze the process to be simulated;
• Collect data;
• Build and validate the model in the Software;
• Analyze information generated;

According to data shown in Tab. 1, the average production time is 4.36 s per piece. Consequently, one obtains the production of pieces per shift, which is around 5786; it is considered that 10% of the total production must be reworked due to operational error in one of the tasks. Occupation of the operators during the workday is presented in Fig. 3. The simulation shows that the bottleneck of the process is the task of assembling the ring in the gasket. The operator of this task is 99.93% busy during the workday.

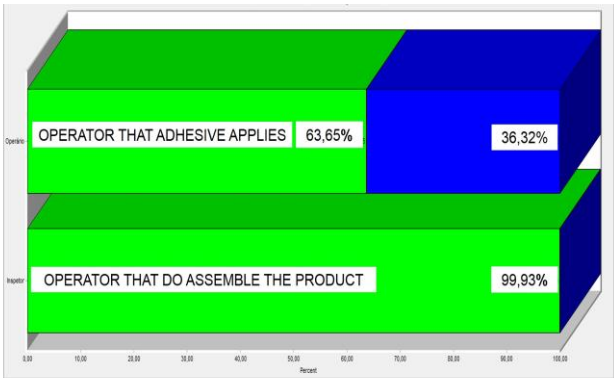

Figure 3. Occupancy by operator.

Table 1. Simulation data.

Data		
Test Production	Total No. Parts	Cycle Time (s)
1	5756	4,38
2	5819	4,33
3	5786	4,35
4	5790	4,35
5	5834	4,32

II. INVESTMENT IN AUTOMATION.

According to Seila (1997), investments in automation and robotization have the potential for reducing costs, increasing flexibility, quality, and increasing productivity, but justifying such investment becomes difficult if only economic and financial aspects are considered. In this sense, the decision about robotization must start with a non-economic analysis, emphasizing ergonomic and human aspects in this case.

In the phase of cost analysis, one must determine the costs and benefits of installing industrial robots, the investment cost, projected sales, profit and operating gains. All operating gains should also be included such as gains in labor, consumables, effective operating time, reduced number of staff on leave due to ergonomic problems, such as RSI "Repetitive Strain Injury" and reduction of scrap material.

After the simulation is performed with ProModel, the importance of developing alternatives of an automated process has been diagnosed. Automation is justifiable linking low productivity with high production cost per piece. Furthermore, problems of process variability, the high number of reworked pieces, high labor cost can be added, as well as the high number of ergonomic problems, as it is repetitive work. In this case, the automation of the process becomes more important beyond what can be measured quantitatively. The simulation also presents the possibility of using a robot to perform the operation of assembling the ring in the gasket.

III. TYPES OF AUTOMATION.

According to Slack et alii (2002), regardless of the need for automation, there are several types of technology to be used, analyzing three situations: (i) the size of the piece; (ii) the degree of automation, and (iii) the degree of interaction required. Considering this information, the type of automation is analyzed for this assembly process, taking into account all the variables of the process. As Groover (2011), the types of automation that can be adopted are:

- Rigid Automation: it is the automation with specific equipment to meet limited objectives. It is characterized by having a sequence of simple operations and high production rate. The downside of working with this model is its inflexibility to absorb changes. The problem of developing a rigid automation is that dimensional change of the product is very high, thus hinders the placement of the components in the assembly.

- Programmable Automation: In this model, the equipment is designed with the ability to change the sequence of operations to adapt to different production configurations. The critical point of this kind of automation is low production when compared to rigid automation.
- Flexible Automation: It is the automation that meets a wider range of objectives, being able to absorb large variations in product design. It can produce various combinations and sequences of products instead of requiring them to be made in batches of products.

Regarding the advantages and disadvantages of each kind of automation, the following Fig. 4 can be created:

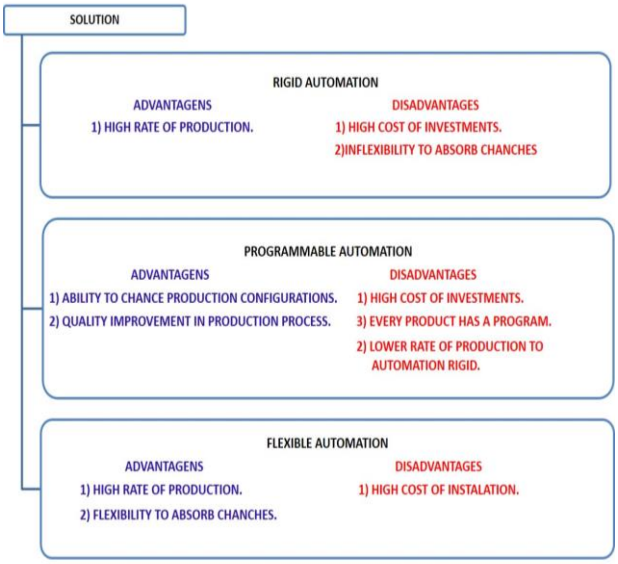

Figure 4. Advantages and disadvantages.

Concerning the reported case, it is diagnosed through the concepts above mentioned the importance for the project to have characteristics of flexible automation because of the variation of the products to be made by the cell. It is fundamental that the process must have the high productivity. Therefore the clear choice is flexible automation.

2. SYNTHESIS OF THE PROCESS.

With the factors above mentioned, the next step is to conceive various project concepts. However, this article presents the study on the basis of the solution already selected and that should be developed for the new process.

The concept of this new process is detailed upon a model of indexed rotating table, since the method was chosen because it was considered a high production machine and particularly useful for processes where the product is small, as it is in this case. Assembling the ring in the gasket is performed by an industrial robot, model SCARA. The decision to use a robot for this task is due to the following characteristics:

- The assembly task has a repetitive cycle of high intensity (the bottleneck of the process);
- This work can damage the operators' health for different reasons;
- It is a difficult task to handle;
- The use of a device that compensates the process variables is required.

The choice of the industrial robot model SCARA is due to the need for high speed, accuracy and repeatability, and also the fact that only four degrees of freedom are necessary. In the final step of the process, the inspection of the assembled product will be performed by a computer vision system. This vision system is what separates the good pieces from the bad ones.

IV. GRIPPER / END EFFECTOR

After definition of the points of manipulation, the robot should take the piece that is to be moved. The movement can fail due to inadequate gripper. It should be avoided to develop a gripper bigger than necessary to fix the piece or composition of the work cell. The end effector has to provide enough space accessible to manipulating the work piece.

Generally types most used in industrial robots are: mechanical, vacuum, magnetized and adhesive. As the part (ring) that is used in question has no area for mechanical grasping (it is a very small size), it is an item that cannot suffer chemical applications. Also it does not have a contact area for use of vacuum and it is a ferrous component. Considering these issues a magnetic gripper has been developed for manipulating. Magnetic grippers can use electromagnets or permanent magnets to carry ferromagnetic materials and design generally resembles the vacuum end effectors. The grippers that use electromagnets have just electric power to set and move. Electric current travelled through a wire, magnetic field is created to pick up the piece. As well as Aguiar (2011) the field strength, magnetic field intensity (H), generated by the tool that uses electromagnets follows the principle of law of Ampere (Eq.(1)), relating the electrical current passing through a conductor to the magnetic field generated by this:

$$\oint_c H \cdot dl = \iint_s l_f \cdot dS \tag{1}$$

$\oint_c$ - Full line of closed curve C;
H - Magnetic field intensity (A / m);
dl - Infinitesimal element of the closed curve C;
$\iint$s - Full Double S surface contained in the curve C;
l_f - Current density across the surface S;
ds - Vector referring unit of area S.

For the prototype of the electromagnetic gripper, a circuit was produced to perform the activation of the electromagnet through signals from the connected control system with the vision system and the robot.

V. VISION.

The computer vision system simulates human vision by improving the quality of the process and a system that provides a higher speed and a higher output. Video cameras are responsible for converting the images into electrical signals that are understood by the system. As seen in Fig. 5 a vision system must be able to capture and process images from a camera in order to find patterns that can be used to identify the quality of parts. The robot in turn can make decisions based on the visual information received and processed through a standard already set in the controller memory.

In the robot cell inspection is developed using the vision system for the following reasons:

1) Check the quality and application of adhesive in gasket and referencing the position of the gasket to robot.
2) Check the quality of the product, the good piece or bad piece for disposal set.

VI. STEPS OF THE PROCESS AND FLOWCHART.

The concept developed, which is detailed above, must go through the following steps (See Fig.6):

1) The gasket is transferred to the rotating table by a mechanical unit;
2) A mechanical unit must place the gasket so that no part moves outside the specified position;
3) In the next step a mechanical unit moved by a cylinder applies adhesive droplets on the gasket;
4) A camera is placed to check if the application of glue was performed. This camera sends the correct position of the gasket to the robot. This speeds up the robot by sending advanced information;
5) The robot grabs the ring that is placed on a conveyor belt and assembles the gasket according to the received signal from the camera in the previous step (4);
6) A mechanical unit exerts a slight pressure on the assembled product to help the adhesive applied in step (3);
7) A camera checks the product, one of these two situations follows:
8) Going out to good pieces, or
9) Going out to bad pieces.

Once the steps of the process have been defined, below is the flowchart as Fig. 6 of the process in a systematic way.

VII. PROJECT AND SIMULATION OF THE PROCESS.

After the process has been defined, the project is carried out using the design software Inventor. The 3D modeling is necessary to define, view and modify the project if necessary. By performing in a physical form what has been defined in the previous steps, one can have a cell assembly in accordance with the fundamental principles of manufacturing process defined according to the need. Below in Fig. 7 the project developed for the new automated process is depicted.

After the 3D project has been completed and the simulation of the new process is achieved, the simulation tool ProModel is used again in order to check and modify production times. This is done to make development in a physical form safer in terms of execution. Fig. 8 illustrates the ProModel simulation.

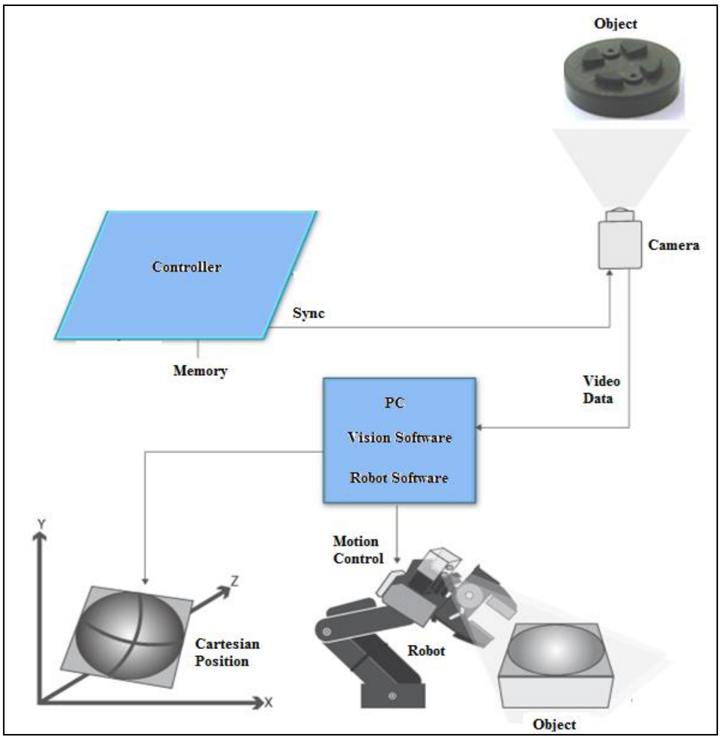

Figure 5. Robot and vision system solutions [adapted from Texas Instruments].

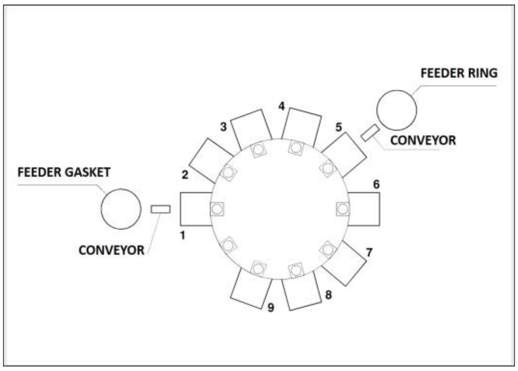

Figure 6. Flowchart of new process.

Handling times for each unit are related according to those reported by the manufacturer, such as the duration of the movement of the robot and the duration of the movement of the indexed table (see center rotary table in Fig.7).

Data obtained in Table 2, show linearity in this simulation as to production time. This occurs because there is no human intervention in any task. This is depicted in Fig.9 where one can see no oscillation in production time as compared to manual process.

3. COMPARING RESULTS.

In the Fig. 10, the amount of pieces produced in manual production process is assessed and compared to the automated production. One can see an increase of 20% in production as we compare the two processes. In the Fig. 11, one can analyze production time per unit which is assessed in each process.

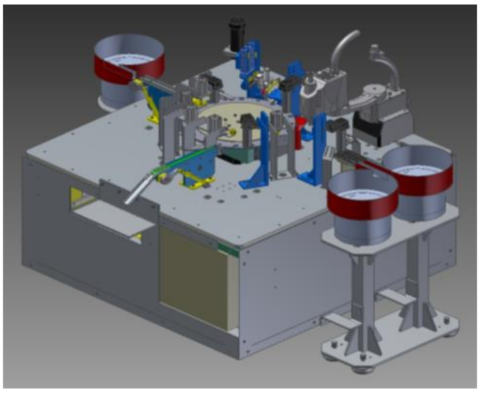

Figure 7. Project 3D [Software Inventor**].**

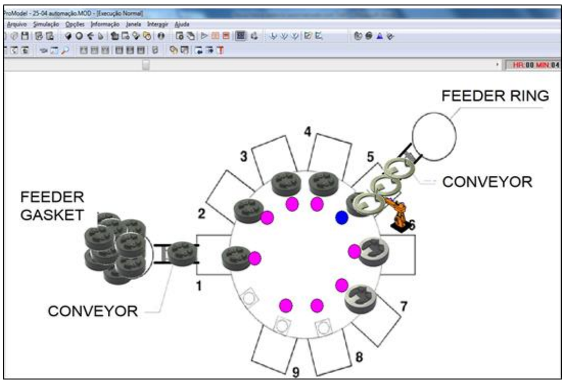

Figure 8. Simulation of the new process in ProModel.

Table 2. Simulation data of new process.

Data		
Test Production	**Total no. of parts**	**Cycle time (s)**
1	6792	3,71
2	6792	3,71
3	6792	3,71
4	6792	3,71
5	6792	3,71

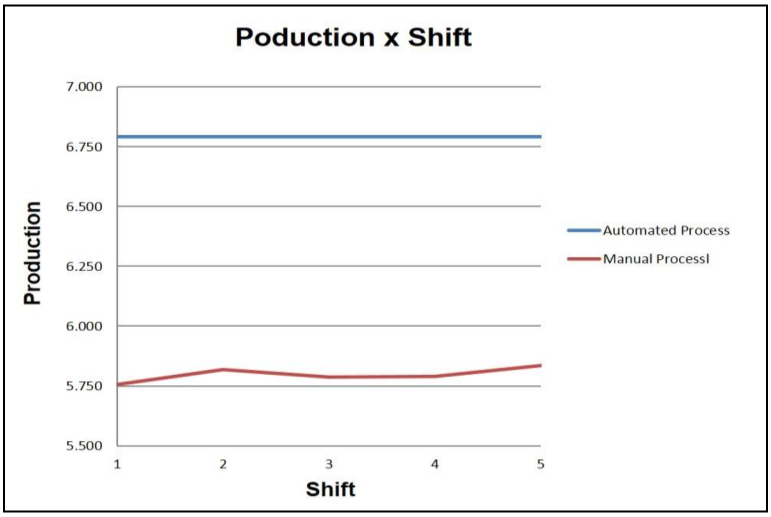

Figure 9. Production x shift.

VIII. ANALYSIS OF INVESTMENT IN LABOR FOR EACH PROCESS.

Considering the cost of a modified table for the manual process and the project conceived for the automatic process, the initial investment required for each procedure is analyzed in Table 3.

Knowing that the manual process requires three operators per shift and that the estimated cost per operator is R$ 12.50 / hour, we can calculate the savings in labor:

Table 3. Investments in Processes.

Initial investment	
Manual Process:	Automatic Process:
R$ 20.000,00	R$ 350.000,00

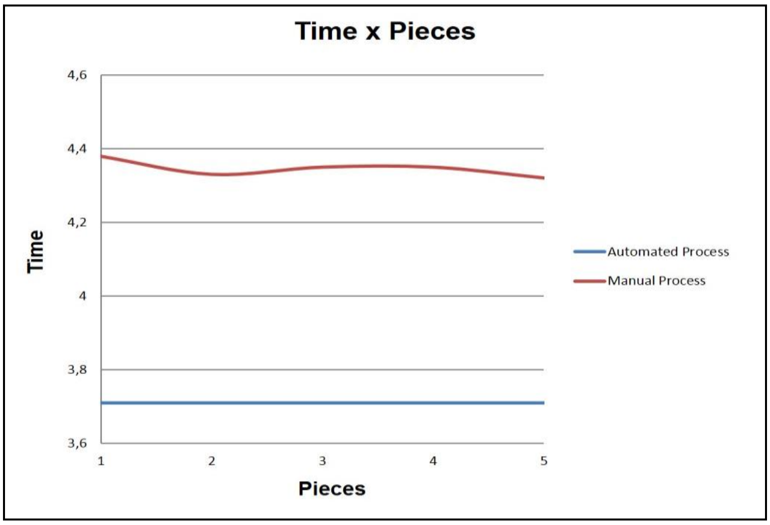

Figure 10. Time x parts.

Savings in labor cost = Labor Cost / hr x N° of worked hours x Month (2)

\$ 12,50 x 220 x 12 = R\$33.000,00

Savings in labor cost x N° operators / shift (3)

R\$ 33.000,00 x 6 operators / 1 shift = R\$ 198.000,00

As in the automatic process there is no human intervention, one saves in labor cost and the pay-back can be calculated in the following way:

Pay-back = Investment / (Savings in labor cost x N° operators / shift). (4)

Pay-back = 350.000,00 / 198.000,00 = 1,8 years.

IX. ANALYSIS OF COST PER PART IN EACH PROCESS.

It is known that the labor cost equals 20% of the cost per piece; with the reduction of operators in the automatic process, we have the following situation (Medina et al., 2010; Lorini, 1993; Sellitto et al, 2006) :

Production Cost - Manual Process = 20.000 + 1 X. (5)

Production Cost - Automatic Process = 350.000 + 0,8 X. (6)

Where ‘X’ is the amount of parts produced and the constants '1 'and '0, 8’ are the relations of production cost per unit in manual and automatic process. Relating the two functions, Fig. 11 represents the number of parts produced up to which the manual process is viable and the amount of pieces produced from which the automatic process starts to become a better investment. With this analysis, one can see that the equilibrium point of the equations is 1670832 pieces.

4. CONCLUSION AND FUTURE WORK.

After completion of this study, advantages of developing an automatic process are notable. The gains in this new process are shown in the following aspects: (i) increased production by 18% compared to the manual process; (ii) the

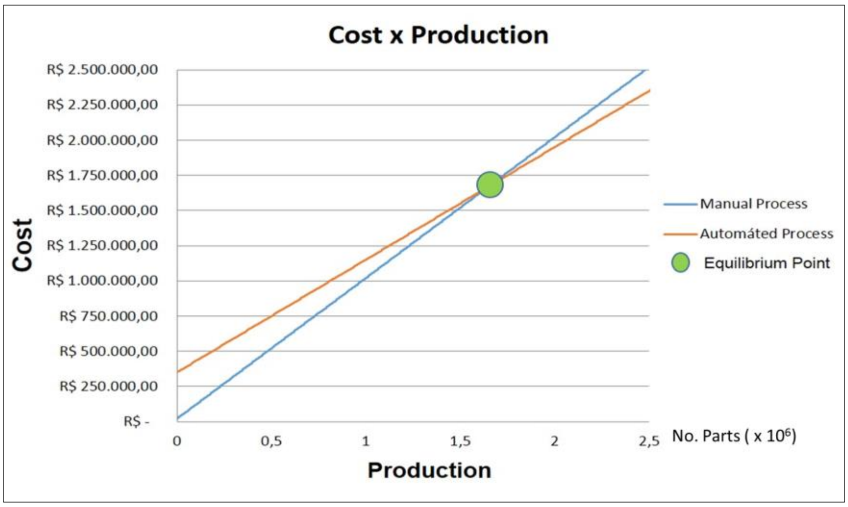

Figure 11. Cost x Production.

automatic process gives a linear production unlike the manual process because as it is done manually, a linear production is impossible to reach due to the exhaustion of the operators in the late shifts and humanistic elements; (iii) increased quality of the pieces produced with the automatic process due to the use of high technology used in inspection, especially vision systems that check all pieces produced; (iv) elimination of a task that is harmful to the operator (RSI – Repetitive Strain Injury) by preventing operators from working in functions that increase the chances of injury and can damage health; (v) a decrease of at least 20 % in production cost per piece, which is a very significant gain in the current scenario, where customers require cost reduction and where the market is increasingly competitive.

The time required for pay-back is also advantageous, because in only 1.8 years investment in the automatic process becomes cost efficient. All the gains presented are results of analyses performed using software that help in decision making. The use of ProModel software is fundamental to the analysis of production, reducing the possibility of errors due to inconsistency of information of the processes, as well as to assist the process of building the new process. The design software Inventor is important to transform the concept developed in a solid project, using various technologies that can serve the idealized process in the best way.

The automation projects carried out with the help of software available on the market are more and more likely to increase the chances of success in the development of automated processes.

Simulation of the same process is done using GRAFCET concept in order to validate the computational code that supervises the automated cell. Unfortunately results are too long to fit in this first article. Research continues to more advanced steps and is directed to control and supervisory issues.

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