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Design and Construction of a Tube Positioning Machine Prototype for an Inline Production

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Abstrak.

Menjaga kualitas produk untuk memenuhi kebutuhan dan kepuasan konsumen menjadi salah satu tujuan utama setiap perusahaan manufaktur dalam menghasilkan produk terbaik. Penulis mengangkat permasalahan produk defect yang dihadapi PT Rapid Plast pada suatu inline production yang melibatkan mesin printing. Hasil print tidak menempel secara sempurna karena produk terkontaminasi kotoran debu dan cairan pada saat dipindahkan dan diputar ke arah berlawanan secara manual oleh operator. Untuk memecahkan masalah, penulis mendesain solusi automatisasi melalui prototipe mesin pneumatik silinder sebagai penggerak dan PLC Outseal Nano V5 sebagai komponen pemrosesnya. Pengujian fungsional dilakukan terhadap prototipe untuk menemukan ketahanan PLC dan komponen mekanik. PLC berfungsi dengan baik untuk operasi non-stop selama 30 menit. Permasalahan ditemukan pada pengujian unit rotary stopper akibat tekanan yang melebihi kebutuhan. Permasalahan ini diatasi dengan mengurangi suplai tekanan udara. Pengujian efisiensi prototipe dilakukan dengan menjalankan 1000 siklus dengan tingkat kesuksesan 99.1%. Sejumlah penyempurnaan seperti penambahan baut dan pengurangan panjang pipa pneumatik menjadi masukan untuk perbaikan desain yang diajukan.

Kata kunci: Produksi inline, Automasi, *PLC*, *Outseal nano V*5.

Abstract.

Maintaining product quality to meet consumer needs and satisfaction is one of the main goals of every manufacturing company in producing the best products. The author raised the problem of defective products faced by PT Rapid Plast in an inline production involving a printing machine. The print does not adhere perfectly because the product is contaminated with dirt, dust, and liquids when manually moved and rotated in the opposite direction by the operator. To solve the problem, the author designed an automation solution through a prototype cylindrical pneumatic machine as the drive and the PLC Outseal Nano V5 as the processor component. Functional testing is performed on the prototype to find the resistance of the PLC and mechanical components. The PLC works well for non-stop operation for 30 minutes. Problems were found in the testing of rotary stopper units due to pressure exceeding the requirement. This problem is overcome by reducing the air pressure supply. Prototype efficiency testing was carried out by running 1000 cycles with a 99.1% success rate. A number of improvements, such as the addition of bolts and the reduction of the length of the pneumatic pipe, are inputs for the proposed design improvements.

Keywords: *Inline production, Automation, PLC, Outseal nano V5.*

Introduction

It is the obligation of manufacturing companies to produce the best quality products that meet consumer expectations. The production process seeks to minimize product failures (defects) that can be caused by various factors such as humans, machines, raw materials, and suboptimal production processes. Quality control is needed so that production results are always in accordance with the standards that have been set. However, quality control needs to be supported by increasing the accuracy and precision of the production process. Automation is one of the solutions to reduce the factors of errors, defects, failures, and deviations in specifications [1].

The inline production process has become common in the manufacturing industry. In this case, the production process takes place in an uninterrupted process, interconnected between one machine and another. Products that prioritize hygiene and health, such as medicines and food, are ideal for production using this process because contact with humans can be minimized and contamination can be minimized [2]. However, the thing that needs to be considered in inline production is the transition from one part of an automatic machine to another, in order to obtain an uninterrupted automatic process [3].

PT. Rapid Plast is a company that produces co-extruded tubes for cosmetic, pharmaceutical, and food packaging. Specifically for cosmetic packaging production, the company operates various types of machines for various stages of packaging production, ranging from tube making, over tube surface printing, to the assembly of tube caps (or caps). In the current condition, there are 2 inline production machines that still use an operator to move the tubes from one machine as input to the next. The first machine, which was in charge of making the tubes from cylindrical-shaped raw material, dispensed the tube in a horizontal position with the head facing in one direction. The second machine, which is in charge of printing names and packaging ornaments, requires a tube with its head facing in the opposite direction. The operator's job is to move the tube while rotating it by 180° to fit the position required by the next machine, to be able to continue the production process.

To overcome the above problem, the author intended to design and construct a prototype of a tube positioning machine, which will replace the role of the operator as a link between two automation machines. The proposed system was very application-specific, and thus no direct comparison to any existing machines could be made. The expected result was the moving of production objects that can take place smoothly with a success rate of at least 98% and free of contamination because it no longer involves human factors. As the first step to obtaining the real-life solution, the prototype was only expected to be able to perform the main task of moving the tube and changing its direction. Furthermore, the construction of the prototype was meant to be a starting point to obtain the best hardware design and machine mechanism in the real implementation. The maximum machine dimension and the minimum movement speed were not set. However, as the minimum criteria, the machine was expected to be able to perform continuously for 30 minutes without any problems.

Design Specification

Co-extruded tubes, also known as multi-layer laminated tubes, are plastic tubes that have three to five layers of plastic, as can be seen in Figure 1(a). Due to the large number of barrier layers made of ethylene vinyl alcohol (EVOH), this type of tube can protect its contents well against the outside environment, such as oxygen, gas, and oil, which can affect the quality of the contents in the packaging. Generally, this packaging is used to package medicines, cosmetics, and food, as shown in Figure 1(b). The priority is the cleanliness and durability of the contents in the package for a certain period of time [4].

(a) (b)

Figure 1. An example of co-extruded tubes;
(a) Layer cross-section; (b) Final products after printing

Outseal PLC Nano V5 is the latest PLC from Outseal, which has an Arduino-based microprocessor. This PLC is made with toughness standards in mind so that it can be used in industrial environments [5]. Because it has Arduino-based hardware, the microcontroller specifications used in the Outseal PLC Nano V5 are made exactly the same as the Arduino Nano, namely the ATmega328P [6]. The bootloader used is also the same, namely Optiboot, so that in addition to using Outseal Studio software, this PLC can also be programmed using Arduino IDE [7]. This makes Outseal PLC Nano V5 a low-cost solution for automation projects that require affordable costs [8]. Figure 2 shows the physical shape of the Outseal PLC Nano V5.

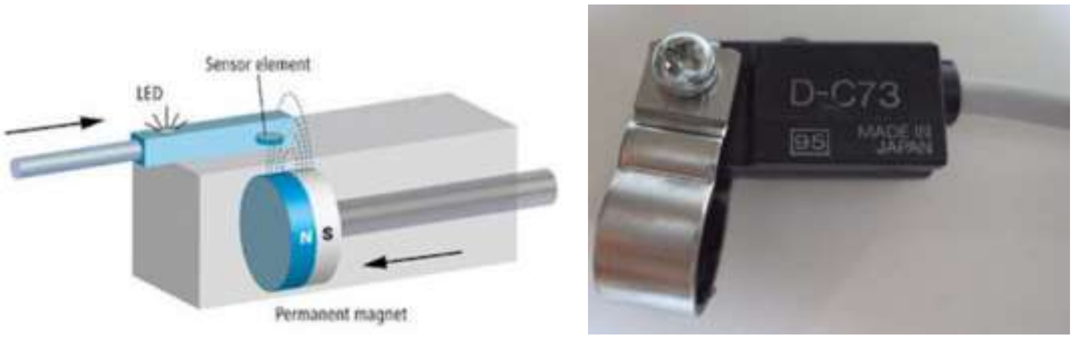
Figure 2. Outseal PLC Nano V5

Photoelectric Sensors are used in the proposed system to detect the presence of products on the input side. Photoelectric sensors are sensors that use light as a sensing medium to detect the presence of an object. There are two types of photoelectric sensors based on the processing of light after light hits an object, namely the reflection type and the penetration type. In a reflection-type sensor, the presence of an object is characterized by the presence of light from the transmitter that is reflected by the object and then received by the receiver. In penetration-type sensors, the presence of an object is characterized by the absence of light from the transmitter received by the receiver, since the object has blocked the light [9].

The PZ-M31 reflection sensor was used in the prototype submitted by the authors. Figure 3 shows the physical shape of this sensor.

Figure 3. Photoelectric sensor PZ-M31

A Reed Switch is an electromechanical switch that operates by utilizing a magnetic field. This sensor will activate if it detects a magnetic field nearby. The reed switch is composed of two metal conductor plates that are close to each other and surrounded by a glass tube containing inert gases. When a magnetic field arises and influences the two plates, they will attract and touch each other, allowing an electric current to flow. If the magnetic field is lost, then the two plates will return to their original position, and the electric current will be cut off again. A working simulation of a reed switch can be seen in Figure 4(a). The prototype submitted using a reed switch type D-C73 can be seen in Figure 4(b).



(a) (b)

Figure 4. (a) The working mechanism of a reed switch; (b) Reed switch D-C73

A Solenoid Valve is a mechanical valve that is controlled by a magnetic force generated by a coil that is powered by an electric current. The solenoid valve is responsible for controlling the pressurized air duct to the pneumatic cylinder [10]. The solenoid valve has three holes including the input hole, the output hole, and the exhaust hole. The solenoid valve will work when the coil is energized, then the pin on the solenoid valve will be attracted by the magnetic force generated by the solenoid coil. When the pin is pulled up, the valve that closes the airway will be lifted, and the air will flow [11].

In this prototype engine, two types of solenoid valves are used, namely type SY5120-5LZD-01 (Figure 5) which functions to regulate air to drive the pneumatic cylinder, and type MHE3-MS1H-3/20-1/8-K525169V102 (Figure 6) which functions as a disconnect of the air supply from the compressor to the prototype engine when the emergency button is pressed.

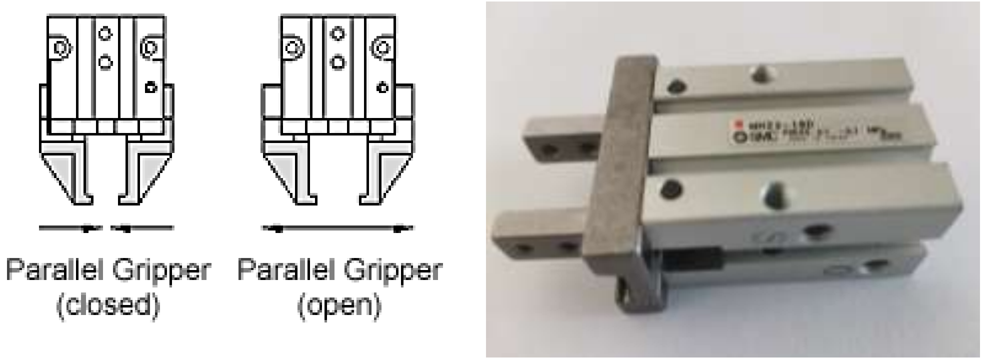
Figure 5. Solenoid valve SY5120-5LZD-01

Figure 6. Solenoid valve MHE3-MS1H-3/20-1/8-K525169V102

A Pneumatic Cylinder is an actuator that uses compressed air to produce a linear alternating movement of the piston [11]. Pneumatic cylinders are often found in industrial machinery, usually used to convert potential energy in the form of air pressure into kinetic energy in the form of linear motion [12]. In this prototype machine, two types of pneumatic cylinders are used: type MA 25×125 as the drive of the swivel arm, and type MMA 20×100 to lift and place products. The pneumatic cylinder type MA 25×125 is shown in Figure 7.

Figure 7. Pneumatic cylinder

A Parallel Gripper is a mechanical clamping device that is commonly used in automation or robotics machines. With the mechanism shown in Figure 8(a), a parallel gripper is used to grasp the object when it is moved. Figure 8(b) shows the parallel gripper used in the proposed prototype, type MHZ2-16D.

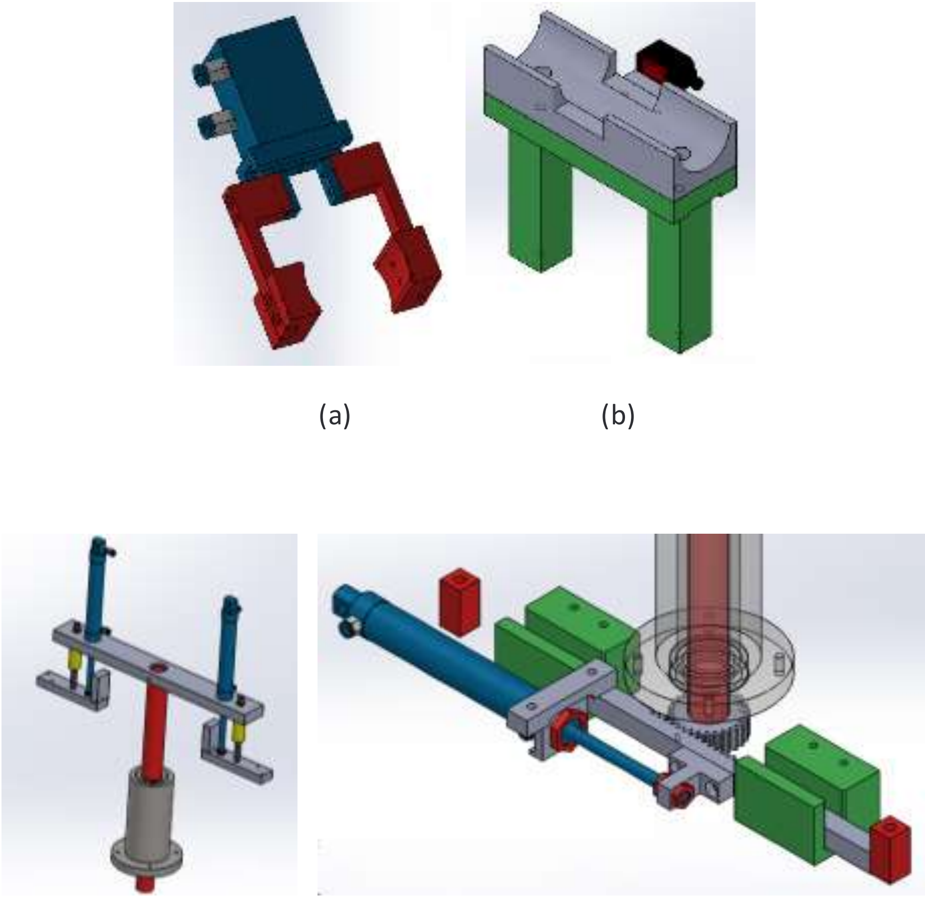


(a) (b)

Figure 8. (a) The working mechanism of a parallel gripper; (b) Parallel gripper MHZ2-16D

The Design of the Machine Parts is depicted in Figure 9. The parallel gripper and the input/output socket are shown in Figure 9(a) and (b). The swivel arm and the rotary unit are presented in Figure 9(c) and (d). A tube will be gripped by the parallel gripper and lifted from the input socket by the lifting mechanism of the swivel arm. Then the rotary unit drives the swivel arm to rotate by 180°. In the final position, the tube will be lowered and released on the output socket.

Two parallel grippers are mounted at each end of the swivel arm. Thus, the machine can simultaneously drop a tube into the output pocket and lift the other tube from the input socket. All mechanical actuators that build the machine are powered pneumatically by the circuit that consists of the pneumatic cylinders, solenoid valves, compressor, and pneumatic hose pipes.



(a) (b)

(c) (d)

Figure 9. The part designs (a) Parallel gripper; (b) Input/output pocket; (c) Swivel arm (d) Rotary unit

The Design of the Machine is presented in Figure 10. A panel box provides storage for all components. The solenoid valves are also organized on the outer side of the panel box.

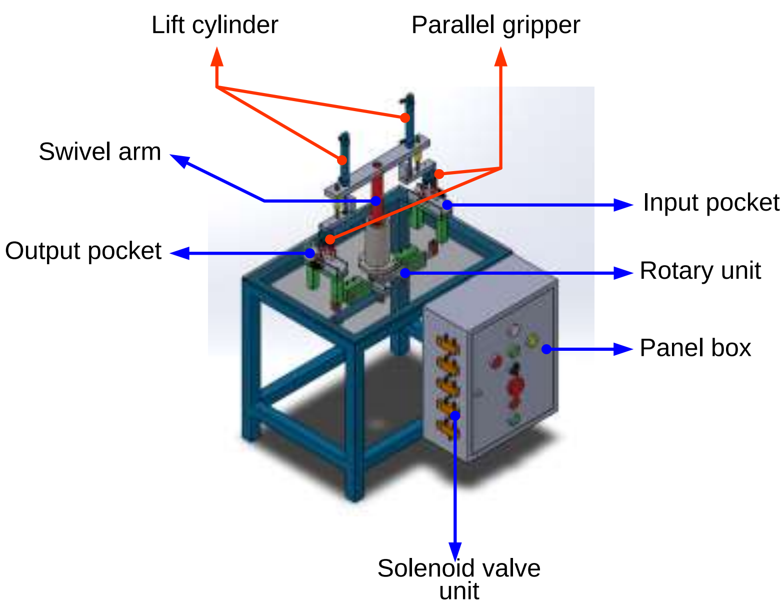


Figure 10. The design of the machine

Design Implementation

The Block Diagram of the proposed system is shown in Figure 11. The prototype is controlled by a PLC. The input from this machine uses the start and stop buttons to start and stop the machine. Photoelectric sensors and reed switches act as inputs to know the position of the product and the machine's work. The output from the PLC is passed to the relay, which will regulate the air from the compressor through the solenoid valve to the pneumatic cylinder and parallel gripper.

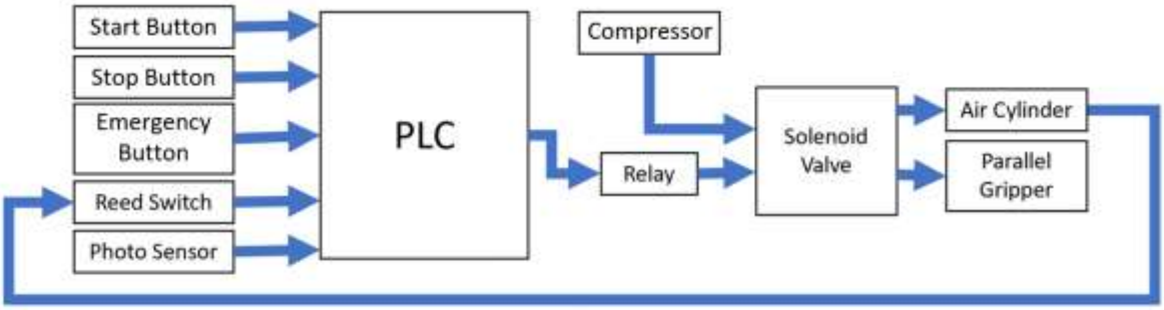


Figure 11. The block diagram of the proposed system

The Flow Diagram of the machine's working process can be seen in Figure 12. The machine's work activity begins by pressing the start button. Then, the photoelectric sensor will start detecting the availability of the product on the original conveyor. If an object is detected, the pneumatic cylinder will go down until the reed switch detects that the arm is in the down position. Furthermore, the vacuum motor will work to provide suction power so that the product will stick to the gripper.

After that, the pneumatic cylinder will rise again, and the reed switch reads that the pneumatic cylinder has risen. The next movement is for the arm to rotate towards the destination conveyor, and the reed switch will read the position of the arm. Then the pneumatic cylinder will go down and the vacuum motor vacuum stop working, so that the product is detached from the parallel gripper and the pneumatic cylinder goes back up.

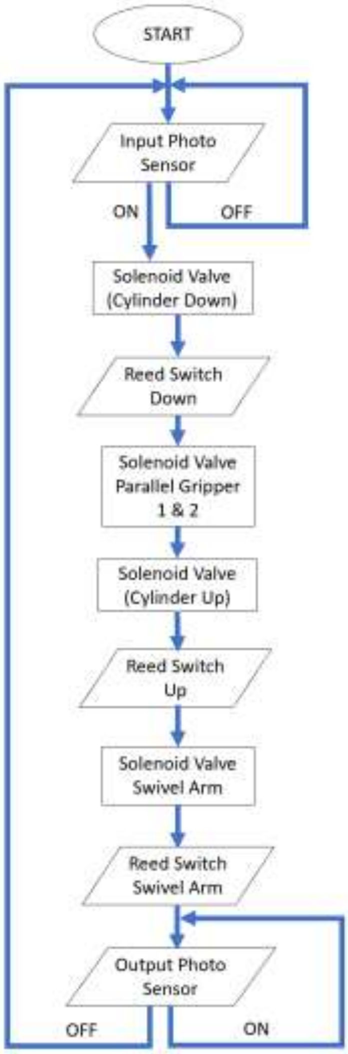


Figure 12. The flowchart of the proposed system

The Realization of the Machine per Part and as a Whole is displayed in sequence as follows. The swivel arm unit and gripper unit are shown in Figure 13. This group of units functions to lift products from the origin conveyor and move, and place products on the destination conveyor. The realization of the rotary unit is shown in Figure 14, which serves to drive the swivel arm unit.

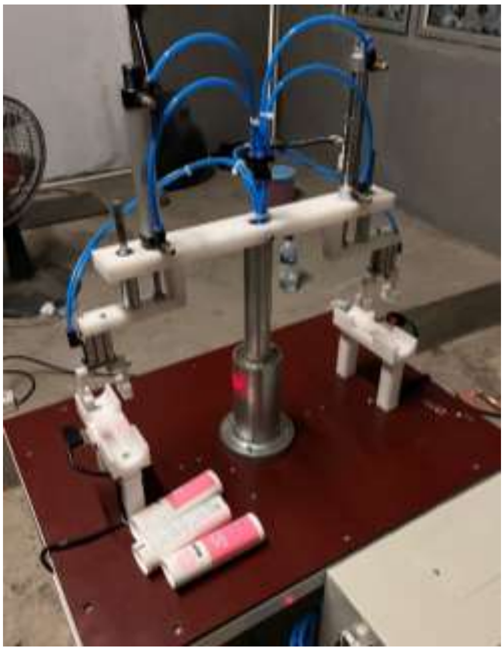


Figure 13. The realization of the swivel arm unit and the gripper unit with a lifting mechanism

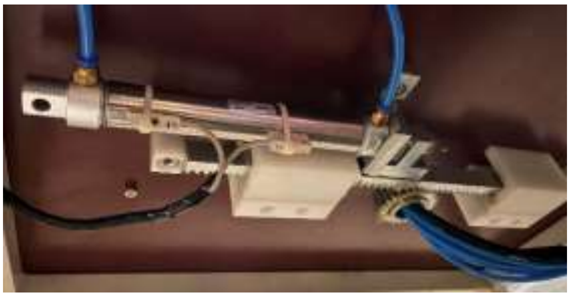


Figure 14. The realization of the rotary unit

The realization of the solenoid valve series can be seen in Figure 15, which consists of 5 solenoid valves with various specific functions to move the pneumatic cylinder in a certain direction.

Figure 15. The realization of the solenoid valve unit

In the end, the realization of the panel box and electrical components is shown in Figure 16. This box is the place where all electrical components are placed. The indicator light can be observed when the box door is closed (Figure 16(a)). On the inside of the box, as can be seen in Figure 16(b), the entire supporting electrical circuit, along with the PLC and wiring, is neatly arranged.

(a) (b)

Figure 16. The realization of the panel box (a) outer appearance; (b) inner appearance

Results and Discussion

Efficiency and durability are the main factor expected in machines used in industry. An effort to reach a good machine design was undertaken during the construction of this machine prototype by setting a bar that the prototype must at least be able to fulfil. The bar is that the machine can perform with at least a 98% success rate cummulatively and can operate in 30 minutes non-stop without problems. The engine durability test was carried out by operating the engine for 10 tests, each lasting 30 minutes non-stop. The engine components tested are various mechanical, pneumatic, and electrical components of the machine.

Test Results are displayed consecutively as follows. Table 1 shows the results of the machine tests. In the first test, only 16 cycles could be carried out due to damage to the stopper rotary unit. In the 2nd to 10th test, a duration of 30 minutes can be achieved without interruption. In each test, between 374 - 376 cycles were achieved without any mismatch of the engine components.

Table 1. Durability Testing of Overall Machine Components

Testing	Duration (minutes)	Malfunctions	Cycle Count	Remarks	Action
1	30	1	16	Failure of stopper rotary unite, broken bolt housing	Air pressure reduced, additional security nut
2	30	None	374	Normal	None
3	30	None	376	Normal functionality	None

4	30	None	376	Normal functionality	None
5	30	None	374	Normal functionality	None
6	30	None	375	Normal functionality	None
7	30	None	375	Normal functionality	None
8	30	None	374	Normal functionality	None
9	30	None	376	Normal functionality	None
10	30	None	375	Normal functionality	None

The second experiment was to test the efficiency of the gripper in gripping, moving, and laying the tube. To test this, the machine is operated for 100 cycles and then the number of successes and failures of the machine in moving the product is observed. A failure rate of 2% can be considered a reasonable rate, where 98 products can be moved well and only 2 products fail.

Table 3 shows the results of the test of the efficiency of the machine, or in particular, the efficiency of the machine in carrying out its task. In each attempt, there is a failure between 0 - 2 times. The gripper size is not very long, resulting in the product not being squeezed perfectly. As a result, when the swivel arm rotates, the product is pulled out of the gripper. This is dismissed as an engine failure. In total, out of a total of 1000 products moved, there were 9 failures, which is equivalent to 0.9%.

Table 3. Machine Efficiency Testing

Testing	**Number of Inputs (pieces)**	**Number of Outputs (pieces)**	**Defective Products (pieces)**	**Defect Percentage (%)**	**Keterangan**
1	100	99	1	1	1 dropped
2	100	100	0	0	-
3	100	99	1	1	1 dropped
4	100	100	0	0	-
5	100	98	2	2	2 dropped
6	100	98	2	2	2 dropped
7	100	99	1	1	1 dropped
8	100	100	0	0	-
9	100	98	2	2	2 dropped
10	100	100	0	0	-
Total	1000	991	9	0.9	

Discussions are held at this stage to discuss the achievements obtained by the submitted machine. In the testing process, 2 types of tests have been carried out: machine functional testing with a duration of 30 minutes and machine efficiency measurement with a number of cycles of 100. For each test, 10 repetitions were carried out.

In the functional testing of the machine, too high the compressor pressure caused the swivel arm unit to not work properly. Repairs are made by reducing pressure and reinforcing a number of bolts using small nuts. The consequence that must be accepted is a decrease in engine speed [13]. For future improvements, a design is needed that adds the number of fastening bolts to the stopper rotary unit, so that the machine can operate at maximum air pressure and maximum speed. After problems occurred in the first run, the machine completed nine 30-minute runs without any further problems, successfully fulfilling the objective.

In the machine efficiency test, a total of 1000 product transfers were carried out. Although there is a product defect due to the failure of the gripper to grip the product during the transfer process, the failure percentage of 0.9% is still below the maximum limit of 2%. Thus, it can be concluded that this prototype machine successfully meets the preset efficiency test threshold. To achieve higher levels of efficiency, design improvements, material selection, and further experimentation are required.

Conclusions

The inline production process is a process that is commonly found in the manufacturing industry. In a cosmetic product packaging company, there are a number of points in the inline production process that still require the role of humans to connect 2 different machines. An operator needs to move and rotate the tube from the origin conveyor to the destination conveyor. In this study, a prototype design of a tube moving and positioning machine was proposed, so that the role of humans can be eliminated and the potential for product contamination can be avoided.

The prototype of the machine is carried out using a series of electrical, mechanical, and pneumatic components. The Outseal PLC Nano V5 is used as the main processor. The machine is then tested in the aspect of working function, the durability aspect of the PLC, and the aspect of efficiency. After the initial problems faced when the machine first faced heavy work challenges, the machine worked well and fulfilled the aspect of the work function, with an average of about 12.5 pieces/minute. This amount can still be increased by making design and material improvements, as well as increasing the compressor pressure to the maximum value. Furthermore, the second objective that the machine must be able to operate for 30 minutes non-stop without any hardware or software failure was achieved.

In the efficiency test, in total, the machine only failed to move 9 out of 1000 products. With a failure rate of 0.9%, which was clearly lower than 2%, the objective of the machine was satisfactorily fulfilled.

The next step of this research is the implementation of the machine in the actual inline production process. In addition, some components require replacement using the best components available on the market, in order to get the best possible engine performance, according to industry demands.

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