Effect of SCARA Robot speed on bottle cap fitting on rotary indexing table

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ABSTRACT

In the Industry 4.0 era, the integration of SCARA robots with rotary indexing tables has significantly improved automation in assembly processes, particularly in bottling lines. This study investigates the effect of speed variation of the SCARA robot on the accuracy and quality of bottle cap installation using a rotary indexing table. The system was developed using a Siemens S7-1200 PLC, an Epson T6 SCARA robot, and supporting actuators such as pneumatic cylinders and stepper motors. Experiments were conducted at five different robot speeds: 10%, 20%, 30%, 40%, and 50%, with five trials for each setting. The results show a 100% success rate at 10%, 20%, and 30% speed, with proper alignment between the bottle and cap. However, at 40% speed, the success rate dropped to 85% due to minor misalignment. At 50% speed, the assembly failed completely due to synchronization issues and excessive force, resulting in a 0% success rate. These findings emphasize the importance of speed optimization to maintain synchronization between the SCARA robot and the rotary indexing table, ensuring an efficient and accurate automated bottling process.

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1. INTRODUCTION

With the technological advancements that occurred during the industrial revolution 4.0, many industries have experienced a significant impact, especially in terms of implementing automation systems to improve production efficiency and accuracy. SCARA (Selective Compliance Assembly Robot Arm) robots are one of the most widely used robotic technologies in machine assembly because they are faster, more precise, and more flexible to complete various assembly tasks, such as moving and installing small components [1], [2]. Robots can perform physical tasks under human control and supervision based on a set of predefined programs [3]. SCARA robots are perfect for assembly processes that require high stability and speed. This is due to its rigid arm on the vertical axis but flexible on the horizontal axis. In addition, SCARA robots can work without fatigue, which allows for reduced operational costs in the long run [4].

To improve efficiency in the assembly process, SCARA robots are often combined with a Rotary Indexing Table, which is a rotary table used to move components from one workstation to another in an assembly line [5]. The combination of SCARA robot and Rotary Indexing Table is an effective automation solution in the assembly process of products such as bottles and bottle caps [6]. Rotary indexing tables excel in precision, speed, and ease of control, making them more ideal for assembly applications that require high accuracy [7]. With programmable control, the movement of the rotary table can be synchronized with the SCARA robot, increasing speed and accuracy in the assembly process [8], [9]. Maintaining synchronization between the motion of the SCARA robot and the rotary index table is one of the challenges in maintaining the quality of bottle cap fitting [10]. The rotary index table positions the bottle accurately for the robot endeffector to reach it, but a synchronization mismatch between the two can cause misalignment, which in turn can lead to bottle cap fitting failure [11]. (As a result, the balance of speed and precision should be a top priority when creating the design of this automation system [12].

In bottle cap installation, the time aspect is needed but the quality of the installation results must also be maintained [13]. It is essential to create a control system that can change the robot's motion speed according to the situation [14]. Such a system looks at the optimal speed in addition to other variables such as pressing force, position precision, and pause time between cycles [15]. This research aims to analyze and determine the relationship between the operating speed of the SCARA robot and the quality of assembly results on the rotary indexation table. It is hoped that the results of this research will become a reference in the development of a more efficient and accurate industrial automation system.

2. METHOD

This research method aims to design and implement a bottle cap fitting system on a rotary indexing table using a SCARA robot. The process involves several interconnected stages, including system design, hardware development, and system testing, which are carefully planned and thoroughly executed to ensure optimal system performance. Figure 1 show the block diagram of proposed system.

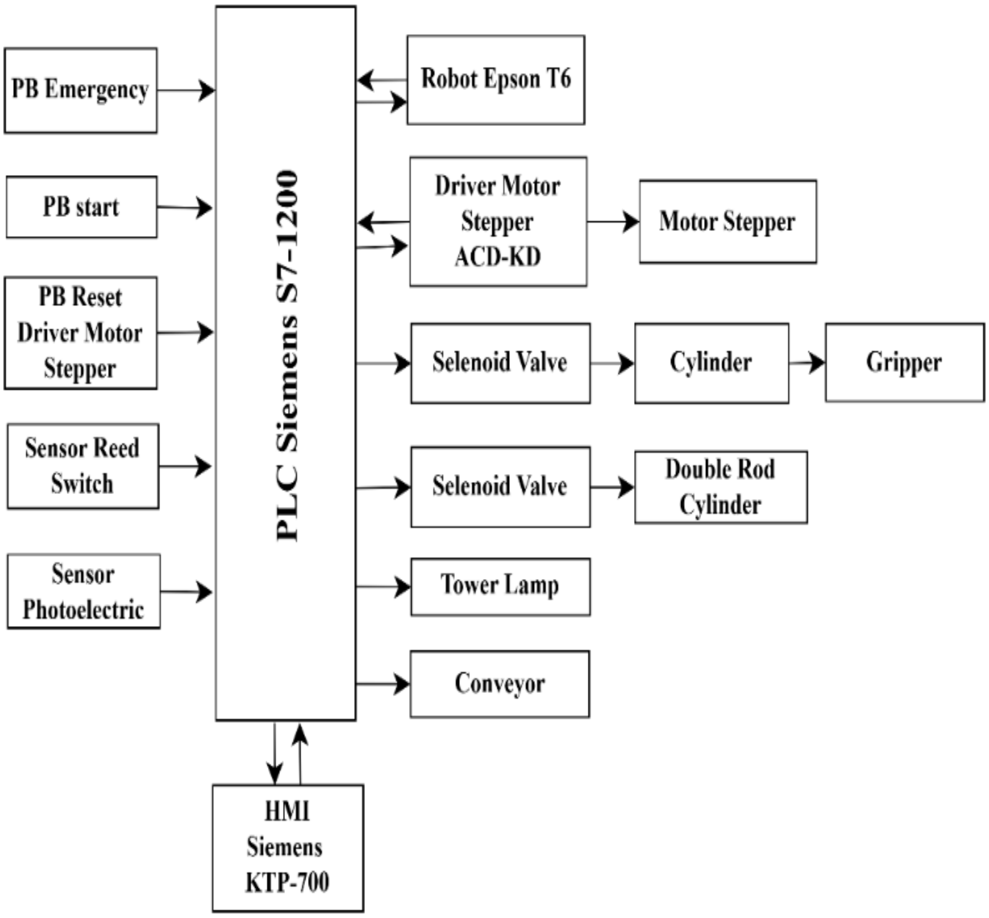

Figure 1. System Block Diagram

A block diagram provides a clear representation of how various system components interact. Figure 1 illustrates the block diagram of the bottle cap fitting system on a rotary indexing table using a SCARA robot. The system's main controller is the Siemens S7-1200 PLC, which manages the input and output of the key components. Additionally, the Siemens KTP-700 HMI interface facilitates user-friendly operation of the bottle cap fitting process. The Epson T6 SCARA robot serves as the primary actuator for executing the bottle cap fitting procedure. Meanwhile, the ACD-KD stepper motor driver controls the rotary indexing table. All components are seamlessly integrated to ensure the system operates efficiently and autonomously.

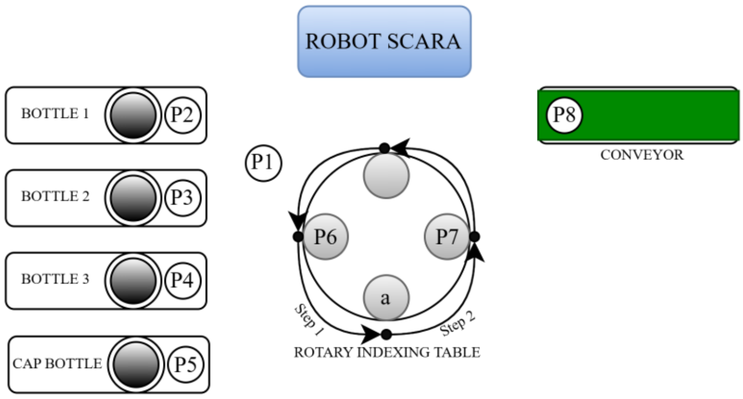

Figure 2. Sketch of the Working Principle

Figure 2 is a sketch or flow of the movement of the robot and rotary indexing table for bottle cap installation. The bottle cap assembly system starts when the robot is in standby (P1). Then, the robot moves to pick up the first bottle (P2). After that, the robot moves the first bottle to the rotary indexing table (P6). Next, the robot goes to P5 to pick up the bottle cap and place it on the index turntable. The process of installing the bottle cap (pressing) is done with the help of a pusher that functions as a stabilizer for the rotary indexing table. After pressing is complete, the index rotary table moves one step (step 1) to position (a).

Next, the robot returns to pick up the second bottle (P3). The assembly process of the second bottle on the index rotary table is similar to that of the first bottle. Once the cap of the second bottle is in place, the index rotary table moves one more step, moving the second bottle to position (a) and the first bottle to position P7. The robot then takes the first bottle from P7 and places it on the conveyor (P8). Once the conveyor is active, the first bottle moves towards the end place.

The same process repeats for the third bottle (P4). After the third bottle cap installation is complete, the index turntable moves one step, moving the third bottle to position a (step 1) and the second bottle to P7 (step 2). The robot takes the second bottle from P7 and places it on the conveyor. Once the conveyor is active, the second bottle moves towards the final place. Finally, the index turntable moves one more step (step 2), moving the third bottle to position P7. The robot picks up the third bottle and places it on the conveyor. Once the conveyor is active, the third bottle moves towards the final place. When all the bottles have been assembled, the robot will return to standby. For the work sequence can be seen in the following Figure 3.

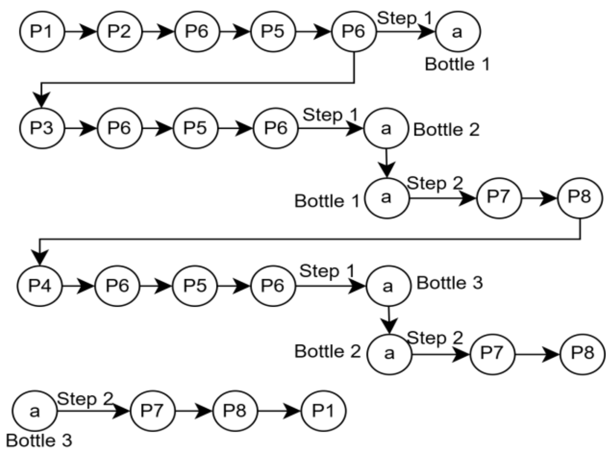

Figure 3. Work Sequence System

To provide a clear understanding of the workflow, a flowchart is used to systematically and structurally illustrate the process. This diagram helps visualize the instructions and stages involved in the bottle cap installation system using the SCARA robot. Figure 4 presents the flowchart depicting the step-by-step process.

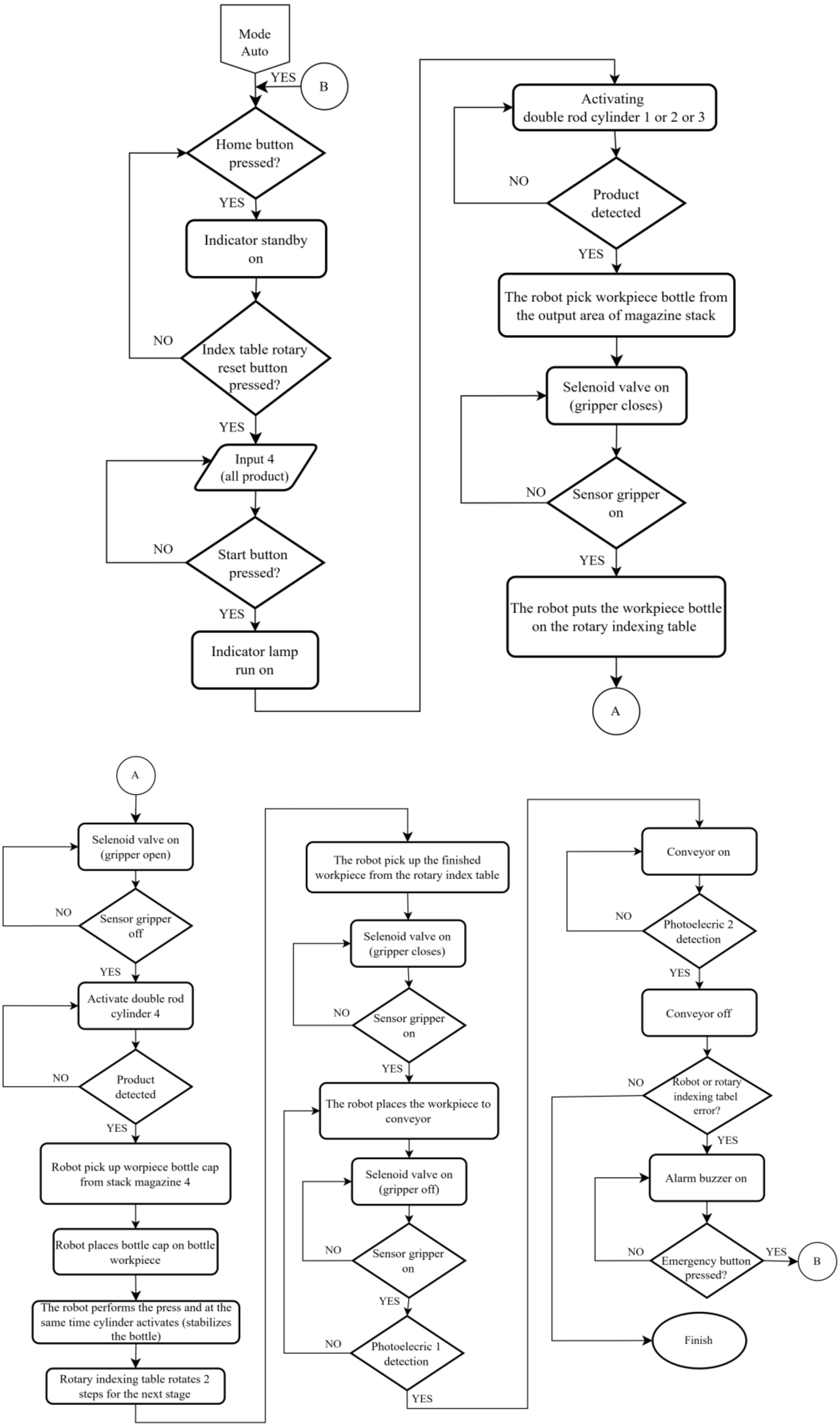

Figure 4. Flowchart System

3. RESULTS AND DISCUSSION

SCARA robot operation testing is done by looking at the final results of the bottle assembly process. This test is conducted to measure the efficiency of the system in the bottle assembly process. This section describes the test results and data obtained during the design process using the SCARA Robot to perform Pick and Place and product assembly. To provide proof, in this test, the assembly of all products at once is carried out with speed variations that will be set in the program, the product used for this experiment is the installation of bottle caps and bottles. To determine the most accurate results, by finding the average data.

This experiment uses 5 speed variations, the variations used are 10%, 20%, 30%, 40% and 50% with high power at each speed, conducted 5 times the experiment selection of this variation may be based on several considerations, so that other speeds are not used.

Table1. Testing Data of 10% Speed Product Results

Speed Robot	Trial	Success Rate (%)	Test Method	Test Result
10 %	1	100%	Assembly Bottle	Succesfull assembly
	2	100%	Assembly Bottle	
	3	100%	Assembly Bottle	
	4	100%	Assembly Bottle	
	5	100%	Assembly Bottle	

Table 2. Testing Data of 20% Speed Product Results

Speed Robot	Trial	Success Rate (%)	Test Method	Test Result
20%	1	100%	Assembly Bottle	Succesfull assembly
	2	100%	Assembly Bottle	
	3	100%	Assembly Bottle	
	4	100%	Assembly Bottle	
	5	100%	Assembly Bottle	

Table 3. Testing Data of 30% Speed Product Result

Speed Robot	Trial	Success Rate (%)	Test Method	Test Result
30%	1	100%	Assembly Bottle	Succesfull assembly
	2	100%	Assembly Bottle	
	3	100%	Assembly Bottle	
	4	100%	Assembly Bottle	
	5	100%	Assembly Bottle	

The 10%, 20% and 30% speed experiments achieved 100% product assembly results with good test results. The process of picking, placing, and pressing the bottle cap was smooth and precise during the test. There were no positioning errors or mismatches between the cap and the bottle, and both had no gaps.

This shows that the SCARA robot can work well in that speed range at the right speed to ensure a precise and accurate assembly process. Thus, a working speed between 10%, 20% and 30% is ideal for the automatic bottle cap assembly process, as shown in figure 5.

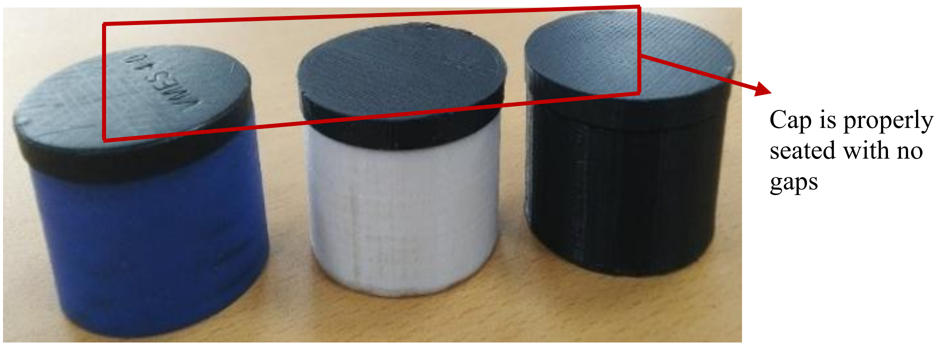

Figure 5. Assembly Succes

Table 4. Testing Data of Speed 40% Product Results

Speed Robot	Trial	Success Rate (%)	Test Method	Test Result
	1	86%	Assembly Bottle	
	2	85%	Assembly Bottle	
40%	3	84%	Assembly Bottle	The result is fairly good, but not optimal
	4	85%	Assembly Bottle	
	5	85%	Assembly Bottle	

The 40% speed experiment decreased in the assembly process to 85% with fairly good test results due to poor bottle caps when the bottle was on the rotary indexing table so that the pressing process experienced imperfect assembly and there was a slight gap between the bottle cap and the bottle, for the product results shown in Figure 6.

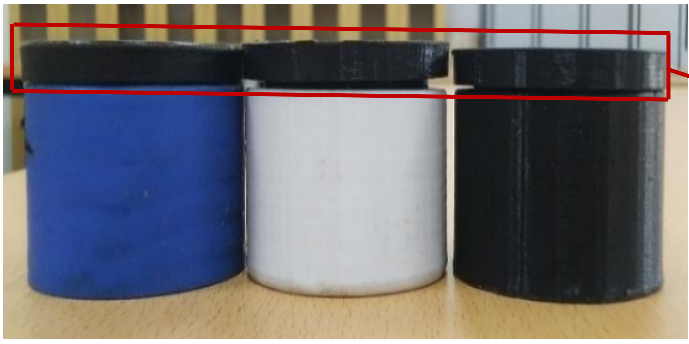

Figure 6. Assembly Success but not Optimal

Table 5. Testing Data of Speed 50% Product Results

Speed Robot	Trial	Success Rate (%)	Test Method	Test Result
	1	0%	Assembly Bottle	
	2	0%	Assembly Bottle	Assembly Failed
50%	3	0%	Assembly Bottle	
	4	0%	Assembly Bottle	
	5	0%	Assembly Bottle	

Experiments with 50% speed experienced errors in the rotary indexing table due to the high speed of the robot, so that the position of the bottle cap on the bottle on the rotary indexing table became imprecise and when pressing experienced excessive pressure so that the rotary indexing table error and could not experience the next process. The result of the bottle cap installation shows a large gap between the cap and the bottle, as shown in Figure 7, which is an example of a failed product due to too high robot speed (50%).

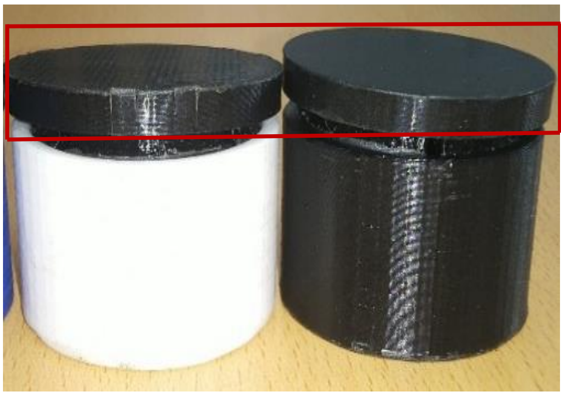

Figure 7. Assembly Failed

4. CONCLUSION

Experiments were conducted with speed variations of 10%, 20%, 30%, 40% and 50%. The first robot operation test was conducted with speeds of 10%, 20%, and 30% with each speed tested five times. The results showed that the assembly process went well, achieving a high success rate. the installation of the bottle cap and the bottle was well closed or there was no gap between the bottle cap and the bottle. However, at 40% speed, the accuracy of bottle cap placement decreased due to the increase in robot speed, affecting the precision of the pressing process on the rotary indexing table. As a result, the assembly success rate drops to 85% but is still within the tolerance of only a small gap in the product. When the robot speed was further increased to 50%, an error occurred on the Rotary Indexing Table. This was caused by the imbalance between the robot speed and the rotary table system, which led to inaccurate positioning of the product components. During the bottle cap pressing stage, excessive pressure caused system instability, which ultimately prevented the operation from continuing. These findings highlight the need for proper speed adjustment to ensure synchronization between the robot and the Rotary Indexing Table, thus enabling a smooth and accurate assembly process.

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