

**THE UNIVERSITY OF DA NANG
UNIVERSITY OF SCIENCE AND TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING**

**CAPSTONE PROJECT
MAJOR: MECHATRONICS ENGINEERING**

**PROJECT TITLE:
DESIGN OF AUTOMATIC PE FILM WRAPPING
SYSTEM FOR MOTORCYCLE TIRES**

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Da Nang, 6/2025

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ABSTRACT

Title: Design of automatic PE film wrapping system for motorcycle tires

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Supervisors : Ph.D Doan Le Anh
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1. Project Purpose

The objective of this project is to design and simulate an improved automatic tire wrapping machine. Specifically, the project aims to replace tasks performed by workers with automation. Workers will only need to press a button, and the machine will automatically perform the tasks without requiring manual effort. This will enhance the machine's automation mode, reduce manual processes, improve efficiency and productivity, and minimize production time

2. Project Objectives

- Improve the design to increase the automation of the machine, reducing 3 manual steps performed by workers in one cycle.
- Increase the accuracy of the tire wrapping and labeling process through a logic control circuit.
- Reduce the time of one cycle from 30 seconds to 15 seconds for one step.
- Ensure safety for operators through protective mechanisms and an emergency stop system in the setup.
- Aim for future development where the machine can be fully automated.

3. Scope and Subjects of Study

Scope:

- Focus on redesigning the mechanical system of the automatic tire wrapping machine to enhance automation and work efficiency.
- Select and calculate suitable materials for load-bearing mechanical components, ensuring durability and longevity during continuous operation.

Subjects of Study:

- Manual mechanical systems need to be replaced with an automated system.
- The control system and sensors will support the automation process.

4. Methodology

- Literature review: Research related to automatic control systems, particularly applications using pneumatic cylinders in industrial production lines.
- Analysis of existing tire wrapping machine models to identify limitations that need improvement.
- Conduct mechanical calculations for current drive mechanisms and propose improvement options.
- Test the performance of the mechanisms through calculations of force, torque, component lifespan, and assess feasibility for integration into the system.
- Create a 3D model using SolidWorks for the entire improved automatic tire wrapping system.
- Generate detailed drawings of mechanical components, overall assembly, and motion simulation to verify design compatibility.
- Control Integration: Design a logic automatic control diagram, integrating the sensor system and actuators (pneumatic cylinders, relays, solenoid valves, etc.) to complete the automation system.

5. Structure of the Thesis

- Chapter 1: Introduction to the Topic
- Chapter 2: Problem identification and design improvement solutions
- Chapter 3: Calculation and verification of machine mechanical
- Chapter 4: Calculation and design improvement of the machine mechanical
- Chapter 5: Control diagram design
- Chapter 6: Conclusion

6. Implemented Outputs

- Number of explanation pages:
- Number of technical drawings: 5
- Prototype: 0

7. Results

- Conduct analysis and re-evaluation of the mechanical components of the current tire wrapping machine, including the drive system and rotary motion mechanisms. The test results help identify weaknesses and limitations in the old design.
- Propose and design new mechanisms to automate three manual operations in a tire wrapping cycle. The improved mechanisms are designed to ensure synchronization, mechanical durability, and practical compatibility with the existing machine.
- Design the improved automatic mechanisms.

Design of automatic pe film wrapping system for motorcycle tires

- Design the logic control electrical circuit for the system.
- Develop a pneumatic logic control diagram, integrating limit sensors, solenoid valves, and controllers to enable automated operation in a predefined sequence. Ensure the control circuit meets safety requirements and is easy to maintain and upgrade.
- Design the system to complete a working cycle 30 seconds faster than the manual operation performed by a worker.

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1. *Project name:* Design of automatic PE film wrapping system for motorcycle tires

2. *Subjects covered by:* Mechanical design, 3D modeling, pneumatics, automatic control, strength calculation, logic control design.

3. *Initial data and figures:*

4. *Contents of theoretical and calculation sections:*

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No	Name	Contents
1	Nguyen Duc Nam	Chapter 1: Introduction to the Topic Chapter 2: Problem identification and design improvement solutions Chapter 3: Calculation and verification of machine mechanical
2	Nguyen Tan Hau	Chapter 4: Calculation and design improvement of the machine mechanical Chapter 5: Control diagram design Chapter 6: Conclusion

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No	Name	Contents
1	Nguyen Duc Nam	Chapter 1: Introduction to the Topic Chapter 5: Control diagram design Chapter 6: Conclusion
2	Nguyen Tan Hau	Chapter 2: Problem identification and design improvement solutions Chapter 3: Calculation and verification of machine mechanical Chapter 4: Calculation and design improvement of the machine mechanical

5. Drawings and graphs (specify types and sizes of drawings):

No	Name	Contents
1	Nguyen Duc Nam	Electrical diagram drawing: 1 A0 Overall drawing : 1A0 Operation diagram: 1A0
2	Nguyen Tan Hau	Kinematic diagram : 2 A0 Part's drawing: 1 A0 Assembly drawing : 1 A0

2. Supervisors's name: *PhD. Doan Le Anh*

3. Project assignment date: *November 25, 2024*

4. Project completion date: *June 5, 2025*

Da Nang, June,5,2025

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PREFACE

In the era of increasing industrialization and automation, improving and automating equipment in production lines plays a crucial role in enhancing productivity, accuracy, and stability of the manufacturing process. Particularly in the motorcycle tire manufacturing industry, manual processes not only reduce labor efficiency but also pose risks to safety and product quality. Therefore, improving existing machinery towards automation is an inevitable trend.

This project is titled "Design and Simulation of an Improved Automatic Tire Wrapping Machine," aiming to replace some manual operations of workers with a mechanical system combined with automatic control. This will contribute to increasing productivity, reducing cycle time, and moving towards the full automation of the tire wrapping process.

The project content includes the mechanical design of improved mechanisms, selection and calculation of drive systems, integration of pneumatic systems and sensors, design of logic control circuits, and 3D modeling using SolidWorks. Throughout the process, the team conducted research, simulation, assembly, and testing to evaluate the operational efficiency of the system after improvements.

We would like to express our sincere gratitude to the Faculty of Mechanical Engineering, especially to our supervising instructors, Dr. Doan Le Anh and Master Cao Thanh Khanh, for their dedicated support and guidance throughout the project. Despite our efforts to finalize it, the project still has shortcomings due to time and experience constraints. We hope to receive valuable feedback from teachers and peers to improve in the future.

Respectfully,

Sincerely,

Nguyen Duc Nam Nguyen Tan hau

DECLARATION OF ACADEMIC INTEGRITY

Da Nang, June 8, 2025

We, the students listed above, hereby declare that the entire content of this graduation thesis titled “*Design of automatic PE film wrapping system for motorcycle tires*” is the result of our own work, research, and execution.

We affirm that all data, figures, images, and references used in this thesis were collected and cited appropriately and transparently. All ideas, methodologies, and results presented are original, and not plagiarized or copied from any source without proper citation.

We bear full responsibility for the integrity and authenticity of this thesis. In the event of any academic misconduct, we are willing to accept all consequences as per the policies of the University of Science and Technology – The University of Danang.

We also express our gratitude for the guidance of our professors and the support of our peers during the project. We hope that this thesis meets the university’s expectations and contributes practical value to the field of mechatronics engineering.

Students:

Nguyen Duc Nam
Nguyen Tan Hau

LIST OF SYMBOLS AND ABBREVIATIONS

Symbols	Full name	Description
RPM	Revolutions Per Minute	Rotational speed (rounds per minute), used to evaluate shuttlecock stability.
DC	Direct Current	Direct current, e.g., 12VDC or 24VDC power supplies.
AC	Alternating Current	Alternating current, e.g., AC 220V input power.
PE	Polyethylene	Thin plastic film for tire wrapping
R	Cylinder	Tire pressing cylinder
A1	Cylinder	Film holding and cutting cylinder
A2	Cylinder	Cylinder for applying line onto the tire
A3	Cylinder	Cylinder for cutting the line
B1	Cylinder	Cylinder for applying tape onto the label surface
B2	Cylinder	Sliding cylinder for tape application
B3	Cylinder	Cylinder for cutting the tape

C1	Cylinder	Cylinder for forward motion to apply the tape
C2	Cylinder	Sliding cylinder to move the tape application point to the suction position
C2	Cylinder	Cylinder for pushing the label and tape to the suction cup
D1	Cylinder	Cylinder for horizontal motion in label application
D2	Cylinder	Cylinder for vertical motion in label application
D3	Cylinder	Cylinder for applying the label onto the tire

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CHAPTER 1: INTRODUCTION TO THE TOPIC

1.1 Introduction to the Shuttlecock Stability Testing Device

1.1.1 General Introduction

In the context of increasingly rapid industrialization and modernization, the application of automation technology in production lines is an inevitable trend aimed at enhancing productivity, reducing labor costs, and ensuring consistent product quality. The motorcycle tire manufacturing industry is no exception to this trend. In the tire production process, the step of wrapping with PE film after the tire is completed plays an important role in protecting the product from dust, impacts, and environmental factors during storage and transportation.



Figure 1.1 DRC Rubber Tire Wrapping Machine [Source: owner]

However, the process of wrapping tires is still performed manually or using semi-automatic machines. This not only reduces labor efficiency but also creates inconsistencies among products, poses risks of human error, and affects the stability of the production line. Additionally, workers must perform repetitive tasks, which are physically demanding and can easily lead to mistakes during extended working hours.

Given these shortcomings, improving the tire wrapping machine towards automation is necessary and has high practical applicability. The goal is to redesign the

mechanical structures, add an automatic control system, and eliminate unnecessary manual operations. This approach will not only increase the wrapping cycle speed but also reduce dependence on worker skills, improve working conditions, and enhance the stability of the entire production line.

With this spirit, the project "Design and Simulation of an Improved Automatic Tire Wrapping Machine" is implemented to meet practical needs while helping students apply their learned knowledge to a specific problem in industrial production, covering areas such as mechanical design, automatic control, pneumatics, and simulation.

1.1.2 Overview of Shuttlecocks

In the motorcycle tire manufacturing process, after the tire is completed and has passed quality inspection, the final step before packaging is wrapping it with PE (Polyethylene) film. This is done to protect the tire surface from dust, scratches, and external impacts during transportation and storage. Wrapping the film also helps enhance the product's appearance and professionalism before it reaches the consumer.



Figure 1.2 Worker operating DRC rubber tire wrapping machine [Source: owner]

However, in many factories, the tire wrapping process is still performed manually or semi-automatically, requiring workers to carry out multiple steps such as placing the tire, pulling the film, holding it in place, wrapping evenly, and cutting the film. This prolongs the cycle time, reduces efficiency, and results in inconsistent wrapping quality between products. Additionally, repetitive manual operations pose a risk of mechanical injuries and increase worker fatigue during long shifts.

Improving and automating the tire wrapping machine is a practical solution to address these issues. An automated system equipped with precise drive mechanisms, positioning sensors, a logic controller, and a supporting pneumatic system can shorten operation time, reduce reliance on operator skills, and enhance the stability and productivity of the production line.

This project focuses on researching, designing, and simulating an improved tire wrapping machine aimed at replacing three key manual steps in the process. The goal is to reduce operation time and gradually move towards full automation of the tire wrapping procedure in the future.

Based on workers' operating procedures and available equipment, the team has proposed a design improvement plan by automating the three main manual steps in a wrapping cycle through the addition of an enhanced pneumatic cylinder mechanism.

1.2 Evaluation: Advantages and Disadvantages

1.2.1 Advantages

- Automates three key manual operations:
 - Holding and cutting the wrapping film
 - Attaching and cutting the alignment line
 - Labeling and applying adhesive tape
- The operator only needs to place the tire in and remove it, significantly reducing operation time and dependency on worker skill.
- The automated system ensures that the wrapping process is carried out with high accuracy and consistency, resulting in evenly wrapped tires that are visually appealing and meet aesthetic standards. At the same time, it shortens the processing time for each product.

1.2.2 Disadvantages

The winding motor speed is difficult to adjust accurately at low speeds : Due to the use of a variable frequency drive for speed control, running at low frequencies results in reduced motor torque, causing stalling, vibration, or instability during the stopping phase for the sensor to detect the cutting position of the film. This affects the accuracy of the winding stop point and cutting position.

Ensuring synchronization between winding speed, cylinder pressure, and film position detection requires multiple adjustments and testing to achieve optimal efficiency.

1.3 The Need for Developing a Stability Testing Device

In the context of the increasingly developing motorcycle tire manufacturing industry, the requirements for professionalism, consistency, and productivity in the product finishing stage are also rising. However, in many factories, the PE film wrapping process for tire protection is still performed manually or semi-automatically, resulting in time consumption, inconsistent quality, and potential occupational safety risks.

Therefore, manufacturers need a reliable, fully automatic film wrapping device that can be integrated into the production line to:

- Automate repetitive operations in the wrapping process.
- Ensure uniform, neat, and secure wrapping quality for each tire.
- Increase productivity and reduce dependence on workers' skills.
- Minimize risks and reduce worker fatigue.

This project focuses on designing and simulating an automatic PE film wrapping machine for motorcycle tires by improving the drive mechanism and adding pneumatic cylinder mechanisms, sensors, and logic control, aiming to shorten operation time, increase productivity, and gradually automate the entire process.

1.4 Research Objectives

- Analyze the current tire wrapping process and identify the manual operations that need automation.
- Design a mechanical and automatic control system capable of replacing three main manual operations (holding and cutting the wrapping film, cutting and sticking the line, and labeling).
- Develop a simulation model of the improved tire wrapping machine, capable of stable and safe operation.
- Apply sensors and signal processing to precisely control the actuators in the machine.
- Integrate a logic relay control system to operate the entire wrapping cycle.
- Ensure that the equipment operates with a wrapping time of compared ≤ 20 seconds/tire and achieves a wrapping uniformity of $\geq 90\%$ to the established standards.

1.5 Research Scope

- Design of mechanical systems, control electronics, and image processing software.
- Design mechanical structures such as the cylinder support frame, labeling and cutting mechanisms.
- Integrate a control system using sensors, pneumatic cylinders, and electric motors.
- Not delve into the design of cooling fan motors or automatic PE film feeding systems - using commercially available equipment.
- Do not evaluate the impact of environmental factors (temperature, dust, humidity) on wrapping quality.
- Testing scope limited to commonly sized tires (20 - 22 inches).

1.6 Estimated Device Specifications

- Overall dimensions: 950 x 700 x 1200 mm
- Machine weight: approximately 2000 kg
- Power supply: 380V – 3 phase – 50Hz
- Drive system: Electric motor combined with inverter
- Rotating ring speed: 680 rpm (adjustable via inverter)
- PE film wrapping speed: 1 revolution/10 seconds
- Cycle completion time: ≤ 20 seconds/tire
- Actuation mechanisms:
- Pneumatic cylinders

Design of automatic pe film wrapping system for motorcycle tires

- Motors through chain and belt drives
- Continuous operating capacity: 8–10 hours/day
- Suitable tire types: Motorcycle tires 20 - 22 inch
- Operating environment: Indoors, temperature conditions from 10 – 50°C.

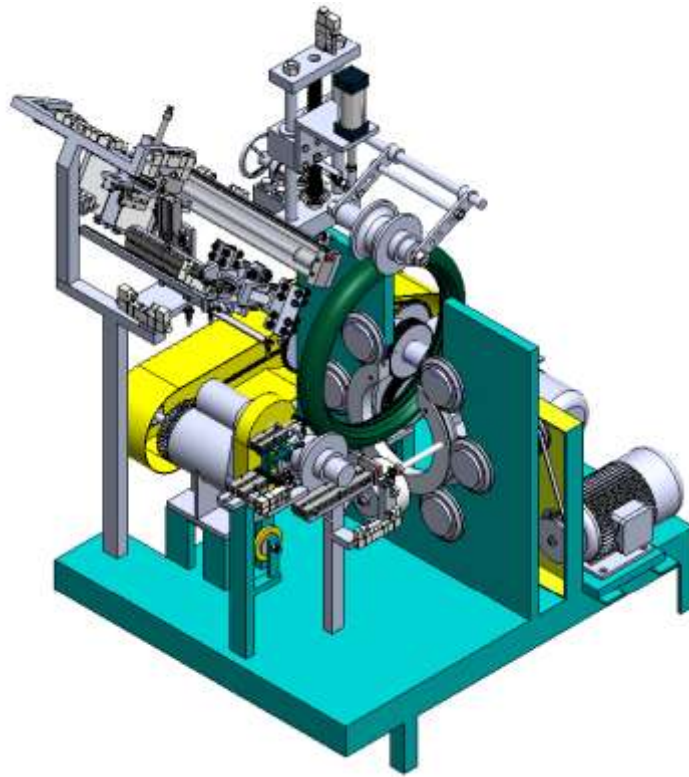


Figure 1.3 Improved model of tire wrapping machine using SolidWorks [Source: owner]

CHAPTER II: PROBLEM IDENTIFICATION AND DESIGN IMPROVEMENT SOLUTIONS

2.1 Original technical specifications



Figure 2.1 DRC rubber tire [Source: Internet]

Tire specifications: 80/90-17 (conducting research for wrapping with PE film)

- Tire width: 80 mm
- Tire height: 72 mm
- Inner diameter: 43.18 cm (17 inches)
- Outer diameter: 57.58 cm
- The outer circumference of the tire is 180.9 cm for one complete wrap.

⇒ The time to complete one rotation of the tire at an input speed of

$$v = 0,2 \text{ m/s}$$
$$t = \frac{C}{v} = \frac{1,8}{0,2} = 9s$$



Figure 2.2 Actual tire wrapping machine at DRC Rubber

In the current process, to complete one PE film wrapping cycle for a motorcycle tire, workers must manually perform the following steps in sequence:

- Hold the PE film with one hand and grip the tire with the other hand.
 - Pull the PE film around the tire, then place the tire into the holding frame.
 - Thread the PE film loop through the center of the tire.
 - Press the RUN button to activate the machine:
 - The pneumatic cylinder presses against the tire to fix it in place and prevent it from being thrown out.
 - The film wrapping motor and the tire rotating motor start operating.
 - After about 3 seconds, when the PE film has been partially wrapped, the worker manually secures the film with a fixed line.
 - When the PE film has been wrapped completely around the tire, the worker uses a hand-held knife to cut the film and presses the button to retract the cylinder.
 - Continue to rotate the tire by hand to the end position of the centerline, then cut the line with the knife.
 - Remove the tire, attach the product label, and use tape to fix the label with two rounds of adhesive.
- ❖ The total time to complete one cycle is about 32 seconds per tire.

In this process, workers must manually perform three main tasks:

- Holding and cutting the PE wrapping film
- Attaching and cutting the fixed line
- Affixing the label and taping it in place

These tasks not only take time but also require precise coordination between hands and eyes, causing worker fatigue and reduced productivity if performed continuously for long periods.

❖ **Identified Problems and Improvement Directions**

- From the above situation, our team found that the tire wrapping process still heavily relies on manual operations. Meanwhile, input components such as the film wrapping motor, tire rotating motor, and the tire pressing cylinder mechanism are already available in the system.
- ❖ Therefore, the team proposes an improved design solution by:
- Utilizing the existing equipment and maintaining the original transmission principle.
 - Designing additional automatic mechanisms using pneumatic cylinders, sensors, and logic controllers to:
 - Automatically hold and cut PE film.
 - Automatically attach and cut the line.
 - Automatically label and wrap adhesive tape.

The goal is to minimize manual operations by workers in each cycle, move toward full automation of repetitive steps, and reduce operation time to under 20 seconds per tire.

❖ Design objectives

Based on the existing equipment in the system, such as the PE film wrapping ring motor and the tire rotation motor, the team conducted a survey on the power, rotational speed, and actual working capacity of each mechanism. Using the measured data, the team calculated the time required for each step in the film wrapping cycle.

From this input data, the team proposed and designed improved automatic mechanisms with the following aims:

- Replace manual operations performed by workers, especially the three main steps: holding – attaching – cutting the film; attaching and cutting the fixed line; attaching the label and taping.
- Increase productivity and reduce operation time to a reasonable and stable level.
- Optimize the operation process, making the system run smoothly, easy to use, and less dependent on worker skills.

The ultimate goal is to move towards partial automation, progressing to a semi-automatic system which can be further upgraded to a fully automatic system in the future, in line with the trend of modernizing production lines at motorcycle tire manufacturing plants.

These are the tested input data calculated below:

❖ Motor for rotating PE wrapping:

- Rotational force: $F = 70\text{N}$
- Speed: $V = 10,7 \text{ (m/s)}$
- Coefficient of friction between the rubber roller and the aluminum wrapping: $0,7 \sim 0.9$
- Diameter of the drum: $D = 30 \text{ cm}$
- Belt transmission efficiency: $\eta = 95\%$
- One-way operation
- Constant load and slight vibration

❖ Motor for rotating tires:

- Rotational force: $F = 7 \text{ N}$
- Speed: $V = 0,2 \text{ (m/s)}$
- Diameter of the drum: $D = 9 \text{ cm}$
- Chain transmission efficiency: $\eta = 92\%$
- One-way operation
- Constant load and slight vibration

⇒ These parameters are calculated and tested to approximate real conditions through surveys and calculations.

❖ Summary of the Design Process for Improving the Supplementary Mechanism to Automate 3 Manual Processes of Workers

- Based on the speed and power parameters of the tire rotation motor, along with the tire diameter, the time for the tire to complete one rotation is calculated as follows:

$$t_{\text{tđp}} = \frac{C}{v} = \frac{1,8}{0,2} = 9\text{s}$$

- To ensure that the PE wrapping covers the tire completely, after completing one rotation, the tire will move an additional distance for 1 second to ensure that the PE film is secured and can be cut safely without being loose.

⇒ Thus, the total rotation time for the PE wrapping motor and the tire rotation motor is:
 $t_{lop} = 10s$.

Design Proposal for the Mechanism to Hold and Cut the PE Wrapping

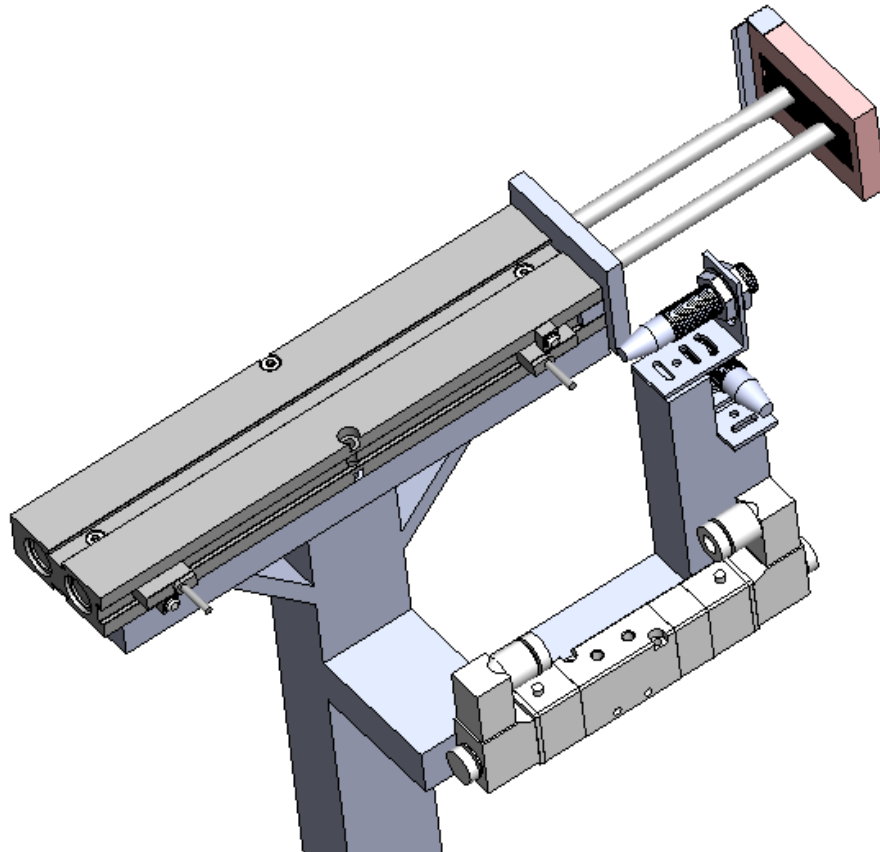


Figure 2.3 Design of PE wrapping film holding and cutting mechanism

The design solution for the PE film holding mechanism is automatic, based on a clamping structure driven by a cylinder. → After pressing the RUN button, the PE film winding motor is activated, rotating the winding ring for a few turns (approximately 0.5 seconds). → 0.5 seconds after pressing RUN, the cylinder advances by 1 cm and stops (using a 5/3 solenoid valve with 3-position stop) to release the PE film. → After completing other processes... → When both motors stop, Cylinder A1 moves forward to the end of its stroke. → The PE film winding motor runs at low speed (controlled by an inverter). When the proximity sensor detects an object on the winding ring, the motor stops. → Cylinder A1 retracts until it hits the sensor, then clamps the PE film tightly using the cylinder clamp. → The tire motor continues to run (because it hasn't reached the end of the line yet); the rotary force of the tire moves the blade mounted at the head of Cylinder A1 to cut the PE film.

❖ **Design Plan for the Line-Cutting and Taping Mechanism**

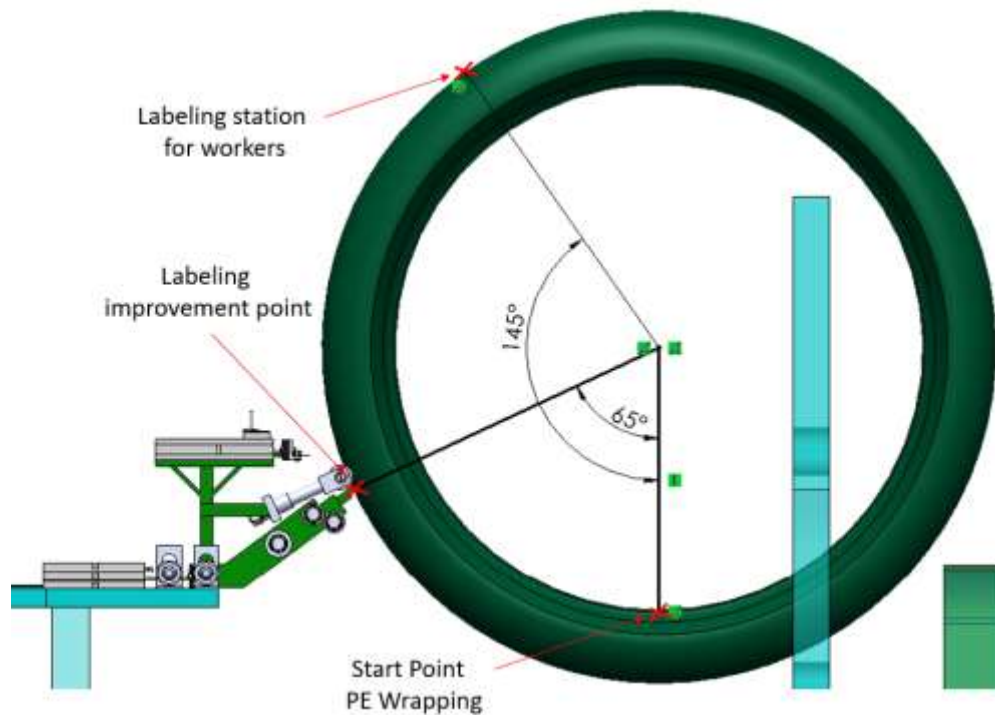


Figure 2.4 Design of line sticking and cutting mechanism

Based on the worker's label placement at an angle of 145°, the total time taken is nearly 4 seconds after the motor starts rotating.

For the design solution of the labeling and cutting mechanism, I propose an automatic system where, approximately 2 seconds after pressing the RUN button, the tire is rotated to an angle of 80°. At this point, the cylinder mechanism (A2) advances to apply the label onto the tire and presses it against the surface with the help of an attached roller. → After both motors stop (the label is applied at an angle of 40°), the PE wrapping film is cut, triggering a sensor signal. → The tire motor then rotates for 1.5 seconds, achieving a label placement angle of 100°. → Afterward, the labeling cylinder retracts, detected by a proximity sensor signal → then cylinder (A3) advances to cut the label.

$$t_{tire} = \frac{C}{v} = \frac{1,8}{0,2} = 9s \rightarrow \text{In 1 second, the wheel rotates 0.2 meters.}$$

$$0.2 \text{ meters in 1 second} \rightarrow \theta = \frac{l \times 360}{\pi \times d} = \frac{20 \times 360}{\pi \times 57,58} = 40^\circ$$

→ In 1 second, the wheel rotates 40 degree

❖ **The design plan of the labeling mechanism is presented in detail in Chapter III.**

CHAPTER III: CALCULATION AND VERIFICATION OF MACHINE MECHANISMS

3.1. Calculation and verification of the transmission system in the wrapping ring mechanism:

- Motor: Provides rotary motion and is directly connected to Pulley 1.
- Pulley 1 transmits torque via a belt to Pulley 2 and Pulley 3.
- Pulley 2 and Pulley 3 are fixed to two rollers, which press against the inner side of the wrapping ring – a circular structure that holds the tire-supporting rollers.
- (The pulleys have equal diameters, and the rollers also have equal diameters.)

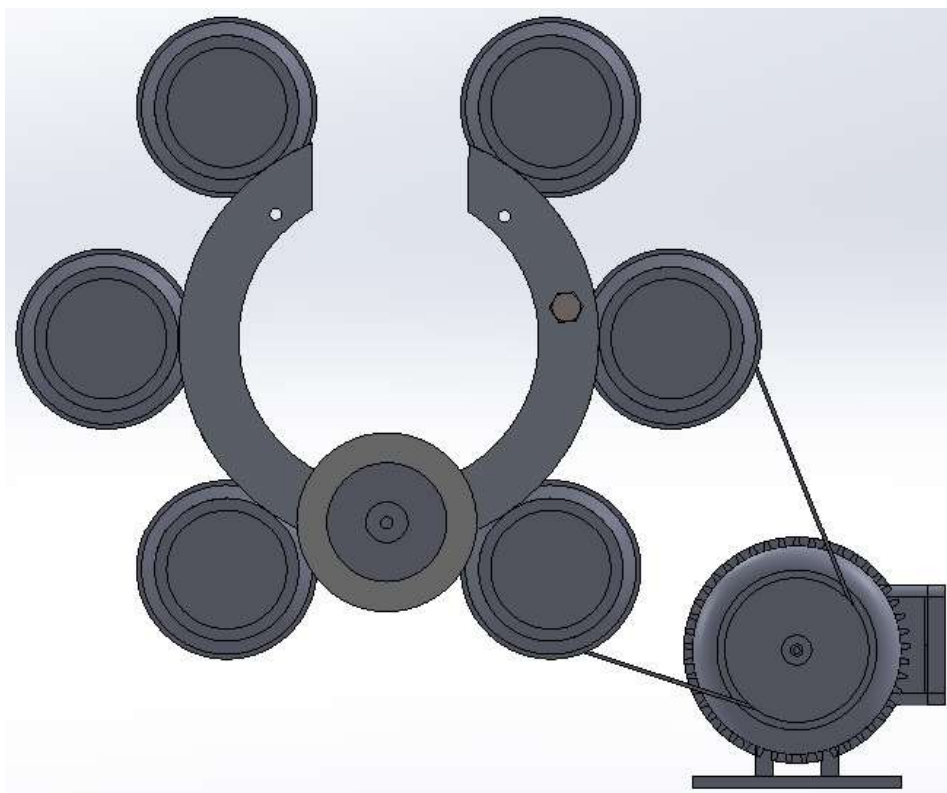


Figure 3.1 Pulley belt transmission system through wrapping ring

Transmission process: The motor transmits rotary motion to Pulley 1 → Pulley 1 drives the belt, transmitting torque to Pulley 2 and Pulley 3 → Pulley 2 and 3 are fixed to two identical rollers that rotate in the same direction → The two rollers press against the groove in the wrapping ring, creating friction → As the rollers rotate, they generate frictional force that drives the wrapping ring to rotate around its axis → The tire is placed on two rotating shafts of Motor 2 and is held firmly by a cylinder → As the wrapping ring rotates, it turns around the tire, and the PE film is evenly wrapped around the tire's circumference.

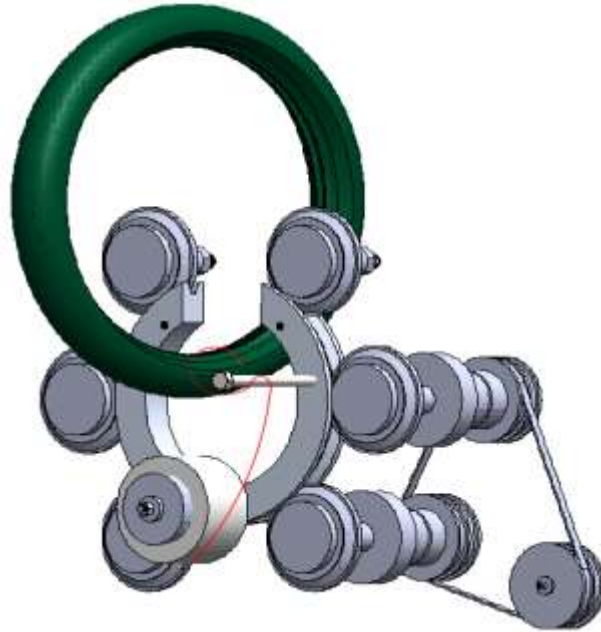


Figure 3.2 Simulation of PE film wrapped around the tire

❖ **Calculation and verification of the motor for PE film wrapping**

Rotational force: $F = 70\text{N}$

Velocity: $V = 10,7 \text{ (m/s)}$

Coefficient of friction between rubber roller and aluminum wrapping ring: $0,7\sim 0,9$

Diameter of the pulley (tang): $D = 30 \text{ cm}$

Efficiency of belt transmission: $\eta = 95\%$

Operates in one direction only

Constant load with slight vibration (safety factor 1.2)

$$\omega = \frac{V}{R} = \frac{10.7}{0.15} = 71.3 \left(\frac{\text{rad}}{\text{s}} \right)$$
$$\Rightarrow n = 680(\text{rpm})$$

Working power:

$$P = T \times \omega = F \times R \times \omega = 70 \times 0.15 \times 71,3 = 0.75 \text{ (kW)}$$

The required motor power formula is:

$$P_{sb} = \frac{P}{\eta} = \frac{0.75}{0.95 \times 0.95 \times 0.8} = 1(\text{kW})$$

Where:

- Belt transmission efficiency: 0.95
- Friction coefficient between rubber roller and aluminum wrapping ring: 0.8

$$P_{ct} = n_k \times P_{sb} = 1.2 \times 1 = 1.2 \text{ (kW)}$$

Rotational speed of the wrapping ring:

$$n_{lv} = \frac{V \times 60}{\pi \times D} = \frac{10.7 \times 60}{\pi \times 0.3} = 680 \text{ (rpm)}$$

Choose gear ratio $i = 2$:

$$\Rightarrow n_{ct} = 2 \times n_{lv} = 2 \times 680 = 1360 \text{ (rpm)}$$

$$i = \frac{n_1}{n_2} = \frac{D_2}{D_1}$$

$$\Rightarrow 2 = \frac{0.3}{D_1} \Rightarrow D_1 = 0.15 \text{ (m)}$$

Required torque: $M_c = \frac{F \times D}{2 \times \eta} = \frac{70 \times 0.3}{2 \times 0.95} = 11 \text{ (N.m)}$

$$M_{sb} = n_k \times M_c = 1.6 \times 11 = 16.5 \text{ (N.m)}$$

With gear ratio $i = 2$:

$$i = \frac{n_1}{n_2} = \frac{M_{sb}}{M_{ct}} \Leftrightarrow 2 = \frac{16.5}{M_{ct}} \Rightarrow M_{ct} = \frac{16.5}{2} = 8.25 \text{ (N.m)}$$

Since Pulley 1 drives Pulley 2 (roller 2) and Pulley 3 (roller 3), rollers 2 and 3 share the torque load equally and share the pulling force on the wrapping ring equally, without changing the speed.

$$M_{2ct} = M_{3ct} = \frac{M_{ct} \times \eta}{2} = \frac{8.25 \times 0.95}{2} = 4.9 \text{ (N.m)}$$

Select motor JO_2:



Figure 3.3 Motor for pulley belt transmission [Source: Internet]

Table 1 - JO2 motor parameters.[3]

JO ₂	22-4	1410 RPM
Kw: 2HP	CONN: Δ/Y	50Hz
220/380V	81%	6,64/3,48A
NO	INS.CLE	20kg

Motor torque:
$$T = \frac{9550 \times P}{n} = \frac{9550 \times 1.5}{1410} = 10.15(N.m)$$

⇒ **Motor JO_2 meets the following conditions:**

$$P_{dc} = 1.5(kW) > P_{ct} = 1.2(kW)$$

$$N_{dc} = 1410(rpm) \approx N_{ct} = 1360(rpm)$$

$$M_{dc} = 10.15(N.m) > M_{ct} = 8,25$$

⇒ The design parameters, after calculation and verification, fully meet the actual conditions, ensuring feasibility for implementation and model improvement.

The design option chooses 2 pulleys to drive the turntable:

- Even distribution of torque and pulling force:
 - Using two adjacent drive rollers divides the pulling force equally, preventing overload on one side.
 - This helps increase the durability of the wrapping ring and reduces uneven wear.
- Improved grip and torque transmission:
 - Since the wrapping ring has certain load and inertia, using only one drive roller can easily cause slipping or insufficient torque.
 - Using two rollers increases contact area and friction force for better torque transmission.
 - Using two rollers also avoids the case where using one roller causes speed deviation and misalignment of the groove in the wrapping ring, which could cause the ring to jam (fall into the gap).
- Maintaining rotational balance:
 - Using only one roller on either the left or right side results in uneven force transmission, causing load imbalance, vibration, or deviation.
 - Two adjacent rollers help the wrapping ring rotate smoothly, balanced, and more stable.
- Increased transmission efficiency:
 - Distributing the pulling force and torque between two rollers reduces the load on each pulley, thus increasing overall efficiency with less loss due to slipping or wear.

3.2 Calculation and verification of the transmission system on the tire rotation mechanism

The tire rotation motor is connected to a gearbox with a gear ratio of 1:30, reducing rotation speed and increasing output torque. The output shaft of the gearbox (shaft 1) is connected to a drive gear, which transmits motion to shaft 2 via a chain drive with a 1:1 ratio; shafts 1 and 2 rotate at the same speed.

On shaft 2, a small gear is designed to transmit motion to shaft 3 also via a chain drive (1:1), so shafts 2 and 3 rotate synchronously. The other end of shaft 2 is fitted with a drive gear that meshes with a gear on shaft 4 via a spur gear transmission (ratio 1:1).

The other end of shaft 3 is also connected directly to shaft 5 by a pair of spur gears with a 1:1 transmission ratio. All shafts from shaft 1 to shaft 5 rotate at the same speed, as all transmission systems have a 1:1 ratio. The motion from the main motor is evenly distributed to multiple shafts through serial transmissions, ensuring synchronized operation of the output mechanisms.

Shafts 3 and 5 are the two main tire support shafts → they cause the tire to rotate. Shaft 4 provides auxiliary drive, helping to distribute load more evenly and stably.

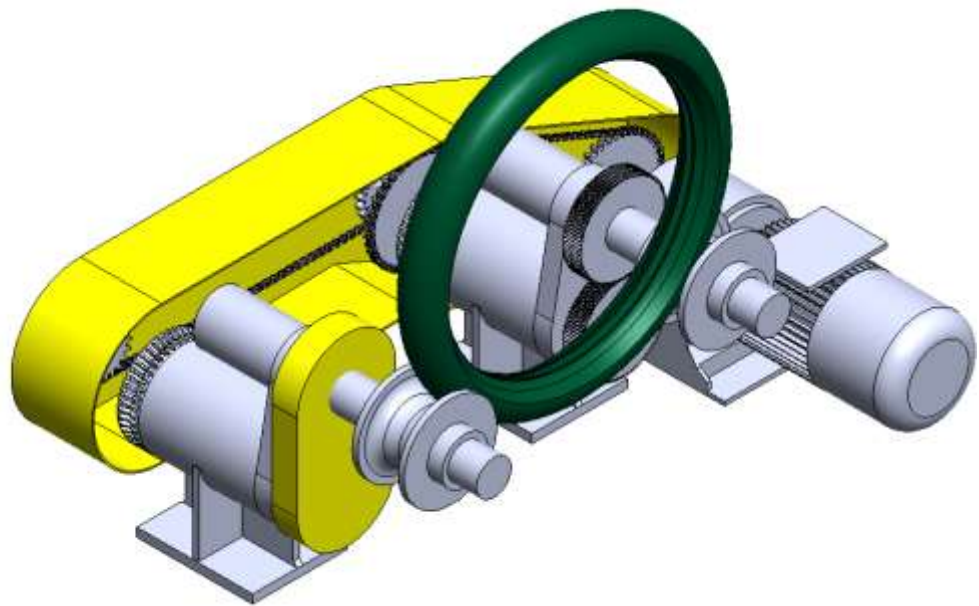


Figure 3.4 Simulation of tire placed on two rotating shafts

Design of the tire rotation transmission system

Calculation and verification of the tire rotation motor

Rotational force: $F = 7 \text{ N}$

Velocity: $V = 0,2 \text{ (m/s)}$

Diameter of the pulley (tang): $D = 9 \text{ cm}$

Chain transmission efficiency: $\eta = 92\%$

Operates in one direction only

Constant load with slight vibration (safety factor 1.2)

$$\omega = \frac{V}{R} = \frac{0,2}{0.045} = 4,4 \left(\frac{rad}{s} \right)$$
$$\Rightarrow n = 42(rpm)$$

Working power:

$$P = T \times \omega = F \times R \times \omega = 7 \times 0.045 \times 4,4 = 1,4 \text{ (kW)}$$

Required motor power formula:

$$P_{sb} = \frac{P}{\eta} = \frac{1,4}{0.92 \times 0.92} = 1,7 \text{ (kW)}$$

Where: Chain transmission efficiency 0.92

$$P_{ct} = n_k \times P_{sb} = 1.7 \times 1,2 = 2 \text{ (kW)}$$

Rotation speed of the wrapping ring:

$$n_{lv} = 42(rpm)$$

Because the transmission uses two chain drives with a 1:1 ratio (the diameter and number of teeth of the driving and driven sprockets are equal), the motor speed is selected based on a transmission ratio of 1:30.

Select gear ratio $i = 1:30$

$$i = \frac{n_1}{n_2} = \frac{D_2}{D_1}$$

$$\Rightarrow n_1 = i \times n_2 = 30 \times 42 = 1260 \text{ rpm}$$

Required torque: $M_c = \frac{F \times D}{2 \times \eta} = \frac{7 \times 0.09}{2 \times 0.92} = 0,34 \text{ (N.m)}$

$$M_{sb} = n_k \times M_c = 1.2 \times 0,34 = 0,41 \text{ (N.m)}$$

With gear ratio $i = 1:30$: $M_{ct} = 30 \times M_{sb} = 0,41 \times 30 = 12,3 \text{ N.m}$

\Rightarrow For shafts 2 and 3, the required torque for each shaft is:

$$M_{ct2,3} = \frac{12,3}{2} = 6,15 \text{ N.m}$$

Select motor TDT:



Figure 3.5 TDT geared motor driving chain transmission[Source: Internet]

Table 2 - TDT motor parameters[3]

TH/TV2200	4P	1420 RPM
Kw: 2,2kW	CONN: Δ/Y	50/60Hz
81%	220/380V	8,7 / 5,04A
INS	INS.CL F	

Motor torque:

$$T = \frac{9550 \times P}{n} = \frac{9550 \times 2,2}{1420} = 14,7(N.m)$$

⇒ **The TDT motor meets the requirements:**

$$P_{dc} = 2,2(kW) > P_{ct} = 2(kW)$$

$$N_{dc} = 1420(rpm) \approx N_{ct} = 1420(rpm)$$

$$M_{dc} = 12,3(N.m) > M_{ct} = 14,7(N.m)$$

Advantages of the transmission system:

- Even and stable load distribution:
 - Distributing the torque from the motor to multiple shafts reduces load on each individual shaft, increasing the lifespan of bearings, gears, and chains.
 - The tire rotation system operates more smoothly and reduces vibration.
- Improved synchronization and precision in tire rotation:
 - Shafts 3 and 5 rotate at the same speed → keeping the tire centered, preventing misalignment, skewing, or deformation during the PE film wrapping process.
 - Ensures the PE film is wrapped evenly and neatly.
- Maximized utilization of a single motor:

- With only one motor and gearbox, the system transmits force to the entire tire rotation mechanism via a smart shaft design.
- Saves cost and space compared to using multiple individual motors.
- Easy to manufacture and maintain:
 - The transmission system uses chains and spur gears, which are common components, easy to assemble, maintain, and replace if needed.
 - Easy to adjust synchronization by changing gears/chains if minor errors occur.
- Flexible for expansion or load adjustment:
 - This design allows easy addition or rearrangement of shafts if machine structure adjustment or future upgrades are required.

3.3 Testing the tire pressing cylinder and bevel gear transmission system:

3.3.1 Testing the tire pressing cylinder

In the PE film wrapping machine for tires, to ensure the tire does not fly off when rotating at high speed, the designer created a pneumatic cylinder pressing mechanism that works as follows:

- The mechanism is positioned above the tire, fixed on a mounting base guided by the driven shaft of the bevel gear transmission through two guide rods.
- On the mounting base is a double-acting pneumatic cylinder.
- The cylinder rod is attached to a pressing shaft shaped to fit the tire's outer surface. When the cylinder pushes down, the pressing shaft presses firmly against the tire surface, ensuring close contact.

Operating principle:

- When activated by a button, the cylinder pushes the pressing lever down onto the tire with sufficient force, synchronized with the two motors rotating the tire and wrapping the film.
- As the motor drives the tire (through shafts 3 and 5), the tire rotates smoothly and steadily without bouncing or slipping out of place.
- After the wrapping process is complete, the cylinder retracts to its original position to release the tire from the machine.

Role of this mechanism:

- Prevents the tire from flying off due to inertia and friction from the PE film during high-speed rotation.
- Stabilizes the tire position, helping the film wrapping process to be even, accurate, and aesthetically pleasing.
- Increases operational safety and reduces risks for workers when loading/unloading tires.

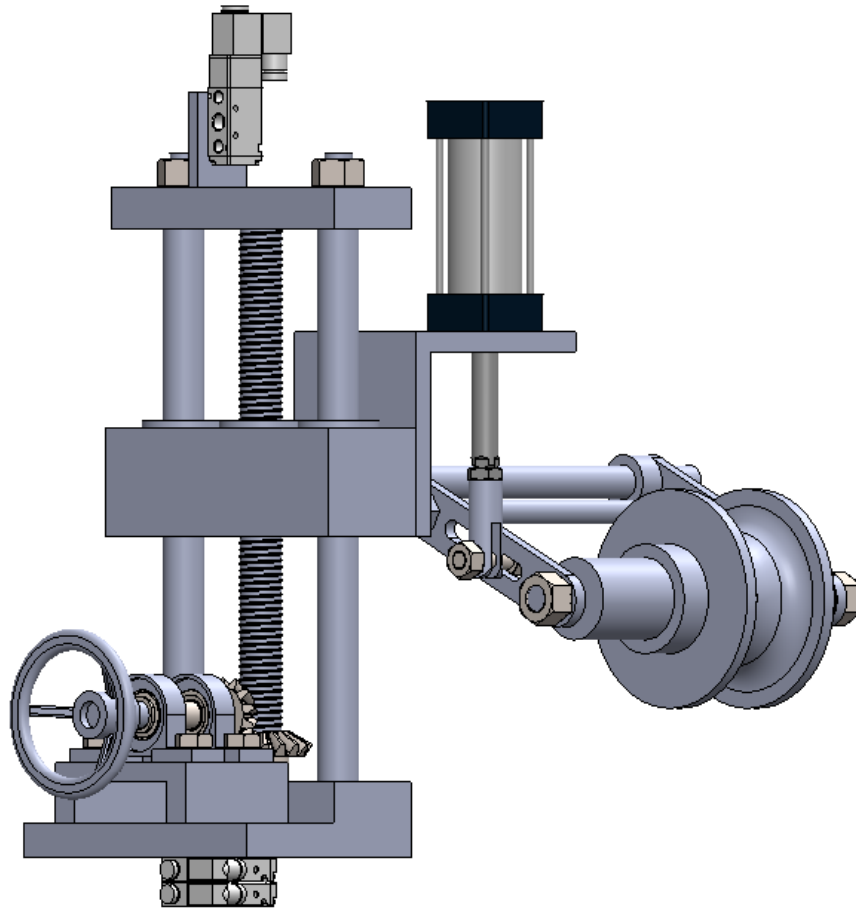


Figure 3.6 Tire pressing mechanism in SolidWorks

- Load acting on the cylinder to be pushed: 13kg
Cylinder diameter: D = 40 mm
Stroke length: L = 75 mm = 0,075 m
Pneumatic pressure: p = 6 bar = 0.6 N/mm²
Piston surface area:

$$A = \pi \times \left(\frac{D}{2}\right)^2 = 1256 \text{ mm}^2 = 0,0013 \text{ m}^2$$

Maximum pushing force of the cylinder (denoted as F):

$$F = p * A = 0.6 * 1256 = 753 \text{ N}$$

Converted to mass: $P = \frac{F}{g} = \frac{753}{10} = 75,3 \text{ Kg}$

Desired time to complete the stroke: t = 0,2 s

⇒ **Cylinder extension speed:** $v = \frac{L}{t} = \frac{0.075}{0,2} = 0.375 \text{ m/s}$

Cylinder extension speed: $v = \frac{Q}{A}$

Required air flow rate to control the cylinder:

$$\Rightarrow Q = v \times A = 0,375 \times 0,0013 = 4,8 \times \frac{10^{-4}m^3}{s} = 28,8 \text{ l/phút}$$

3.3.2 Testing the straight bevel gear transmission system

The manufacturer has designed a mechanism to hold the tire when it is rotated by two driving shafts of the tire rotating mechanism. The manufacturer designed a pneumatic cylinder to push a rotating shaft mechanism downwards to press against the tire, preventing the tire from flying off when the two driving shafts rotate the tire.

The cylinder is mounted on a base, and this base moves linearly by a threaded shaft and two guide rods through the straight bevel gear transmission system, allowing adjustment of the tire height.

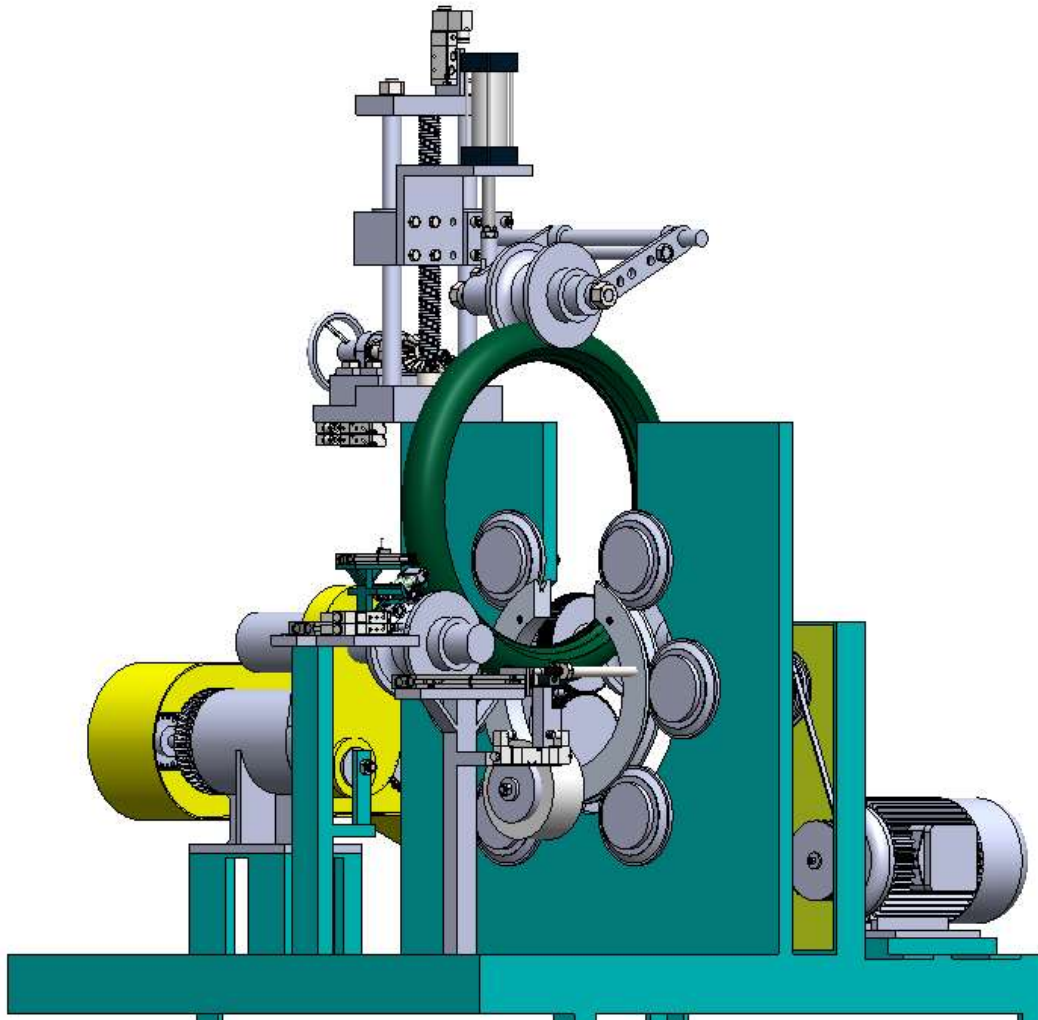


Figure 3.7 Tire pressing mechanism in SolidWorks before improvement

The function of the straight bevel gear transmission is to translate (move linearly) the mounting assembly along a threaded shaft and two guide rods, so that the tire pressing shaft can be adjusted to match the tire's height layer as needed, controlled via the handwheel on the drive shaft.

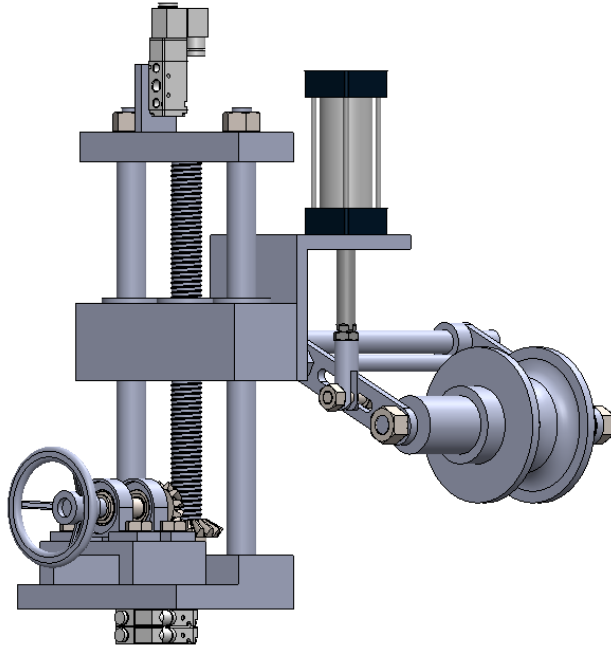


Figure 3.8 Tire pressing mechanism in SolidWorks

Stress Analysis on Straight Bevel Gear Transmission:

Load acting on the driven gear: 28 kg

This is a straight bevel gear transmission system, where the driving gear is manually operated via a handwheel. Therefore, the speed is very low and the system is rarely used.

⇒ The force acting on the driven shaft is gravitational:

$$F = P = mg = 10 \times 28 = 280(N)$$

Gear material:

Normalized steel with surface hardness HB < 350

Driving gear: Material: Normalized C15 steel

Blank diameter < 100 mm

Tensile strength: $\sigma_{bk} = 360 \text{ N/mm}^2$

Yield strength: $\sigma_{ch} = 210 \text{ N/mm}^2$

Driven gear: Material: Normalized C10 steel

Blank diameter < 100 mm

Tensile strength: $\sigma_{bk} = 340 \text{ N/mm}^2$

Yield strength: $\sigma_{ch} = 210 \text{ N/mm}^2$

Driven gear torque:

$$T_2 = \frac{F \times p}{2\pi} = \frac{280 \times 5}{2\pi} = 223 \text{ (N.mm)}$$

Where:

- Lead of the screw shaft: $p = 5 \text{ mm}$
- Force acting on the driven gear: $F = 280 \text{ N}$

Transmission ratio: $u = \frac{Z_2}{Z_1} = \frac{M_2}{M_1} = \frac{18}{12} = 1,5$

Where:

- Teeth of driving gear: $Z_1 = 12$
- Teeth of driven gear: $Z_2 = 18$

Input torque (on driving gear):

$$T_1 = \frac{T_2}{i} = \frac{223}{1.5} = 149 \text{ (N.mm)}$$

Driving gear:

$$\delta_1 = \tan^{-1}\left(\frac{1}{i}\right) = \tan^{-1}\left(\frac{1}{1.5}\right) = 33.7^\circ$$

Driven gear:

$$\delta_2 = 90^\circ - \delta_1 = 90^\circ - 33.7^\circ = 56.3^\circ$$

δ_1, δ_2 : Formulas from "Machine Elements Vol.1" by Nguyễn Trọng Hiệp, page 165

Contact Stress Check for Straight Bevel Gear:

$$\sigma_H = \frac{Z_H Z_M}{d_1} \sqrt{\frac{2 \cdot T_1 \cdot \sqrt{u^2 + 1} K_{H\beta} K_{Hv}}{0,85bu}} \leq [\sigma_H]$$

Where: $Z_{H1} = \sqrt{\frac{2 \cos(\delta_1)}{\sin(2\alpha)}} = \sqrt{\frac{2 \cos(33.7^\circ)}{\sin(2 \times 20^\circ)}} = 1,6$

$$Z_{H2} = \sqrt{\frac{2 \cos(\delta_2)}{\sin(2\alpha)}} = \sqrt{\frac{2 \cos(56.3^\circ)}{\sin(2 \times 20^\circ)}} = 1,6$$

$$Z_M = 275 \text{ MPa}$$

$$d_1 = \frac{m_n \times Z_1}{\cos(\beta_n)} = \frac{1.5 \times 12}{\cos(35^\circ)} = 22 \text{ (mm)} \quad , \text{With module: } m_n = 1,5$$

$$d_2 = \frac{m_n \times Z_2}{\cos(\beta_n)} = \frac{1.5 \times 18}{\cos(35^\circ)} = 32 \text{ (mm)} \quad , \text{Helix angle: } \beta_n = 35^\circ$$

$$T_1 = \frac{M_2}{u} = \frac{223}{1.5} = 149 \text{ (N.mm)}$$

$$T_2 = \frac{F \times p}{2\pi} = \frac{280 \times 5}{2\pi} = 223 \text{ (N.mm)}$$

$K_{Hv} = 1,1 \div 1,3$: **Dynamic load factor** (refer to textbook, page150):

$K_{H\beta} = 1$: **Load distribution factor** for uneven load distribution (refer to Table 10-15, textbook page 148)

$$b_1 = \Psi_d \cdot m_n \cdot Z_1 = 0.3 \times 1,5 \times 12 = 7.2 \text{ (mm)}$$

$$b_2 = \Psi_d \cdot m_n \cdot Z_2 = 0.3 \times 1,5 \times 18 = 10.8 \text{ (mm)}$$

Tooth face width $\Psi_d = 0.3 \div 0.6$

Contact stress strength of the straight bevel gear on the driving gear

$$\sigma_{H1} = \frac{1.6 \times 275}{22} \times \sqrt{\frac{2 \times 149 \times \sqrt{1,5^2 + 1} \times 1 \times 1,3}{0,85 \times 7,2 \times 1,5}} = 174 \text{ (N/mm}^2\text{)}$$

$$\sigma_{H1} = 174 \times K_t = 174 \times 2 = 348 \left(\frac{N}{\text{mm}^2} \right)$$

Với $K_t = 1,5 \div 2,5$: Factor of safety

$$\Rightarrow \sigma_{H1} = 348 \left(\frac{N}{\text{mm}^2} \right) \leq [\sigma_{H1}] = 360 \text{ (N/mm}^2\text{)}$$

Contact Stress Strength on the Straight Bevel Gear (Driving Gear)

$$\sigma_{H2} = \frac{1.6 \times 275}{32} \times \sqrt{\frac{2 \times 223 \times \sqrt{1,5^2 + 1} \times 1 \times 1,3}{0,85 \times 10.8 \times 1,5}} = 119 \text{ (N/mm}^2\text{)}$$

$\sigma_{H2} = 119 \times K_t = 119 \times 2 = 238 \left(\frac{N}{\text{mm}^2} \right)$ Với $K_t = 1,5 \div 2,5$: Hệ số an toàn

$$\Rightarrow \sigma_{H2} = 238 \left(\frac{N}{\text{mm}^2} \right) \leq [\sigma_{H1}] = 340 \text{ (N/mm}^2\text{)}$$

Bending Strength Check for the Straight Bevel Gear Transmission

$$\sigma_{F1} = \frac{2 \cdot T_1 \cdot K_{Fb} \cdot K_{Fv} \cdot Y_{F1}}{0,85 \cdot b \cdot d_1 \cdot m_n}$$

Where: $T_1 = \frac{M_2}{u} = \frac{223}{1.5} = 149 \text{ (N.mm)}$

$$T_2 = \frac{F \times p}{2\pi} = \frac{280 \times 5}{2\pi} = 223 \text{ (N.mm)}$$

$$K_{Fb} = 1,1$$

$$K_{Fv} = 1,1 \quad \text{(Load variation factor – from Table 10-14)}$$

$$Y_{F1} = Z_{td1} = \frac{12}{\cos(33.7^\circ)} = 11.4 \text{ mm} \quad : \text{Tooth form factor}$$

$$Y_{F2} = Z_{td2} = \frac{18}{\cos(56.3^\circ)} = 32 \text{ mm} \quad : \text{Tooth form factor}$$

$$m_n = 1.5 \quad : \text{Module}$$

Bending Strength of the Driving Straight Bevel Gear:

$$\sigma_{F1} = \frac{2 \times 149 \times 1,1 \times 1,1 \times 11,4}{0,85 \times 7.2 \times 22 \times 1.5} = 20 \text{ (N/mm}^2\text{)}$$

$$\sigma_{H1} = 20 \times K_t = 20 \times 2,5 = 50 \text{ (N/mm}^2\text{)},$$

Với $K_t = 1,5 \div 2,5$: Factor of Safety

Bending Strength of the Driven Straight Bevel Gear:

$$\sigma_{F2} = \frac{2 \times 223 \times 1,1 \times 1,1 \times 32}{0,85 \times 10.8 \times 32 \times 1.5} = 39 \text{ (N/mm}^2\text{)}$$

$$\sigma_{H1} = 39 \times K_t = 39 \times 2,5 = 78 \left(\frac{\text{N}}{\text{mm}^2} \right)$$

Với $K_t = 1,5 \div 2,5$: Factor of Safety

⇒ Both the contact and bending stresses during operation are lower than the allowable stresses of the materials used for the gears. The safety factors meet mechanical design standards.

⇒ The size and transmission ratio of the bevel gear set are suitable for the required translational movement of the threaded shaft, allowing flexible and accurate height adjustment.

Forces Acting on Shaft and Bearings:

Lực tiếp tuyến:

$$F_t = \frac{2T}{d} = \frac{2 \times 149}{22} = 13,5 \text{ (N)}$$

Lực dọc trục và lực hướng tâm:

$$F_{r1} = F_{a2} = F_t \times \tan(\alpha) \times \cos(\delta_1) = 13.5 \times \tan(20^\circ) \times \cos(33.7^\circ) = 4,8 \text{ (N)}$$

$$F_{r2} = F_{a1} = F_t \times \tan(\alpha) \times \cos(\delta_2) = 13.5 \times \tan(20^\circ) \times \cos(56.3^\circ) = 2.7 \text{ (N)}$$

Góc ăn khớp: $\alpha = 20^\circ$

In bevel gear transmission systems, when gears engage, axial and radial forces are small due to the use of a handwheel only when adjusting the load. Thus, the solution is to select deep groove ball bearings with housing for easy installation, compact structure, and convenient maintenance.

⇒ Selected bearing housing type: **Deep groove ball bearing with housing UCP204-22**



Figure 3.9 Groove-type bearing housing [Source: Internet]

Table 3 – UCP204-22 Pillow Block Bearing Parameters[5]

Model	d	D mm	B mm	T_{max} mm	r	r ₁	d ₂	D ₂	Ball Diameter	C	Q_{lm} , (daN)
UCP204-22	22	47	14	14.8	1	0.6	33.7	33.7	7.9	9850	5200

Operating angle: 0°

Basic dynamic load rating (C) is calculated using the formula:

$$C = Q \cdot (nh)^3 \leq C_{table}$$

Where: h=16000, Total operating hours over 3 years

n = 1 Very low speed (1 rpm) due to infrequent use

Corresponding load is calculated using the formula:

$$Q = (K_v \cdot R + m \cdot A_t) \cdot K_n \cdot K_t (2,7 + 4,8) \times 1 = 7,7 \text{ (N)}$$

Factors used: m = 1

$K_v = 1$: Inner ring rotates

$K_n = 1$: Operating temperature below 100°C

$K_t = 1$: Static load

$A_t = 4,8 \text{ N}$: Axial force

$R = 2,7 \text{ N}$: Radial force

Working capacity coefficient: $C = Q \cdot (nh)^3 = 7,7 \times 16000^{0.3} = 140$

Since: $C \leq C_{bang}$, The UC204-22 bearing meets the required conditions..

⇒ Select the UCP204-22 type pillow block with deep groove ball bearing, using two bearing units to support the shaft of the straight bevel gear driving mechanism.

CHAPTER IV: CALCULATION AND DESIGN IMPROVEMENT OF THE MACHINE MECHANISM

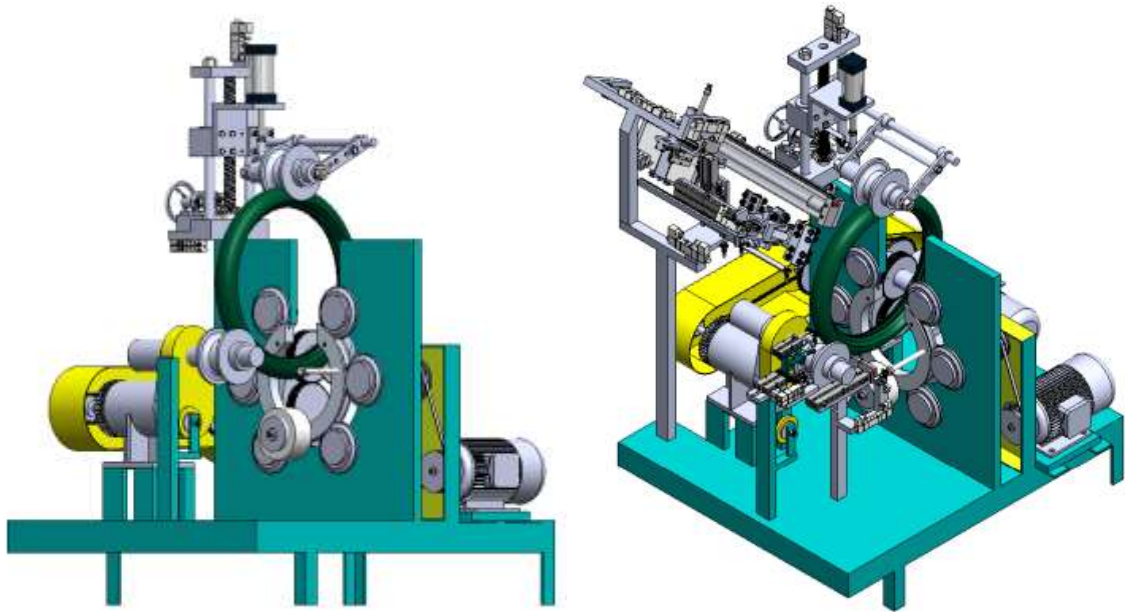


Figure 4.1 Model before and after SolidWorks design

4.1 Design of the Holding and Releasing Mechanism for the Wrapping Tape

4.1.1 Survey and Problem Analysis

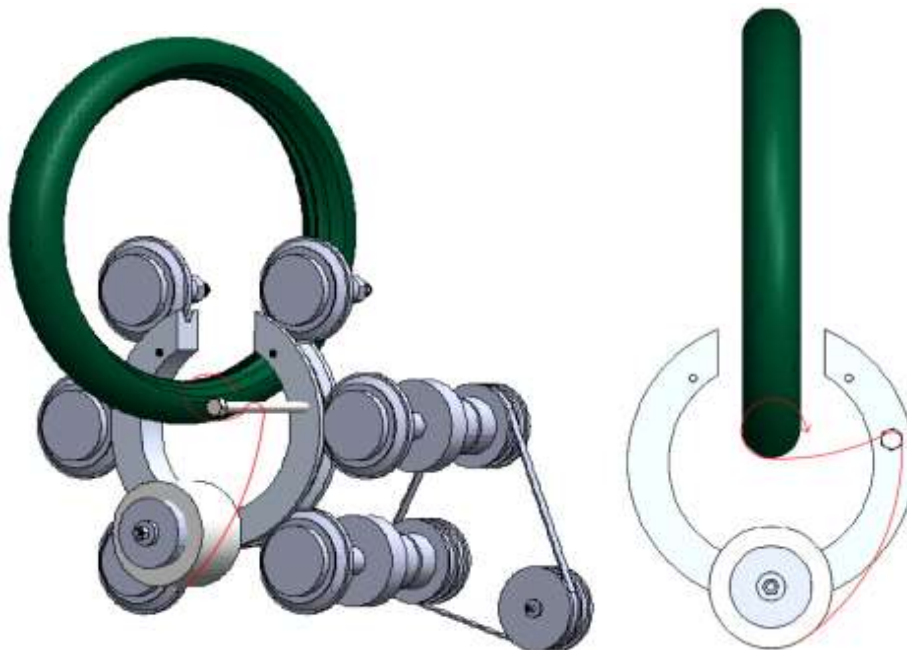


Figure 4.2 3D and 2D PE wrapping film in SolidWorks

Currently, in each cycle of wrapping PE film around motorcycle tires, workers must manually perform several repetitive tasks, which consumes time and reduces operational efficiency.

- The PE film roll has a diameter of approximately 150 mm and is mounted on a rotating frame (wrapping ring). The roll has a width of 65 mm.
- In each cycle, the worker must manually pull the end of the PE film, loop it around the tire from bottom to top, and then press the start (RUN) button for the motor to begin rotating and wrapping.
- After completing one wrap, the worker must use a manual cutter to cut the film before removing the tire from the machine.
- The total time required for loading the tire, threading the PE film, and manually cutting the film takes around 3–4 seconds per cycle, which results in time waste—especially during continuous operation on a production line.

4.1.2 Improvement Goals for the Tape Holding and Releasing Process

The main goal is to fully automate the holding and releasing of the PE film to:

- Eliminate the need for workers to manually loop the film around the tire.
- Reduce manual handling time and thereby increase overall system productivity.

Specific improvement objectives:

- When the worker places the tire in position and presses the RUN button, within approximately 0.5–1 second, the system will automatically release the PE film to begin wrapping.
- After the wrapping is complete, the motor stops, and the system will automatically cut the film and clamp the film end, preparing it for the next cycle.
- The worker only needs to remove the wrapped tire and insert a new one, then press the button to repeat the cycle.

4.1.3 Concept and Design Proposals

To achieve the above goals, the team proposes two design solutions for an automatic mechanism that can release and clamp the PE film, fully replacing the manual tasks of placing and cutting the film with automated film handling and cutting.

➤ First Proposal:

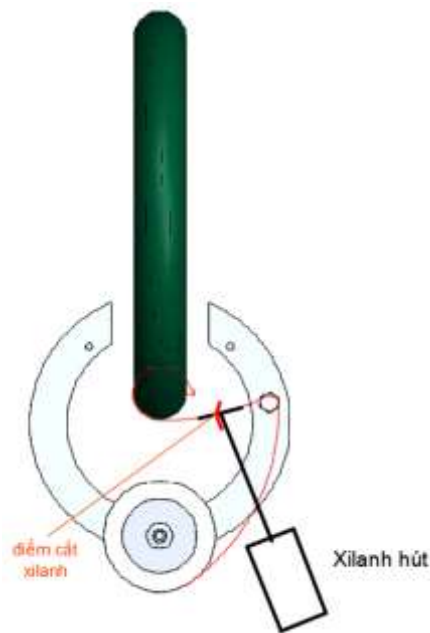


Figure 4.3 First option for PE wrapping film selection

Use a cylinder that moves forward to suction and hold the wrapping tape, then activate another cylinder to cut the tape, and finally retract to hold the tape. When the RUN button is pressed, after 1 second, the motor starts rotating and the tape is released.

→ This method lacks high precision because using a suction valve may result in loss of suction pressure, and operating two cylinders simultaneously can lead to synchronization issues. Therefore, this is not considered an optimal solution.

➤ Second Proposal:

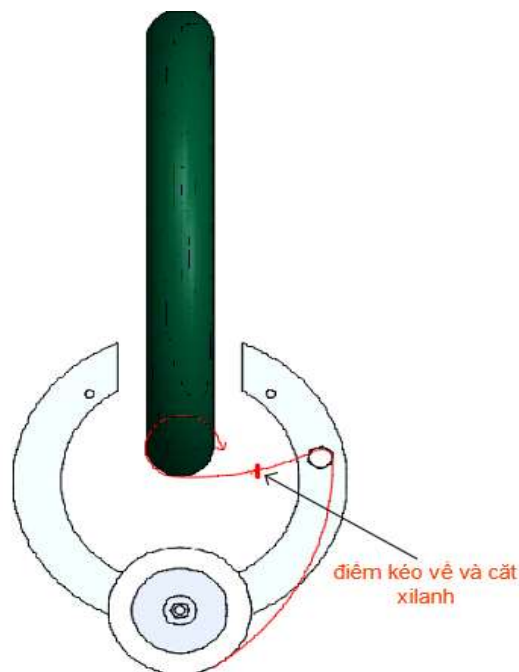


Figure 4.4 Second option for PE wrapping film selection

The design approach for the automatic PE film holding mechanism is based on a cylinder clamping system. → After pressing the RUN button, the PE film wrapping motor drives the rotating ring for a few rotations (approximately 0.5 seconds). → Then, 0.5 seconds after the RUN button is pressed, the cylinder advances by 1 cm (triggered by a proximity sensor) and stops (using a 5/3 solenoid valve with a mid-stop position) to release the PE film. → The process continues through the wrapping steps... → Once both motors stop, Cylinder A1 moves forward to the end of its stroke. → The PE film motor then rotates at a low speed (controlled by an inverter)—when a proximity sensor detects an object on the rotating ring, the motor stops. → Cylinder A1 retracts and, upon touching a magnetic sensor, clamps the PE film tightly. → The tire motor begins to rotate (as the line has not yet ended); a blade mounted at the tip of Cylinder A1 is used to cut the PE film thanks to the rotational force from the tire. → (Through other intermediate stages...) → The process ends → The cycle begins again when the worker places a new tire between the two rotating shafts → ...

4.1.4 Design Option Selection: Chosen Option – Proposal 2

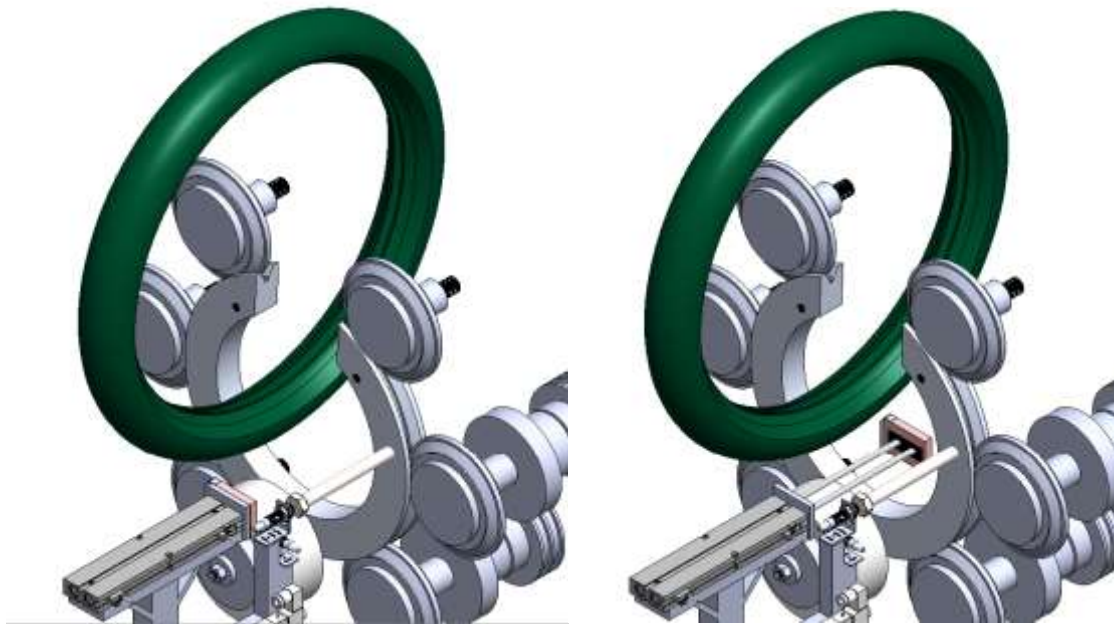


Figure 4.5 PE film clamping and releasing mechanism before and after

Advantages:

- Only one cylinder is used → simple, cost-effective, and easy to control.
- The mechanism has high repeatability and greater accuracy thanks to the use of limit sensors at both forward and backward positions, combined with a proximity sensor that detects the object at the correct stopping point (bolt position).
- No vacuum suction is used, which eliminates the risk of suction failure and avoids dependence on airtight conditions.
- The structure is simple, easy to manufacture, easy to maintain, and has low mechanical error due to being purely mechanical.

- Significantly reduces the risk of errors during operation → increased reliability.

4.1.5 Working Procedure:

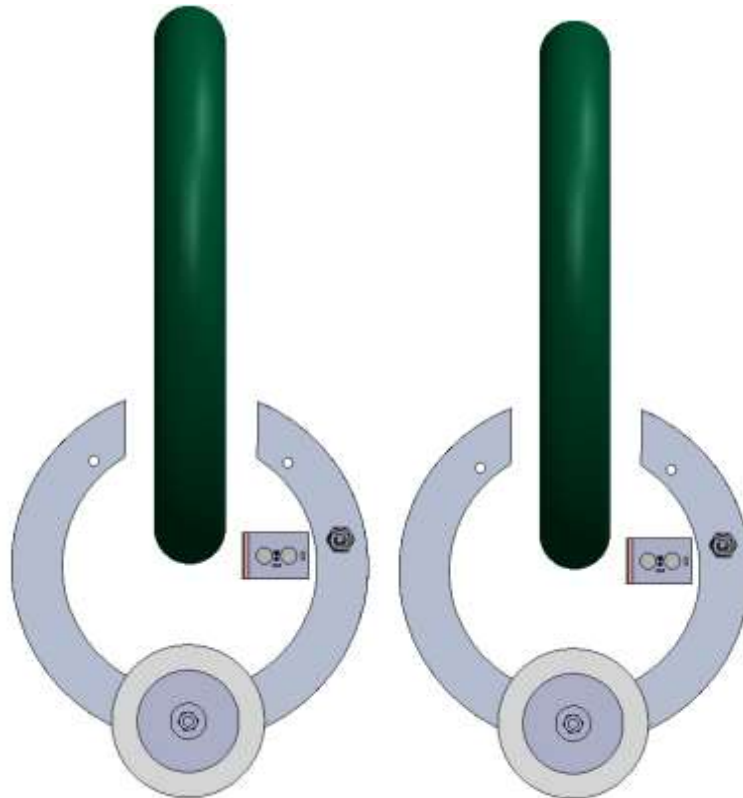


Figure 4.6 Motor stop position before and after cutting PE film

Initially, the PE wrapping film is tightly clamped at the end of the cylinder's stroke → The cycle starts by pressing the RUN button, causing the PE film wrapping motor to drive the rotating ring for a few turns (about 0.5 seconds) → After 0.5 seconds from pressing RUN, the cylinder advances 1 cm (signaled by a proximity sensor) and then stops (using a 5/3 solenoid valve with mid-stop position) to release the PE film → Other steps follow... → When both motors stop, Cylinder A1 moves to its forward end position → The PE wrapping motor continues to rotate at low speed (controlled by a frequency inverter); when the proximity sensor detects an object on the rotating ring, the motor stops → Cylinder A1 retracts until it touches a magnetic sensor and clamps the PE film tightly → The tire-rotating motor turns the tire (still on the line), and the rotation force causes the blade mounted on the tip of Cylinder A1 to cut the film → (other stages follow) → Process ends → The cycle restarts when the worker places a new tire between the two rotating shafts → ...

4.1.6. Cylinder Design and Selection

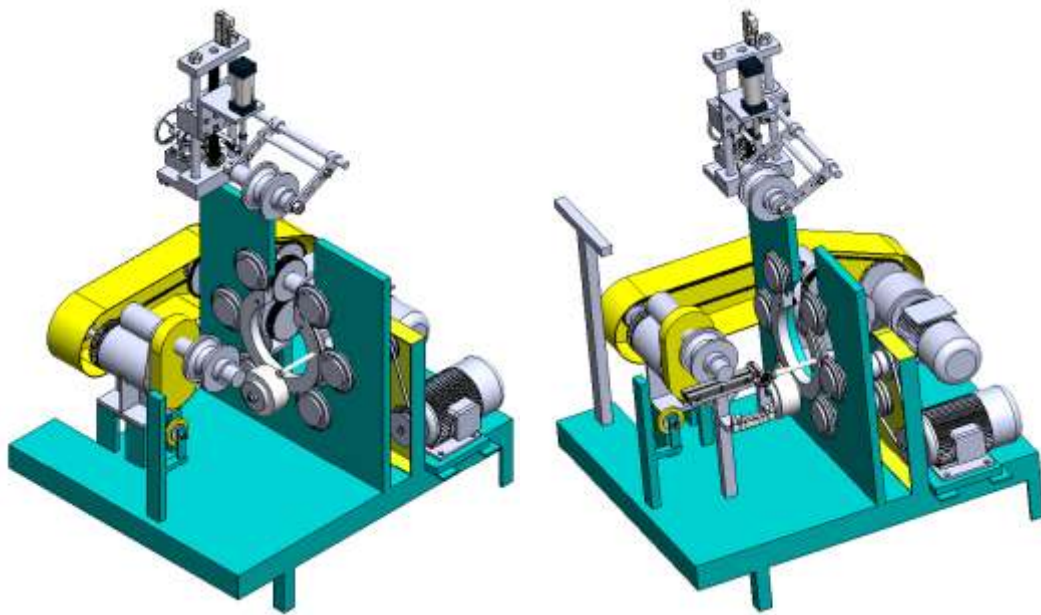


Figure 4.7 Model before and after designing PE film holding and cutting mechanism

Purpose of Using a Cylinder in the Machine Mechanism:

To create a linear motion for the film-cutting blade and the clamping fixture of the film strip.

To perform precise forward–backward movements to:

- Clamp the film strip tightly when the cylinder retracts.
- Hold the film at a fixed position.
- Assist in tensioning the film before the blade performs the cutting operation.

Operational Requirements for the Cylinder:

- Direction of movement: Parallel to the rotation direction of the wrapping ring.
- Applied load: Very small, since the mechanism mounted on the cylinder head only carries a small cutting blade and a lightweight fixture—no heavy objects or significant resistance.
- No long-term force holding required (unlike clamping cylinders).
- Speed and accuracy: Medium to high; requires precise positioning to cut at the correct timing.

Cylinder Size Selection Method:

Since the load is very small, it's unnecessary to calculate the pushing force in detail (i.e., using $F = P \times A$). Instead, the selection is based on:

- Actual stroke length (distance from the standby position to the cutting position).
- Machine installation space (compact design that avoids interference with rotating mechanisms).

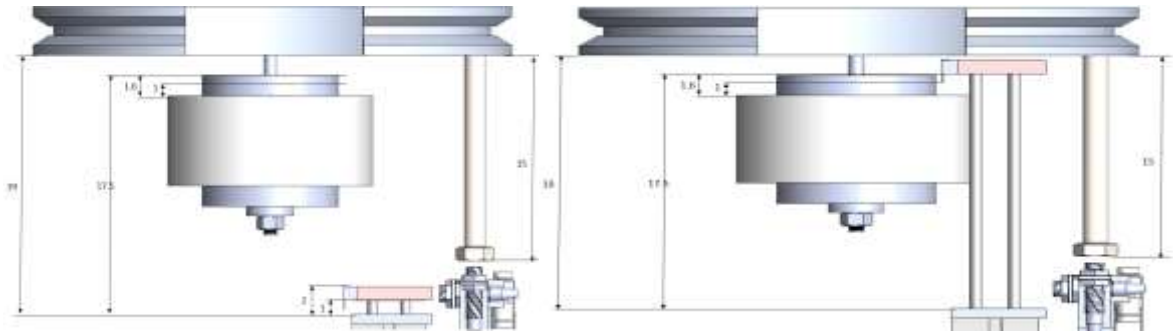


Figure 4.8 Start and end stroke positions of cylinder in PE film holding and cutting mechanism

Cylinder Diameter: $D = 16 \text{ mm}$

Stroke Length: $L = 175 \text{ mm} = 0,175 \text{ m}$

Compressed Air Pressure: $p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$

Piston Surface Area: $A = \pi \times \left(\frac{D}{2}\right)^2 = 200 \text{ mm}^2 = 0,0002 \text{ m}^2$

Maximum Thrust Force of the Cylinder (F): $F = p * A = 0.6 * 200 = 120 \text{ N}$

Equivalent Mass Load: $P = \frac{F}{g} = \frac{120}{10} = 12 \text{ Kg}$

Desired Time to Complete Full Stroke: $t = 0,5 \text{ s}$

\Rightarrow Cylinder Extension Velocity: $v = \frac{L}{t} = \frac{0,175}{0,5} = 0,35 \text{ m/s}$

Cylinder Extension Velocity (Alternative Calculation):: $v = \frac{Q}{A}$

Required Air Flow Rate to Control the Cylinder:

$$\Rightarrow Q = v \times A = 0,35 \times 0,0002 = 0,7 \times \frac{10^{-4} \text{ m}^3}{\text{s}} = 4,2 \text{ l/phút}$$

Selected Cylinder: Pneumatic guided cylinder, parallel type – Model: TN16-175



Figure 4.9 Cylinder for holding and cutting PE film [Source: Internet]

Stroke length: 175 mm – suitable for the required movement range. Cylinder diameter: 16 mm – provides sufficient force for cutting and clamping. Dual guide rods – help prevent rotation and ensure stability when attaching a cutting blade or fixture. Compatible with proximity sensors – for precise control and positioning.

Table 4 – TN16-175 Cylinder Parameters[6]

Parameter	Specification
Cylinder Model	TN16-175
Piston Diameter (Bore)	16 mm
Working Stroke	175 mm
Type of Actuation	Double Acting
Guide Rods	2 parallel guide rods
Working Pressure	0.1 ~ 1.0 MPa (1 ~ 10 bar)
Maximum Pressure	1.2 MPa
Operating Temperature	-20°C ~ 80°C
Operating Speed	30 ~ 500 mm/s
Working Medium	Compressed air (dry or lightly lubricated)
Air Connection Port	M5 × 0.8

4.1.7: Mechanism and Components of Phase 1 (Holding and Releasing the Wrapping Tape Mechanism)

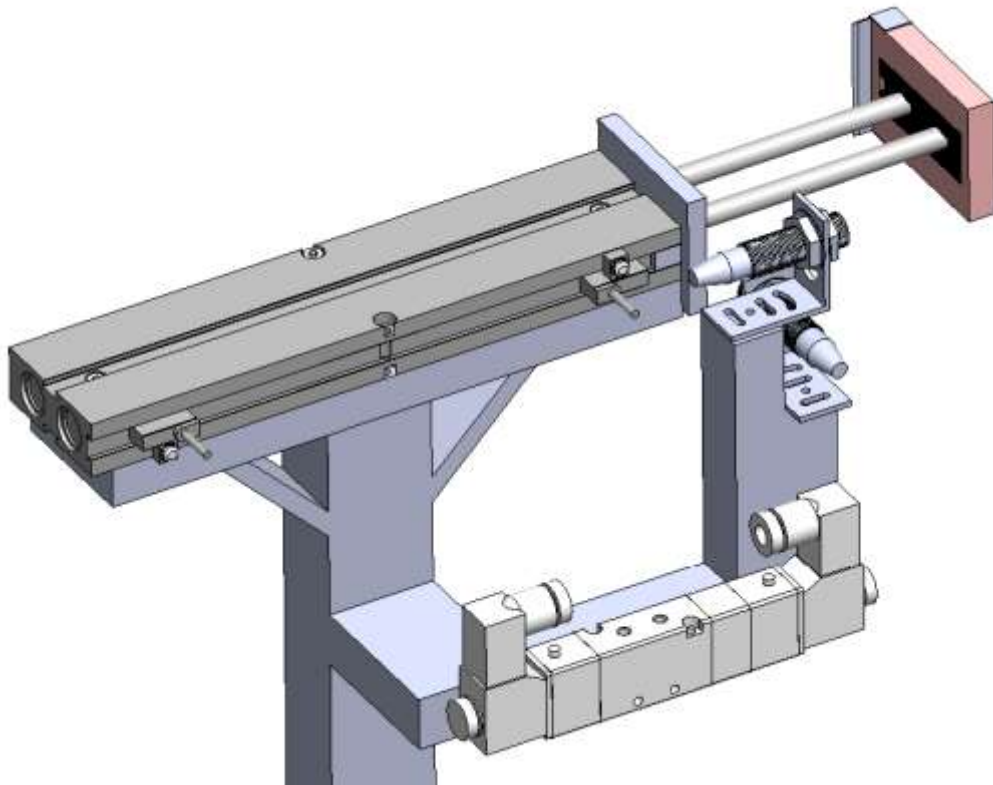


Figure 4.10 PE film holding and cutting mechanism in SolidWorks

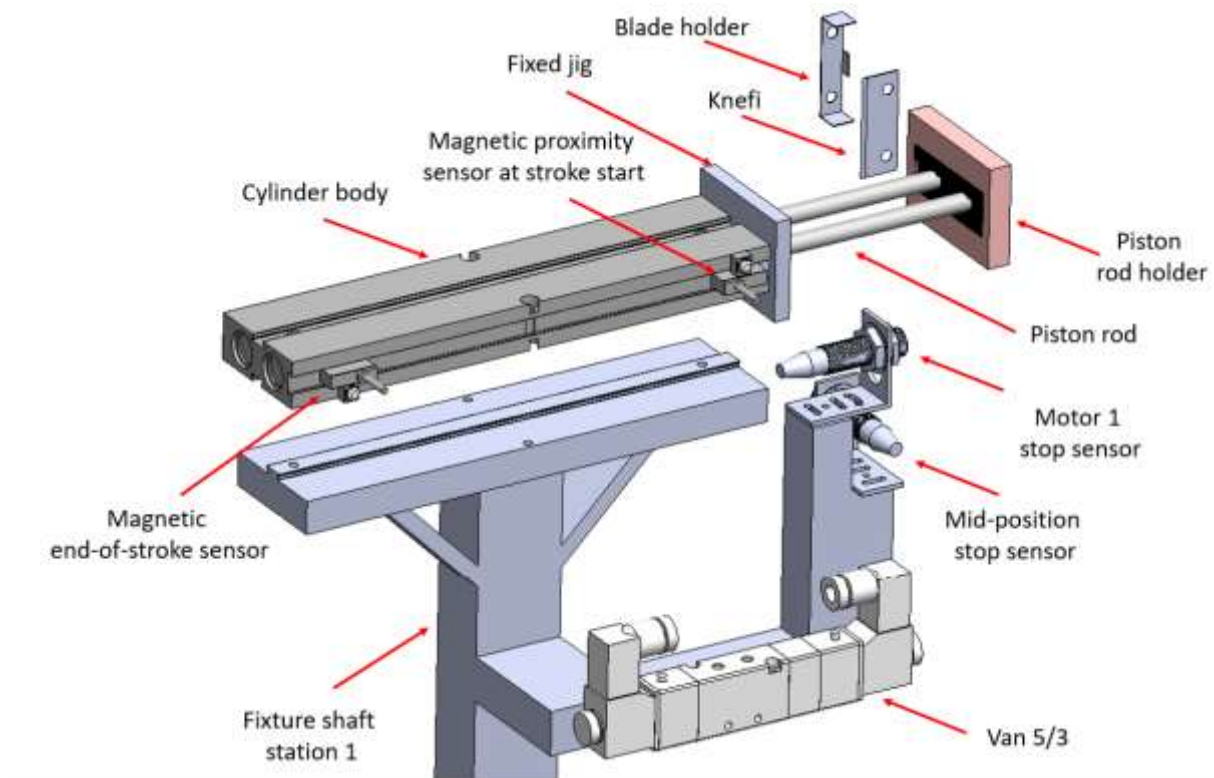


Figure 4.11 Components in PE film holding and cutting mechanism

Table 5 – Components of the PE Film Holding and Cutting Mechanism

Component	Material	Function
Shaft for Holding & Cutting Mechanism	Steel	Structural shaft for mounting holding and cutting components
5/3 Solenoid Valve	Aluminum alloy	Sends electrical signals to control the advance/return movement of the cylinder
Cylinder Body	Aluminum alloy	Main body of the pneumatic cylinder
Piston Rod	Steel	Transmits force from cylinder to external components
Piston Rod Bracket	Steel	Fixes the piston rod end and increases contact area with PE film holding bracket
Holding Bracket	Steel	Connects with piston rod bracket to tightly clamp the PE film
Cutter Blade	Steel	Cuts the PE film
Blade Holder	Steel	Mounts the blade onto the piston head

End-Stroke Magnetic Sensor (AIRTAC DMSJ-N020)		Detects when piston reaches the end position; mounted on cylinder body due to limited space
Return-Stroke Magnetic Sensor (AIRTAC DMSJ-N020)		Detects when piston completes return stroke; also mounted on cylinder body
Mid-Stroke Sensor (Autonics PRDL12-8DN)		Proximity sensor to stop the cylinder at 1 cm position for PE tape release
Motor Stop Sensor (Proximity Type)		Detects shaft position on wrapping ring; stops the motor when detected (detection range ~0.5 cm)

4.2. Design of the Line Taping and Cutting Mechanism

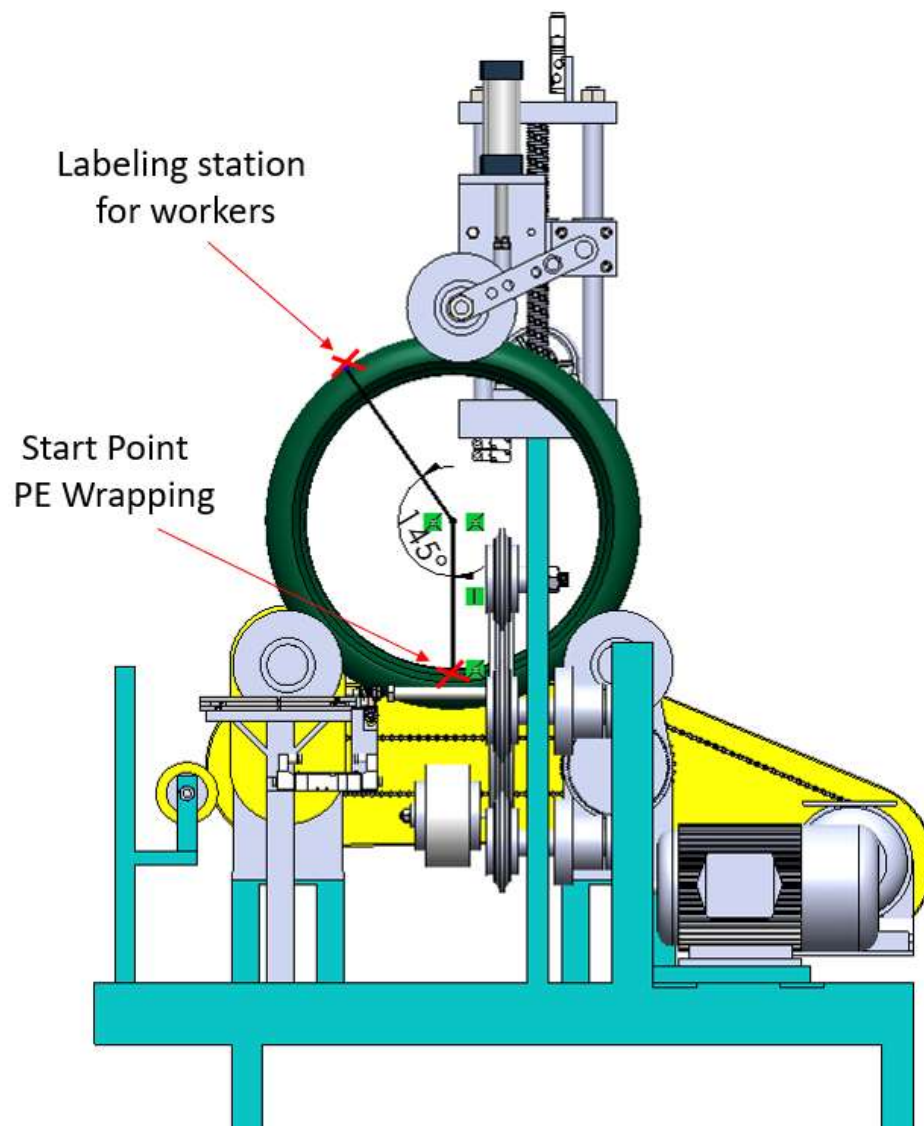


Figure 4.12 Survey of actual line sticking points

4.2.1 Survey and Problem Analysis:

Currently, in the PE film wrapping process for motorcycle tires, an essential step to ensure that the film does not unravel is applying a strip of tape, 2 cm in width, to the center of the tire.

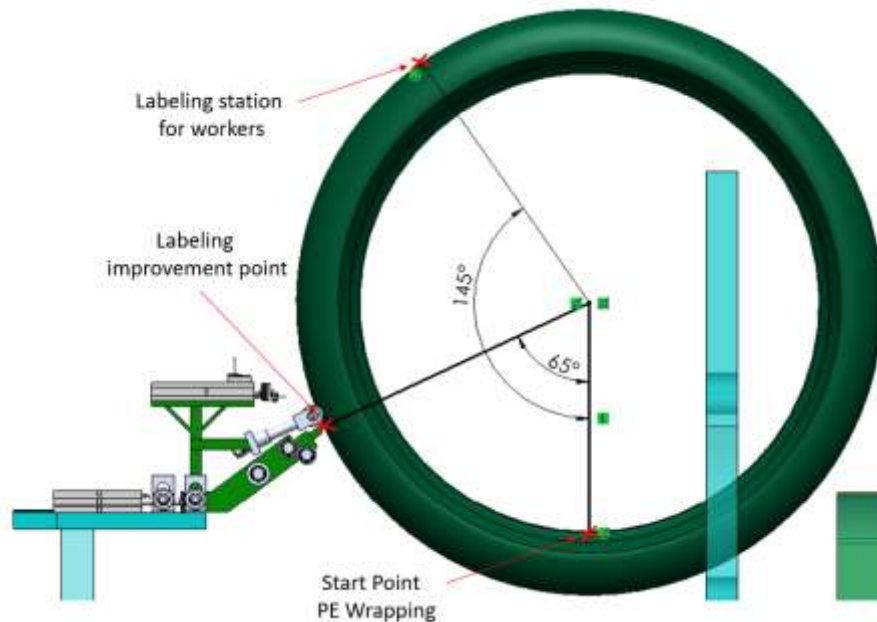


Figure 4.13 Comparison of line sticking points between worker and improved design

Current Process:

- When the tire has been wrapped with about one portion of the PE film (approximately 4 seconds after pressing the start button), the worker manually pulls a 2 cm wide tape and sticks it onto the center of the tire surface.
- After the motor stops rotating, the worker manually rotates the tire to continue applying the tape around the entire circumference.
- Finally, the worker uses a manual knife to cut the tape, completing the step of securing the film.

This process is repeated for each tire, resulting in time consumption and a high dependency on manual labor. The current limitations include:

- Manual operations are time-consuming (rotating the tire, pulling the tape, cutting the tape).
- Inconsistent tape application quality, depending on the worker's experience.
- Difficulty in precisely controlling the start/end positions of the tape.
- Errors such as off-center placement, insufficient coverage, or overlapping edges are likely to occur.

4.2.2 Improvement Objectives:

To enhance productivity and automate this stage, the team has set specific improvement goals:

- Minimize manual labor, especially in the tire rotation and tape application steps.
- Shorten the production cycle time, reducing the time required per tire and increasing the number of output products per shift.
- Improve the precision and consistency of the tape application to ensure all products meet the same aesthetic and technical standards.
- Reduce operational errors, especially human-related issues like misaligned tape, incomplete adhesion, or incorrect cutting positions.

4.2.3 Proposed Design Improvement Plan:

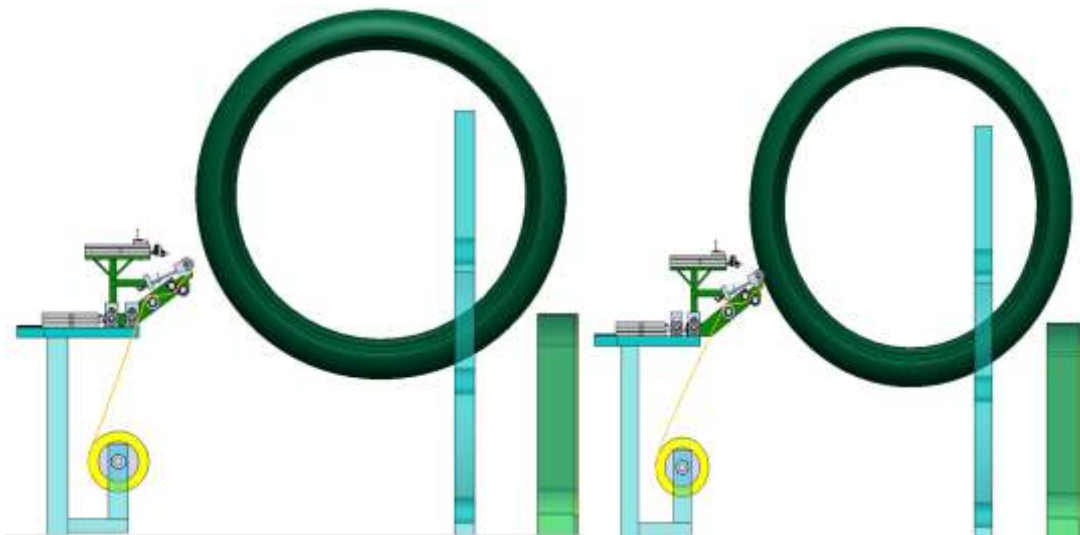


Figure 4.14 Line sticking mechanism before and after applying the line

Guiding and Aligning the Tape Line:

- A 2 cm wide tape line is fed from a supply roll, passing through the first roller made of non-stick material to shape the tape and prevent displacement during movement.
- Next, the tape passes through a pair of friction rollers, which hold and stabilize the tape to prevent slippage or misalignment during operation.
- The tape is then guided through a directional groove, leading it directly to the contact point with the outer surface of the tire.

Phase 1: Applying the Tape to the Tire:

- A pneumatic cylinder controls the mechanism that presses the tape line onto the tire surface.

- When the cylinder reaches the end of its stroke (proximity sensor at the forward end sends a signal), the tape's leading edge makes contact with the tire.
- At the same time, a spring-loaded roller moves forward and presses the tape firmly against the tire, ensuring strong and even adhesion to prevent peeling during rotation.

Phase 2: Cutting the Tape Line:

- After taping is complete, the cylinder retracts to its initial position (proximity sensor at the rear end sends a signal).
- The tape-holding mechanism remains in place, creating a slight tension between the taped portion on the tire and the remaining tape held by the guide.
- At this moment, a cutting cylinder integrated into the same mechanism is activated, moving swiftly and decisively to cut the tape.

→ A sharp blade and a fast cylinder ensure a clean, precise cut without pulling or misalignment.

Preparation for the Next Cycle:

Once the cutting cylinder completes the cut, the remaining 2 cm end of the tape stays outside the guiding groove, resting on the pressing roller.

This structure remains fixed, ensuring the following benefits:

- The tape is always ready for the next cycle without requiring manual handling by the worker.
- Cycle preparation time is minimized for each repetition.
- The tape stays in the correct position to start the next application quickly and accurately as the taping cylinder advances again.

❖ Tape Position Analysis and Process:

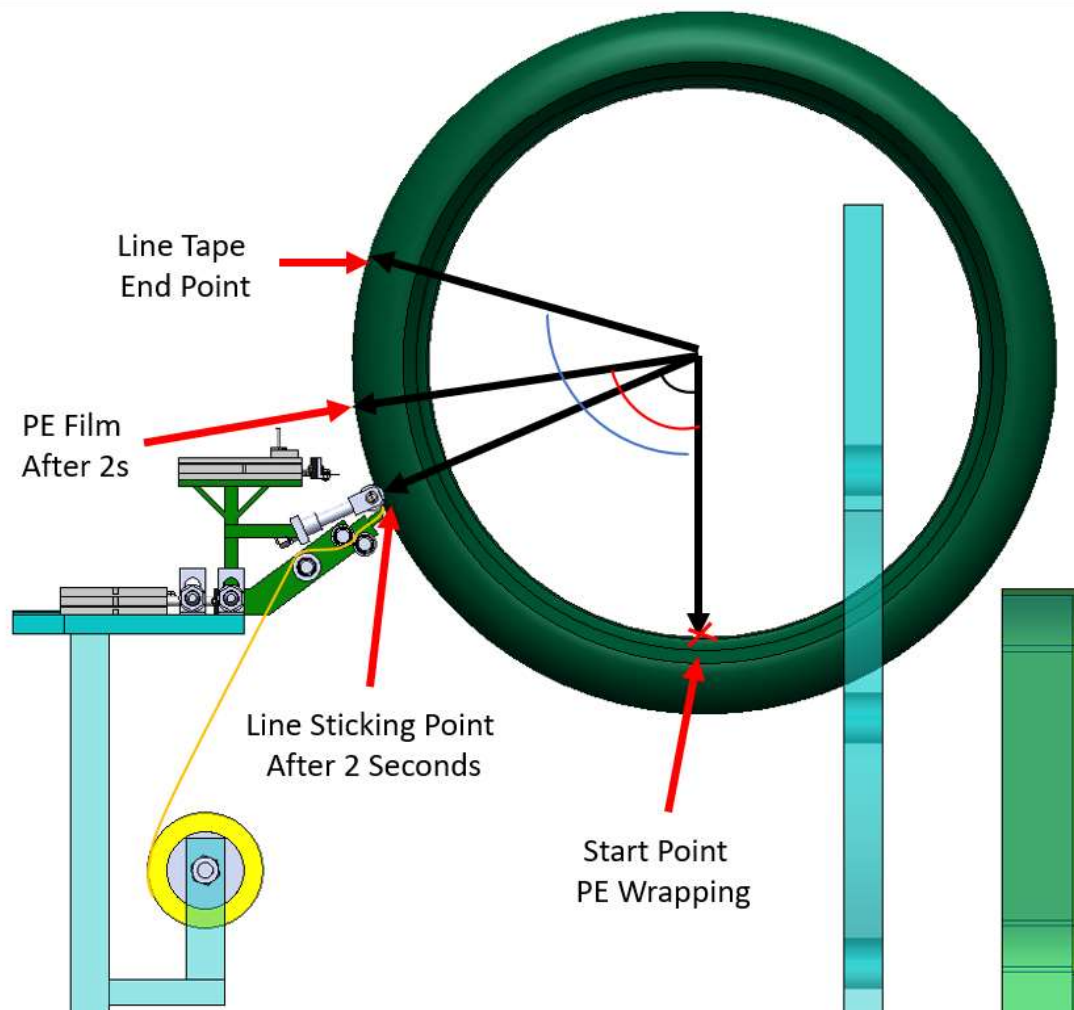


Figure 4.15 Coordinates of operating points after improvement

Approximately 2 seconds after pressing the RUN button, the tire is wrapped until it reaches an angle of 80° . At this point, cylinder A2 advances to apply the tape onto the tire (a proximity sensor at the end of the stroke sends a signal), and the tape is pressed against the tire surface by an accompanying roller. → (Other intermediate stages take place) → When both motors stop (the tape has been applied up to an angle of 40°), and after the PE wrapping film is cut, a signal is sent by a sensor. → The tire motor rotates for another 1.5 seconds, bringing the tape application angle to 100° → Then, the tape application cylinder (A2) retracts, confirmed by a proximity sensor → Next, cylinder A3 advances to cut the tape (a signal is sent by a proximity sensor at the end of the stroke). → Finally, cylinder A3 retracts to its original position.

4.2.4 Components, Structure, and Process

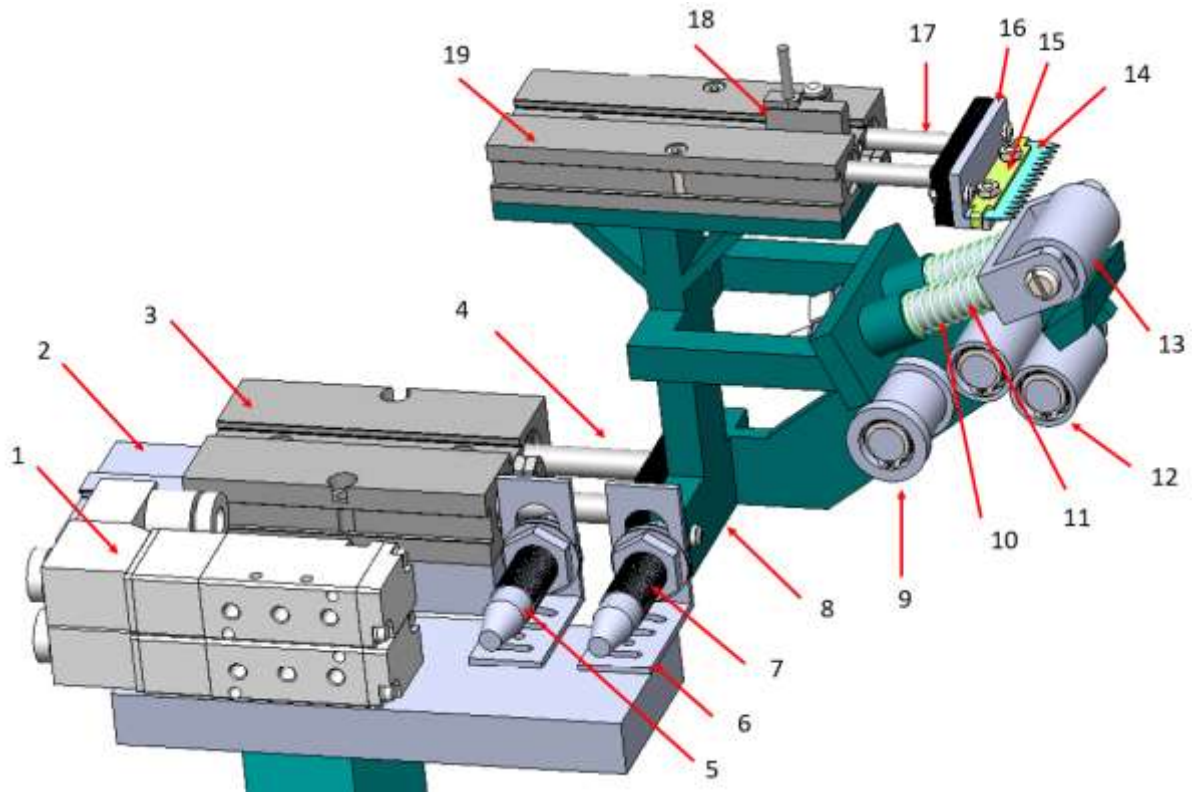


Figure 4.16 Components of the line sticking mechanism

Table 6 – Components of the Line Applying and Cutting Mechanism

No.	Component	Material	Function
1	Solenoid valve 5/2	—	Controls the extension and retraction of the cylinder via electric signals
2	Mounting base	—	Mounts the entire tape applying and cutting mechanism
3	Cylinder body	Metal	—
4	Piston rod (applying)	Aluminum alloy	—
5	Proximity sensor (front)	—	Detects the front end of the cylinder stroke
6	Sensor bracket	Steel	Holds the sensor in place
7	Proximity sensor (rear)	—	Detects the rear end of the cylinder stroke
8	Tape mechanism bracket	Steel	Holds the entire tape applying and cutting mechanism

9	Guide roller	Steel	Shapes the tape and prevents shifting
10	Line pressing roller shaft	Steel	Presses the tape against the tire surface
11	Spring	Steel	Provides elasticity to the roller shaft
12	Friction roller	Steel	Holds the tape firmly
13	Press roller	Steel	Presses the tape onto the tire with friction
14	Serrated blade	Steel	Cuts the tape
15	Blade clamp	—	Fixes the blade in place
16	Blade holder	—	Provides extra area for mounting the blade
17	Piston rod (cutting)	—	—
18	Proximity sensor	—	Detects the end of the cylinder stroke
19	Cylinder body	—	—

4.2.4.1 Design of the Line Interruption Mechanism

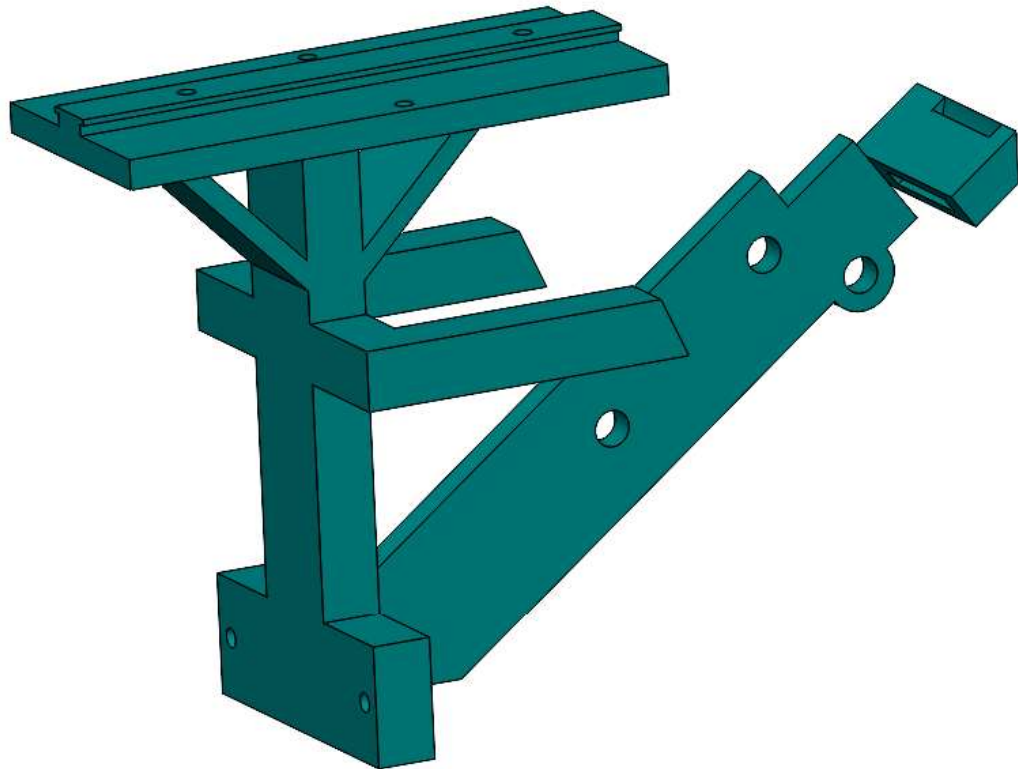


Figure 4.17 Actuation mechanism of the line sticking unit

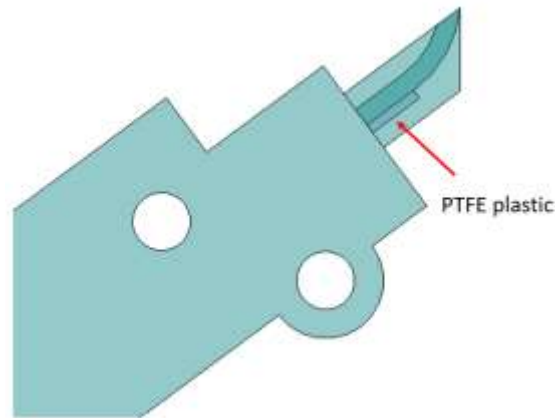


Figure 4.18 Output of the line sticking mechanism

The actuator mechanism of the line-taping cylinder features a curved tape outlet, with half of the surface covered by a non-stick PTFE plastic sheet to prevent the tape from sticking.

PTFE (Polytetrafluoroethylene) is a high-performance engineering plastic with an extremely low coefficient of friction, excellent non-stick properties, and strong chemical resistance. Due to its non-adhesive characteristics with most adhesives and molten plastics, PTFE is widely used as a coating or lining material in adhesive-related applications. Its surface prevents adhesives from sticking, allows easy cleaning, and can withstand high temperatures up to 260°C. This material is ideal for rollers, guiding channels, or contact surfaces exposed to adhesive tape during manufacturing processes.

4.2.4.2 Free-Forming Roller and Friction Roller

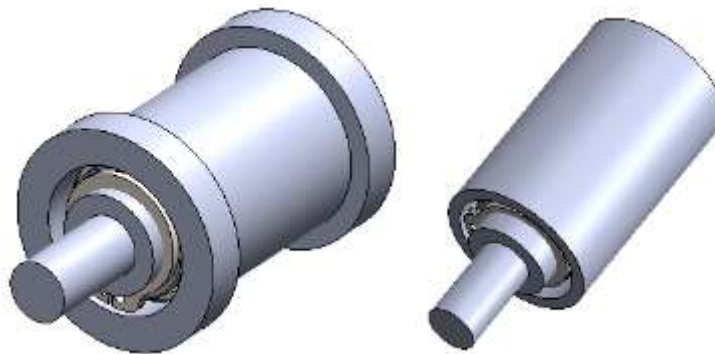


Figure 4.19 Free-forming roller and friction roller

Selection of Forming Roller and Friction Roller: Based on the actual design, the rollers are only used to convey the line tape at low speeds and are not subjected to heavy loads, so PTFE rollers are selected.

PTFE rollers are designed with either a coating or a full surface made of PTFE (Teflon) – a super non-stick material.

- Roller core: Made of stainless steel to ensure high strength and durability.

- Outer coating: Thin layer of PTFE (Teflon) – absolutely non-stick to adhesives and tapes.
- Bearing shaft: Precisely machined for smooth rotation, anti-vibration, and wear resistance.
- High heat resistance: Operates effectively at temperatures up to 260°C, suitable for hot-melt adhesives.
- Stable motion: The steel shaft and bearings ensure smooth and stable rotation even at high speeds.

4.2.4.3 Selection of Friction Roller for Tire Contact



Figure 4.20 Tire surface friction roller

In an automatic line taping system, the pressing roller plays a critical role in pressing the tape firmly onto the surface of the tire, ensuring consistent adhesion and preventing peeling during operation.

Roller Mechanism Design:

- The roller is mounted on two support shafts that can move freely up and down within elastic limits.
- Each support shaft is connected to a compression spring, generating elastic pressing force when the roller contacts the tire.
- When the taping cylinder pushes the line against the tire, the roller is also gently pressed onto the tire surface via the two springs, producing a uniform and flexible pressing force.

Assumed roller shaft diameter: 10 mm, outer diameter: 20 mm

Operating time: 16 hours per day over a period of 6 months

Load applied perpendicular to the roller shaft: $P = 80 \text{ N}$

Rotational speed: $n = 680 \text{ rpm}$

$$\omega = 2\pi \times \frac{n}{60} = 2\pi \times \frac{680}{60} = 71.24 \text{ rad/s}$$

Friction force:

$$F = \mu \times P = 0.8 \times 80 = 64N$$

Friction torque:

$$M = F \times r = 16 \times 0.05 = 0.32 Nm$$

Power consumption:

$$P = M \times \omega = 0.32 \times 71.24 = 22,8 W$$

Estimated total revolutions (lifetime): $680 \cdot 60 \cdot 2880 = 117504000$ revolutions

Proposed roller selection: Hardened C45 steel with a $\varnothing 10$ mm through-hole

- Outer diameter: 20 mm
- Inner bore: $\varnothing 10$ mm (sliding fit H7/g6 or with a bushing)
- Length: 32 mm
- Surface finish: Lightly ground (Ra 3.2–6.3 μm)
- Equipped with a bushing

Surface may be lightly knurled or coated with thin black oxide to enhance rubber grip

Table 7 – Friction Roller Parameters

Item	Specification
Roller Body Material	Hardened C45 steel
Roller Dimensions	Outer diameter $\varnothing = 20$ mm, Length = 32 mm
Bushing Dimensions	Outer $\varnothing = 14$ mm, Inner $\varnothing = 10$ mm, Length = 0.45 mm
Bushing Material	Copper alloy
Shaft	$\varnothing = 10$ mm, light sliding fit, lubricated
Target Lifespan	≥ 6 months, operating 16 hours/day
Rotational Speed	(Missing value) rpm — please provide to complete the table

4.2.4.4 Design of the Damping Spring for Tire Friction Roller

In the automatic line taping system, the pressing roller plays a critical role in firmly pressing the tape onto the surface of the tire, ensuring consistent adhesion and preventing peeling during operation.

The roller mechanism is designed as follows:

- The roller is mounted on two support shafts that can move freely up and down within an elastic range.
- Each support shaft is connected to a compression spring, which generates elastic pressing force when the roller contacts the tire.

- When the taping cylinder pushes the line tape onto the tire surface, the roller is also lightly pressed against the tire via the two springs, creating even and flexible pressure.

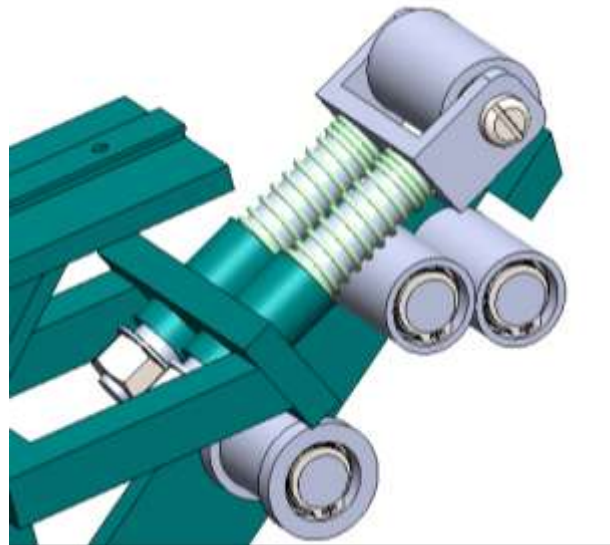


Figure 4.21 Damping spring for tire friction roller

Compression force per spring: $F = 40 \text{ N}$

Elastic deflection: $\Delta l = 7 \text{ mm}$

Inner diameter: $D_t = 10 \text{ mm}$

Free length: $l_0 = 30 \text{ mm}$

Material: 65Mn spring steel: $G = 79300 \text{ MPa}$

Tensile strength: $850 \div 1200 \text{ Mpa}$

Yield strength: $600 \div 1000 \text{ Mpa}$

Allowable shear stress: $346 \div 577 \text{ MPa}$

Selected wire diameter: $d = 1,8 \text{ mm}$

Mean diameter:

$$D = D_t + d = 11,8 \text{ mm}$$

Spring constant:

$$k = \frac{F}{\Delta l} = \frac{40}{7} = 5,7 \text{ N/mm}$$

Number of active coils:

$$n = \frac{G \times d^4}{8 \times D^3 \times k} = \frac{79300 \times 1,8^4}{8 \times 11,8^3 \times 5,7} = 11,1 \text{ turns}$$

Chosen number of active coils: $n = 12$

Check spring free length:

$$l_0 = (n + 2) \cdot d = (12 + 2) \cdot 1,8 = 25 \text{ mm}$$

Shorter than required \rightarrow increase number of coils

To achieve a free length of 30 mm, we select the number of active coils:

$n = 15$

$$\Rightarrow l_0 = (n + 2) \cdot d = 17 \cdot 1,8 = 30,6 \text{ mm}$$

$\Rightarrow n = 15$ is selected, as a slightly longer spring is acceptable due to the spring being compressed within the housing.

Spring index:

$$C = \frac{D}{d} = \frac{11,8}{1,8} = 6,5$$

Wahl correction factor:

$$K_w = \frac{4C - 1}{4C - 4} + \frac{0,615}{C} = 1,24$$

Shear stress on spring:

$$\tau = \frac{8 \cdot F \cdot D}{\pi \cdot d^3} \cdot K_w = \frac{8 \times 40 \times 11,8}{\pi \times 1,8^3} \times 1,24 = 255 \text{ MPa}$$

Chosen safety factor: 1,5: $\tau = 255 \times 1,5 = 383 \text{ MPa}$

$\Rightarrow \tau = 255 \text{ MPa} < \text{Allowable shear stress for 65Mn} \Rightarrow \text{Spring design is safe}$

4.2.4.5 Design and Selection of the Line-Pushing Cylinder

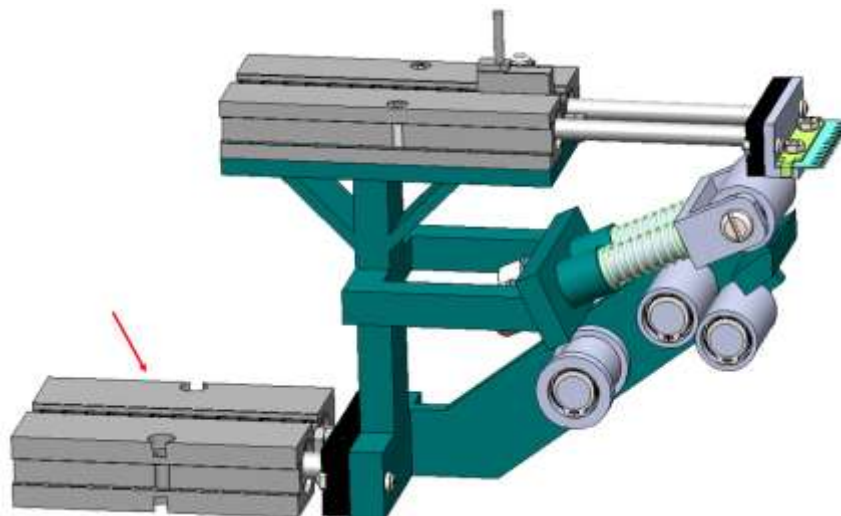


Figure 4.22 Line-pushing cylinder and line sticking mechanism

Based on the operating principle of the system, when the cylinder needs to move forward and press against the tire surface, the load acting on the actuator is primarily the weight of the entire mechanism. Therefore, the input load applied to the cylinder can be determined as follows:

Input load applied to the cylinder:

$$P = 1,55 \text{ kg} \Rightarrow F = P \times g = 1,55 \times 10 = 15,5 \text{ N}$$

\Rightarrow The cylinder must generate a pushing force $\geq 15.5 \text{ N}$ to ensure stable operation of the mechanism.

Stroke length: $S = 30 \text{ mm} = 0,03 \text{ m}$

Pneumatic pressure: $p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$

Minimum required piston area:

$$F = p \times A \Rightarrow A = \frac{F}{p} = \frac{15,5}{0,6} = 25,8 \text{ mm}^2$$

Piston diameter:

$$A = \pi \times \left(\frac{D}{2}\right)^2$$

$$\text{Minimum piston diameter} \Rightarrow D = \sqrt{\frac{4 \times A}{\pi}} = \sqrt{\frac{4 \times 25,8}{\pi}} = 5,7 \text{ mm}$$

\Rightarrow To ensure mechanical strength and reliability, a standard cylinder diameter of 10 mm is selected, larger than the calculated value, to increase the safety factor during operation.

Required time for the cylinder to complete the stroke: $t = 0,3 \text{ s}$

$$\Rightarrow \text{Piston extension speed: } v = \frac{L}{t} = \frac{0,03}{0,3} = 0.1 \text{ m/s}$$

Area with selected piston diameter

$$D = 10\text{mm: } S = \pi \times \left(\frac{D}{2}\right)^2 = \pi \times \left(\frac{10}{2}\right)^2 = 78,5 \text{ mm}^2$$

$$\text{Cylinder extension speed: } v = \frac{Q}{A}$$

Required air flow to operate the cylinder:

$$\Rightarrow Q = v \times A = 0,1 \times 0,00078 = 0,78 \times 10^{-6} \text{ m}^3/\text{s} = 0,47 \text{ l/phút}$$

\Rightarrow **The pushing force generated by the cylinder meets the required load ($\geq 15.5 \text{ N}$). The required air flow is low, which results in energy savings and is well-suited for compact pneumatic systems**

Selected cylinder: TN10-30, with the following advantages:

Compact design, suitable for installation in confined spaces

⇒ Dual rod construction → provides excellent anti-rotation capability, ensuring stability and precision during operation.

Table 8 – TN10-30 Cylinder Parameters[8]

Item	Value
Cylinder Model	TN10-30
Piston Bore Diameter	10 mm
Stroke Length	30 mm
Type of Actuation	Double Acting
Number of Guide Rods	2 Parallel Guide Rods
Operating Pressure	0.1 ~ 1.0 MPa (1 ~ 10 bar)
Maximum Pressure	1.2 MPa
Operating Temperature	0 ~ 60°C
Operating Speed	50 ~ 500 mm/s (0.05 ~ 0.5 m/s)
Working Medium	Compressed air (oil-free or lightly lubricated)
Air Port Size	M5

4.2.4.6 Design and Selection of Line-Cutting Cylinder

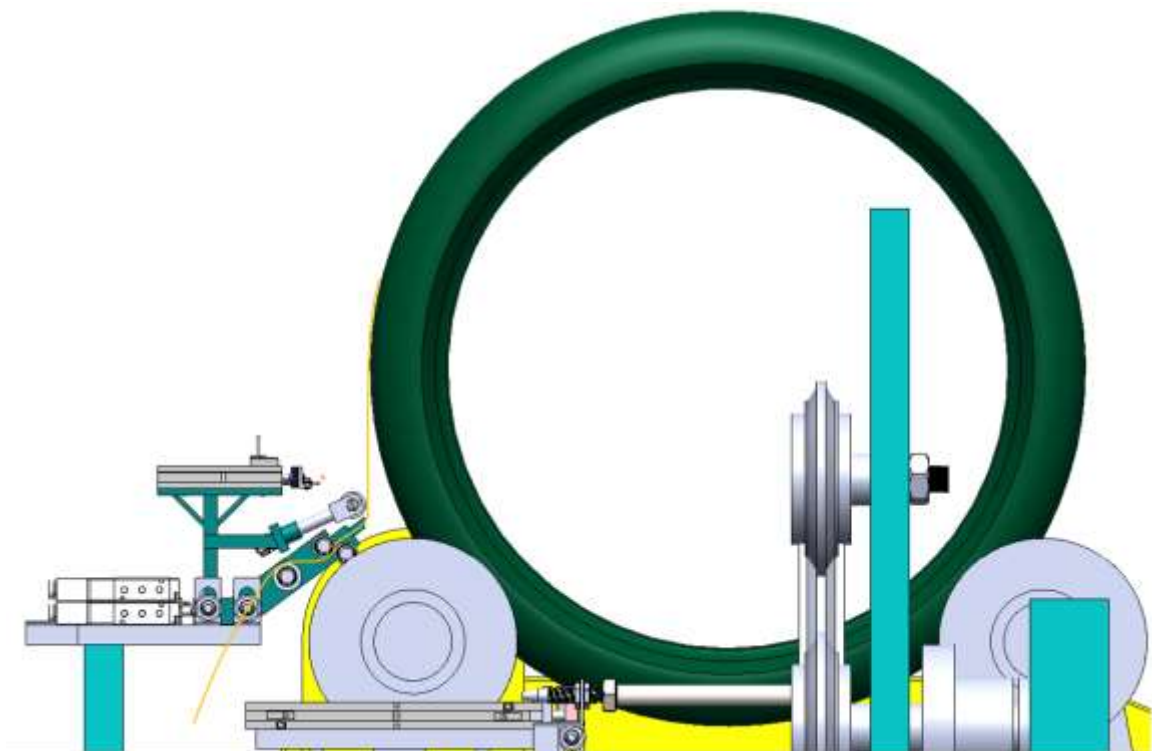


Figure 4.23 Mechanism before line cutting

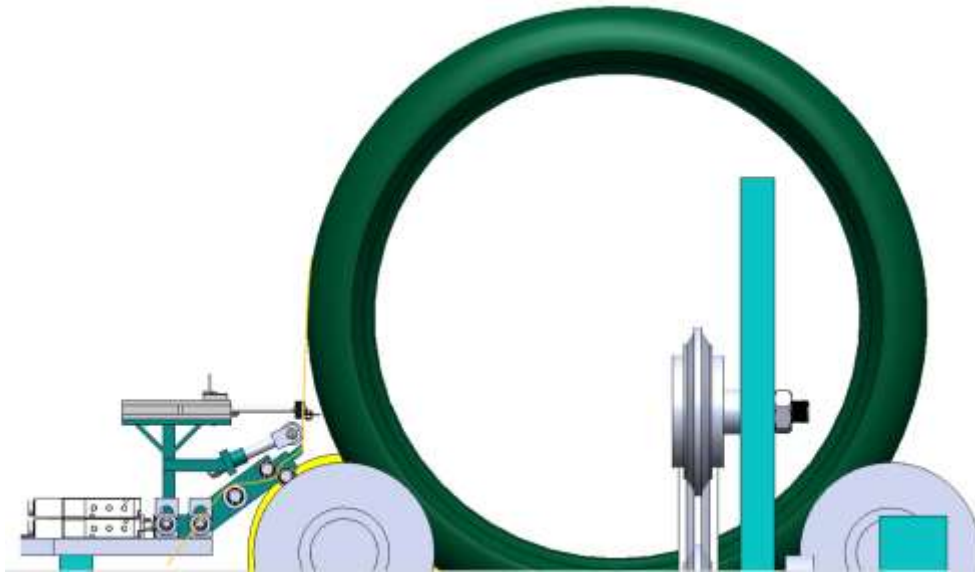


Figure 4.24 Mechanism after line cutting

After the cylinder pushes the line assembly against the tire surface to perform the bonding process, it retracts to complete the gluing step. At this point, the cutting cylinder is activated to move forward and cut the line that has just been glued. The cutting process is effectively carried out thanks to the tension of the line being firmly held on the tire surface and by the line bonding mechanism.

This tension helps keep the line stable and prevents it from shifting, facilitating precise, quick, and clean cutting without the need for additional holding mechanisms

Purpose of using the cylinder in the machine mechanism:

- Generate linear motion for the cutting blade and the fixture assembly to cut the line.
- Perform precise forward-backward movements: advance (touch the sensor at the start of the stroke) to cut, and then retract.

Working requirements of the cylinder:

- Direction of motion: parallel to the line-pushing cylinder.
- Acting load: very small, as the mechanism mounted on the cylinder head only carries a small cutting blade and a light fixture - no heavy load or significant resistance.
- No need to maintain force over time (unlike clamping cylinders).
- Speed and accuracy: high speed with precise positioning required to cut at the correct moment.

How to select the cylinder size:

Due to the very light load, there is no need to calculate pushing force in detail (using the formula $F = P \times A$). Instead, selection is based on:

- Actual stroke length (distance from standby position to cutting position).
- Available installation space on the machine (compact, avoiding interference with rotating mechanisms).

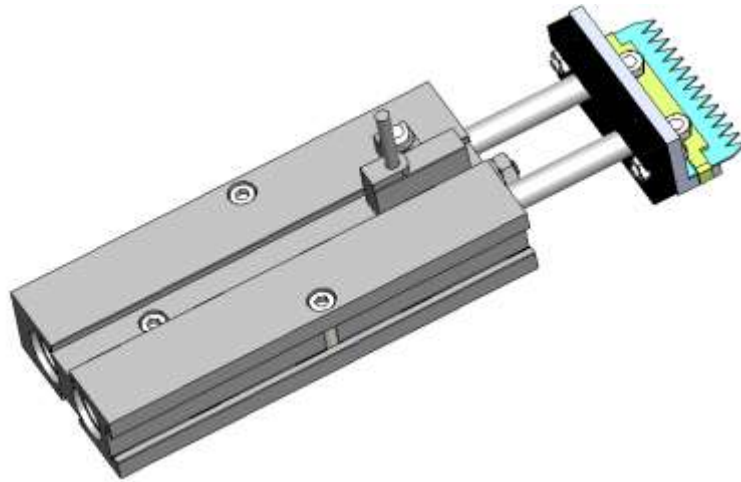


Figure 4.25 Line-cutting cylinder and actuator mechanism

Stroke length: $L = 50 \text{ mm} = 0,05 \text{ m}$

Assumed piston diameter: $D = 10 \text{ mm}$

Compressed air pressure: $p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$

Piston surface area: $A = \pi \times \left(\frac{D}{2}\right)^2 = \pi \times \left(\frac{10}{2}\right)^2 = 78 \text{ mm}^2$

Maximum pushing force of the cylinder: $F = P \times A = 0,6 \times 78 = 46 \text{ N}$

Equivalent mass: $P = \frac{F}{g} = \frac{46}{10} = 4,6 \text{ kg}$

Required time to complete the stroke: $t = 0,2 \text{ s}$

\Rightarrow Cylinder forward speed: $v = \frac{L}{t} = \frac{0,05}{0,2} = 0.25 \text{ m/s}$

Speed formula: $v = \frac{Q}{A}$

Required air flow rate to control the cylinder:

$$\Rightarrow Q = v \times A = 0,25 \times 0,000078 = 0,2 \times 10^{-4} \text{ m}^3/\text{s} = 1,2 \text{ l/phút}$$

The cylinder provides sufficient pushing force for the required load.

The required air flow rate is low \rightarrow energy-efficient and suitable for compact pneumatic systems.

\Rightarrow Selected cylinder: TN16-50

Compact design, suitable for installation in limited space

Dual parallel rods → good anti-rotation capability, ensuring stability and accuracy
 Suitable for precise clamping applications

Table 9 – TN16-50 Cylinder Parameters[8]

Cylinder Model	TN10-50
Piston Bore Diameter	10 mm
Stroke Length	50 mm
Type of Operation	Double acting
Guide Rods	2 parallel guide rods
Working Pressure	0.1 ~ 1.0 MPa (1 ~ 10 bar)
Maximum Pressure	1.2 MPa
Operating Temperature	0 ~ 60 °C
Operating Speed	50 ~ 500 mm/s
Working Medium	Compressed air (dry or lightly lubricated)
Air Port Size	M5

4.3 Labeling Mechanism Design

4.3.1 Problem Identification and Design Approach:

The label sheet has a rectangular size of **15 × 5 cm**. It is manually placed onto the tire by a worker, after which **adhesive tape** with a **width of 5.5 cm** is wrapped around the tire to secure the label.



Figure 4.26 Actual label and adhesive tape [Source: Internet]

Survey and Problem Analysis:

In the current process, after the tire is wrapped with PE film and the positioning line is applied, workers manually perform the next step: removing the tire from the machine, applying a product label, and securing it with adhesive tape. Specifically:

- The product label (containing information such as tire type, product code, manufacturing location, etc.) is manually affixed to the tire surface.
- Then, workers use transparent tape to wrap one loop above and one loop below the label to ensure it stays in place during transportation and storage.

This step is not only frequently repeated but also heavily depends on the worker's skill and attention to detail, which leads to the following issues:

- Inconsistency in label position and adhesion strength across different products.
- Increased handling time, which can reduce production line efficiency during continuous operation.

Improvement Objectives:

To enhance the system's level of automation and reduce human dependency, the team proposed a fully automated labeling solution, with the following specific goals:

- Reduce manual labor, especially repetitive tasks such as label application and taping.
- Shorten cycle time by integrating the labeling step into the machine's operating sequence, instead of performing it after tire removal.
- Improve precision and consistency, ensuring that labels are applied in the correct position with stable pressure to prevent peeling or misalignment.
- Minimize operational errors by eliminating issues caused by manual handling such as off-position labels, insufficient taping, or missing labels.

Proposed Design Solution:

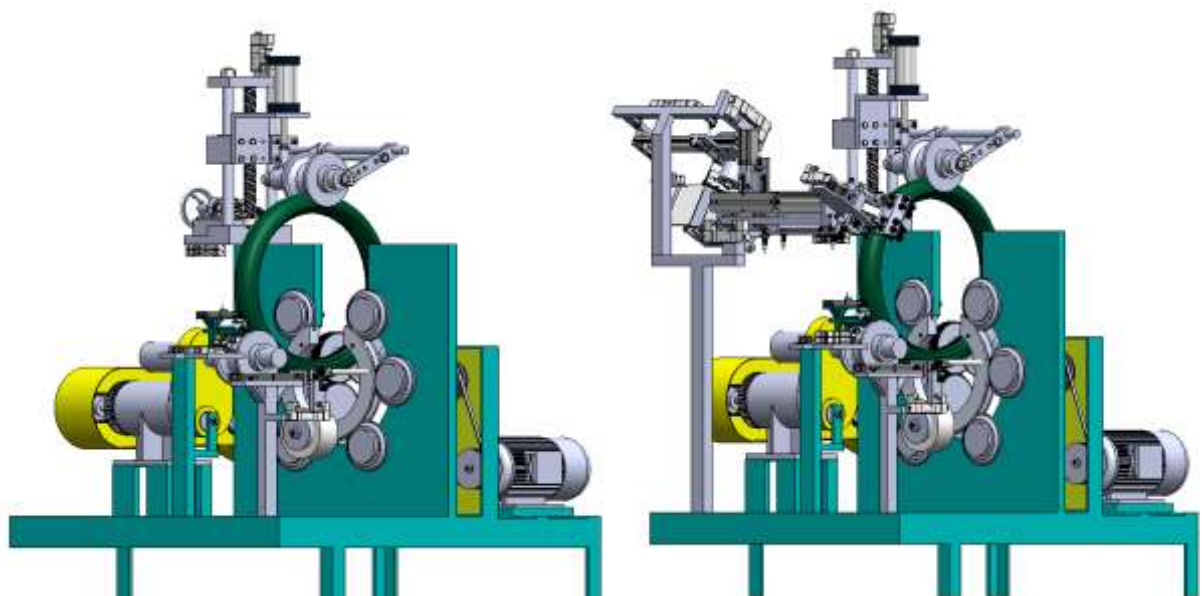


Figure 4.27 Model before and after improving all three manual operations

Due to the limited space inside the machine and the presence of two previously designed automated mechanisms, the remaining space has become even more constrained. Therefore, the labeling mechanism is required to be compact and designed with an appropriate application angle.

The team selected an **inclined angle of 30°** relative to the ground to position the labeling mechanism. This angle was chosen to best fit the available space while ensuring operational efficiency.

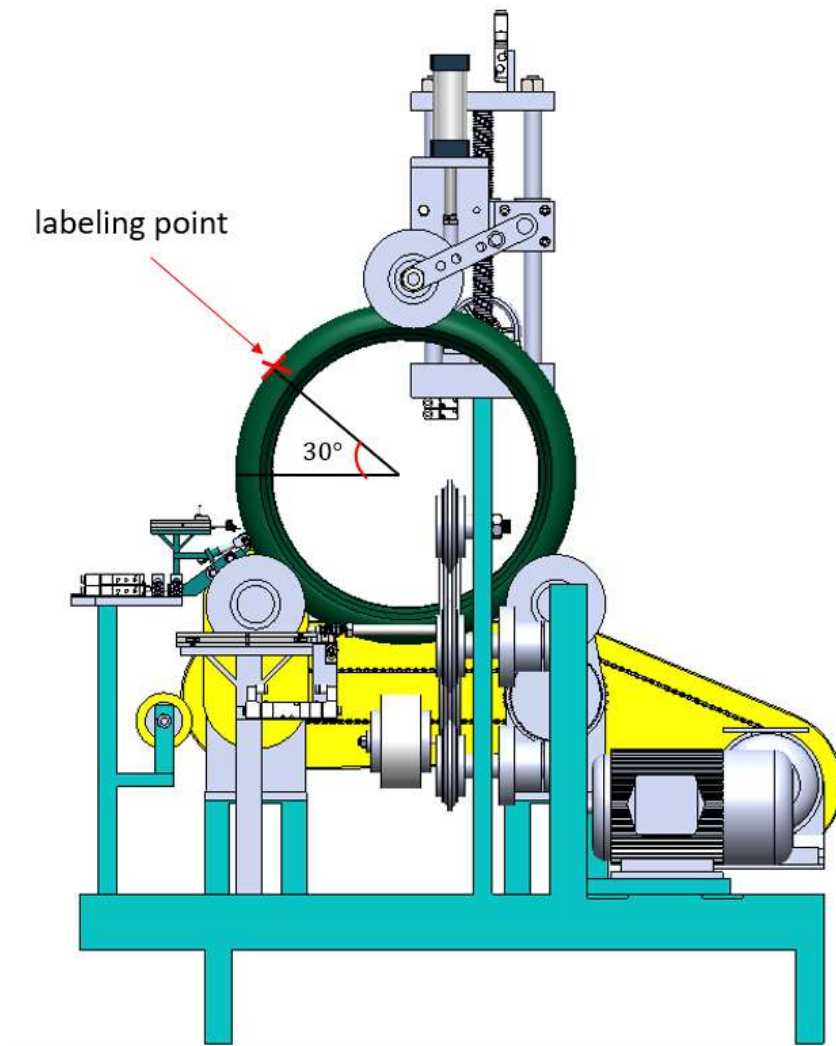


Figure 4.28 Label sticking point identification

Problem Statement:

How can the label and adhesive tape be applied to the tire simultaneously?

Proposed Solution:

The chosen solution is to use a gripper arm integrated with suction cups (labeling mechanism), capable of simultaneously picking up both the label and the adhesive tape. This gripper arm is driven by a pneumatic cylinder, which moves it forward to press the label and tape onto the tire surface.

Before pressing onto the tire, the suction cup holding the label and tape should be positioned approximately 1 cm away from the tire surface.

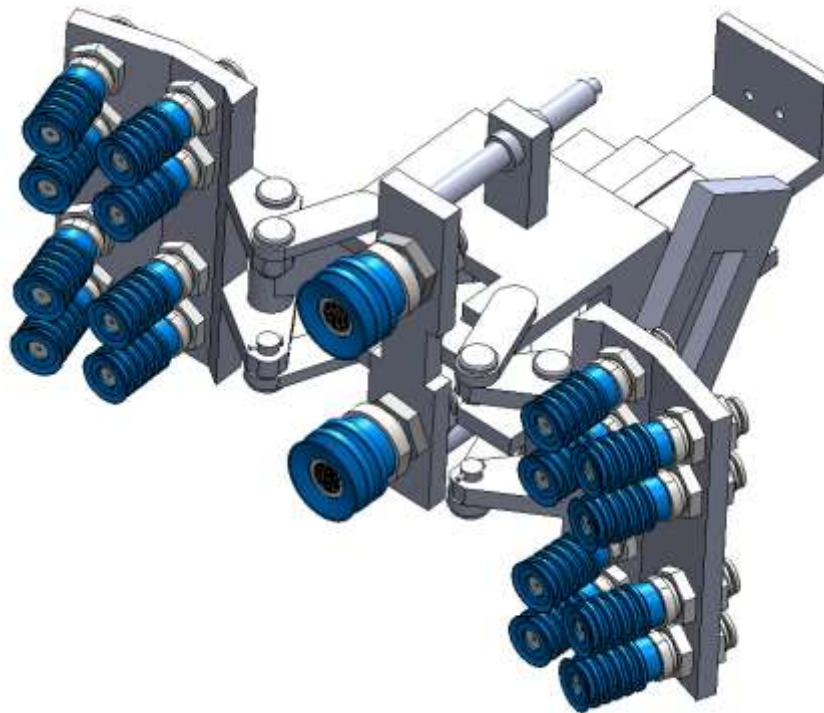


Figure 4.29 Label sticking and tape clamping mechanism on tire

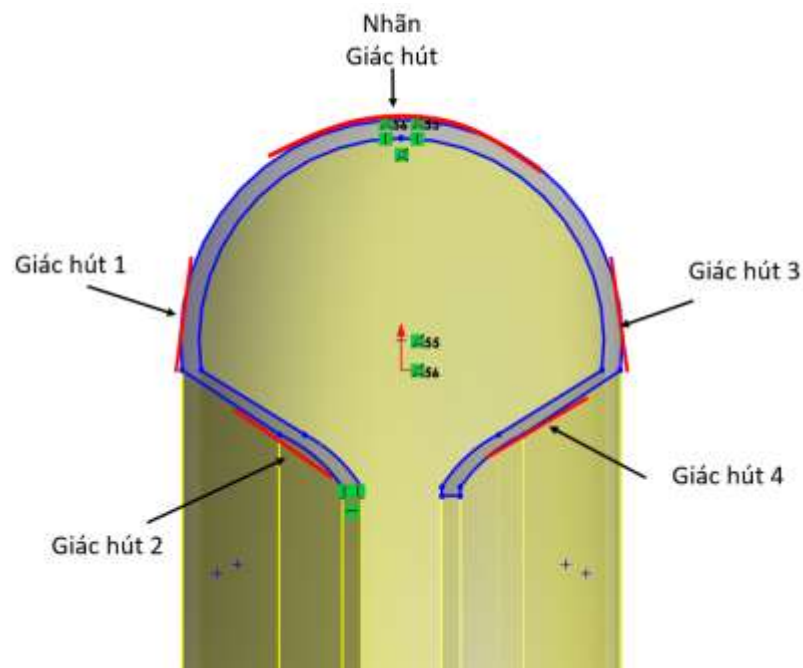


Figure 4.30 Suction cup position on tire

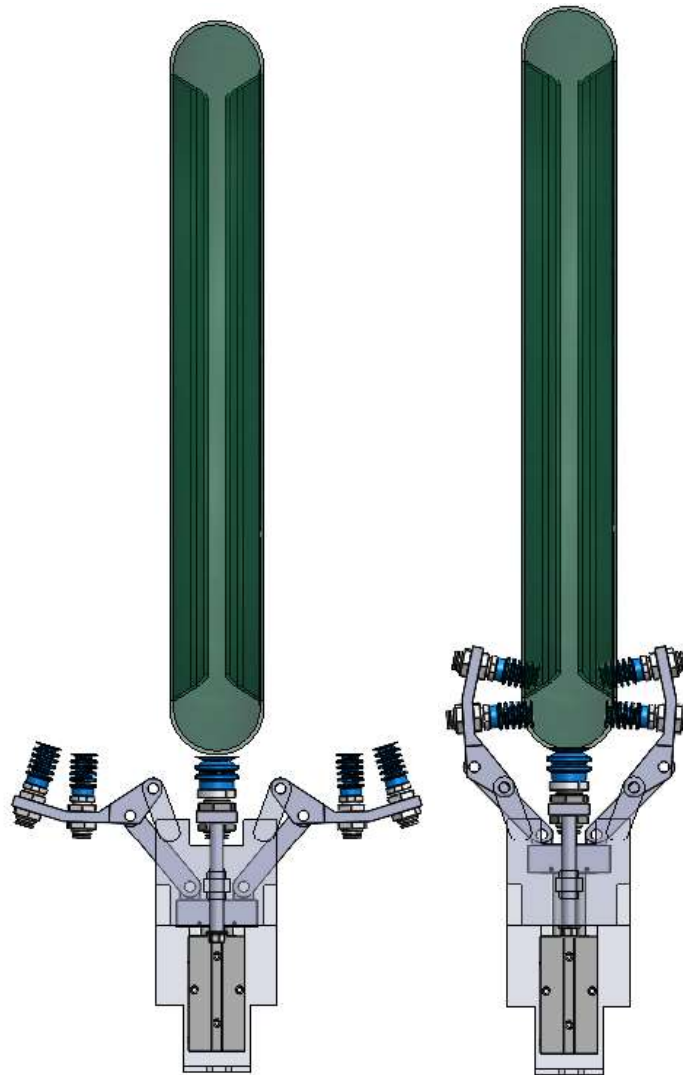


Figure 4.31 Labeling mechanism before and after sticking

Challenges and Solutions:

During the design process, the team encountered an issue: when the gripper arm moved horizontally to pick up the label and tape, and then continued to move horizontally from left to right toward the center of the tire to apply them, the suction cup **collided with the tire**. This was a critical issue due to the **limited space** and the insufficient clearance between the gripper and the tire surface, posing a safety risk during operation.

To address this problem, the team revised the gripper's motion sequence as follows:

- After picking up the label and adhesive tape, the gripper arm moves horizontally from left to right to reach the correct application position (the center of the tire).
- Then, the gripper moves vertically downward, stopping approximately 1 cm above the tire surface to prepare for application.
- Finally, the pneumatic cylinder drives the gripper forward, pressing the label and adhesive tape onto the tire surface.

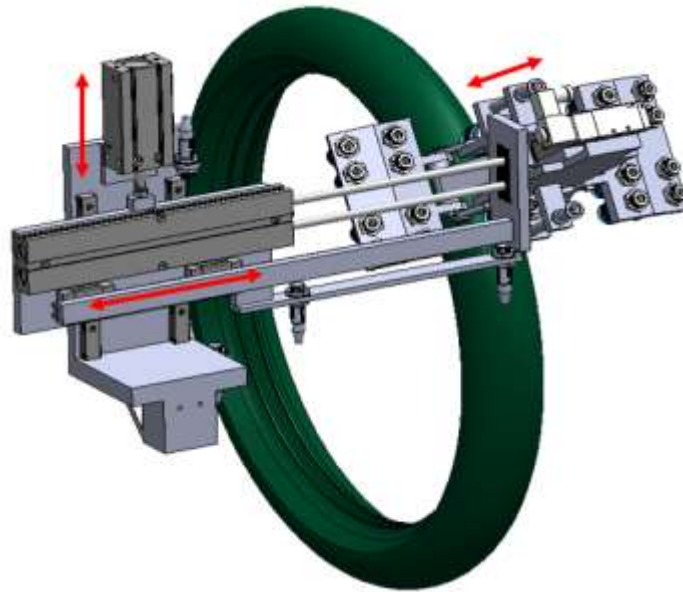


Figure 4.32 Movement directions of the labeling mechanism's cylinder

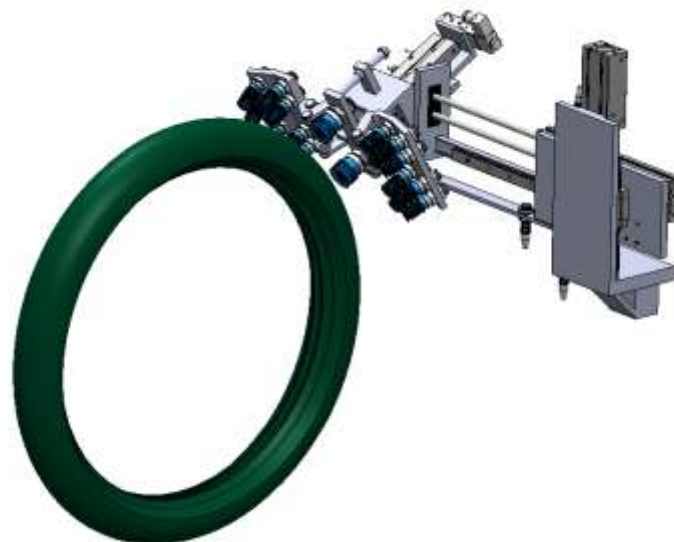


Figure 4.33 3D view of labeling mechanism

This is the solution proposed by the team for the stage where the label and adhesive tape have already been picked up by the gripper, ready for the application process. The remaining part of the design task is to develop the tape application mechanism and the label feeding system in detail, in order to complete the fully automated labeling process.

After the gripper has applied the label and adhesive tape onto the tire, the mechanism retracts following this sequence:

- The **forward-backward cylinder** retracts, pulling the gripper away from the tire surface.
- The **vertical cylinder** (moving upward) lifts the gripper to a higher position.

- The **horizontal cylinder** retracts from right to left, returning the gripper to its original position.

The final stopping position of the mechanism is designed to be at a safe distance from the tire, allowing sufficient space for the integration and layout of the label and tape feeding units.

The team has proposed a label holder box with the following features:

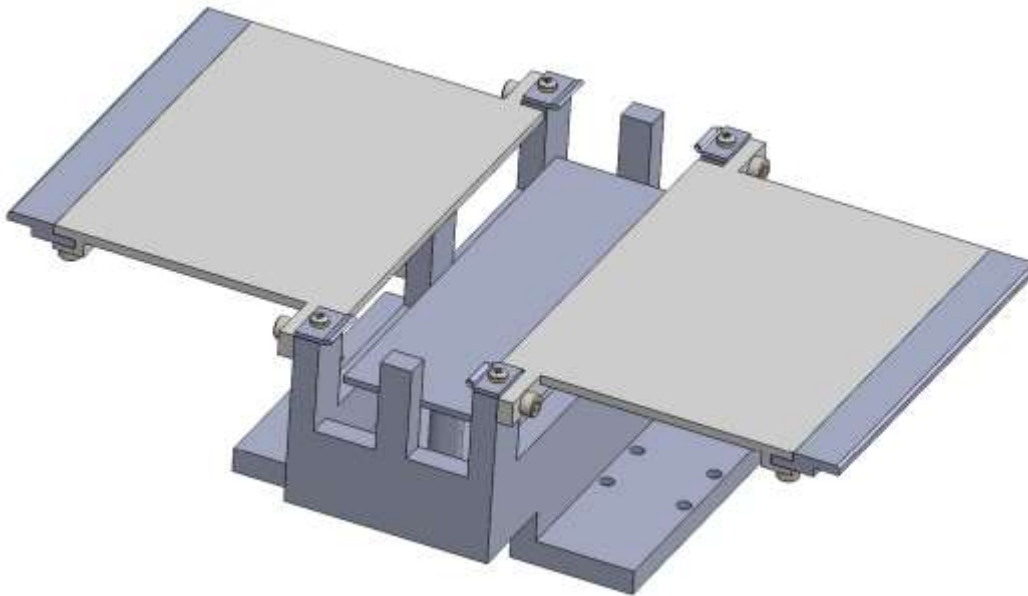


Figure 4.34 Label container box

- The label holder box functions as a storage container for labels and features two side flaps that integrate the adhesive tape application mechanism.
- Each label is held in place by four clamps at its corners to ensure accurate positioning, allowing the two suction cups at the center to easily pick up the label.

Label Holder Box Structure:

- The box has a height of 2 cm and can hold up to 100 labels.
- At the bottom of the box, three spring-loaded shafts push the label stack upward, allowing labels to be dispensed one at a time in a continuous manner.
- The two side flaps are made of FEFT plastic, a non-stick material that prevents adhesive tape from sticking to undesired areas.
- The outermost edges are made of aluminum, which allows the adhesive tape to stick - ensuring the start and end of the tape strip are secured properly when applied to the label.

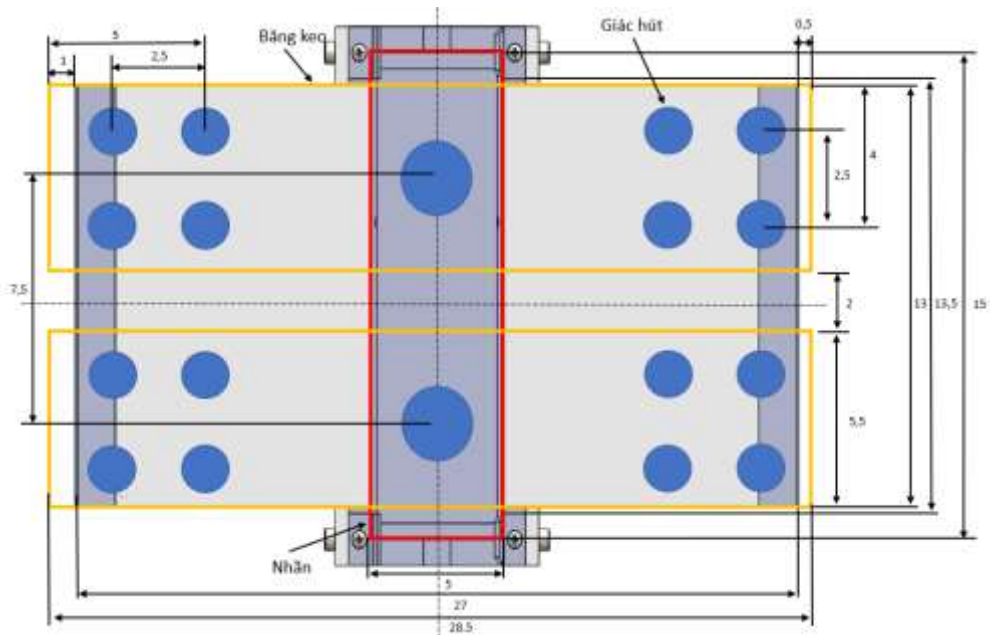


Figure 4.35 Suction cup positions on tape and label surface

Design Specifications and Suction Cup Arrangement for Label and Tape Application on Tire:

- Tire circumference: 32 cm
- Effective tape application length: 28.5 cm

Suction Cup Arrangement:

- A central suction cup is used to pick up and hold the label.
- Four corner suction cups are responsible for gripping and evenly holding the adhesive tape, ensuring that it is applied smoothly without misalignment or wrinkles.

Operational Challenge and Solution:

During operation, when the vertical cylinder retracts (after label and tape application is complete), the gripper assembly collides with the label holder mechanism.

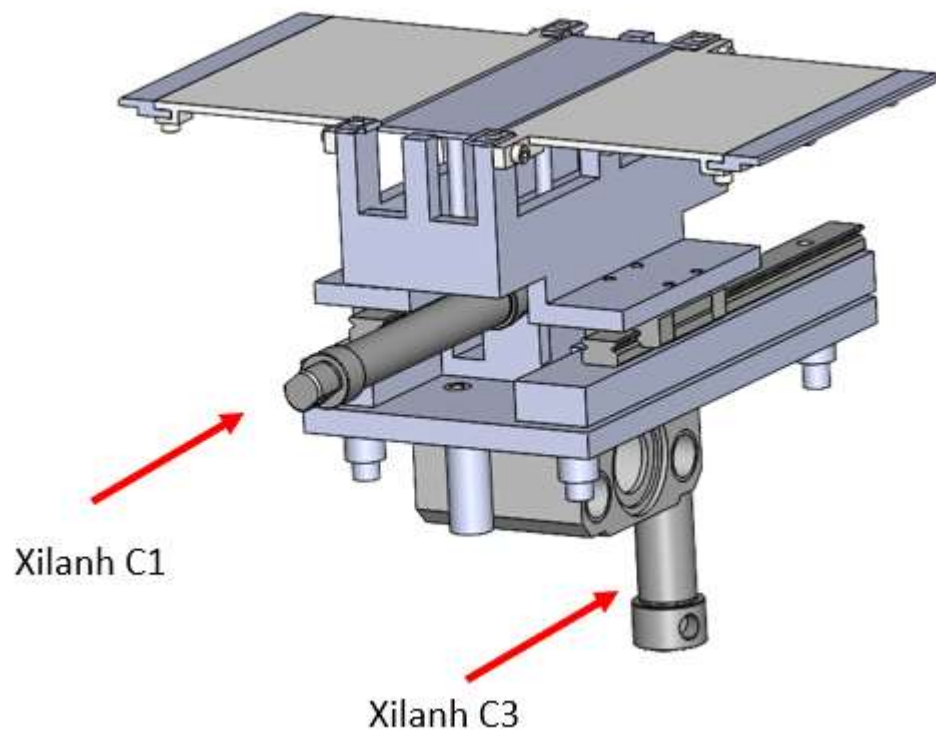


Figure 4.36 Position of C1 tape-pressing cylinder and C3 label suction cylinder

Proposed Solution by the Team:

- An additional cylinder (C3) is introduced to lift the label holder unit vertically (from bottom to top), operating in parallel with the movement direction of the gripper cylinder.
- When the suction cups are ready to pick up the label and adhesive tape, the label holder unit is temporarily lifted by cylinder C3 to allow space for pickup.
- Once the label and tape are successfully picked up by the suction cups, cylinder C3 lowers the label holder unit back to its original position.
- In this mechanism, the extended state of C3 provides pickup clearance, and the retracted state ensures operational safety.

Tape Application Mechanism Design with Cylinder C1 (Mounted Perpendicular to C3):

- On the C3 vertical cylinder, which moves the label holder up and down, the team has added another cylinder, C1, mounted perpendicularly to the motion direction of C3.
- This means C3 carries both the label holder unit and C1 as it moves.

Function of Cylinder C1:

- C1 performs a linear movement (up-down) of the label holder to precisely position the label for tape application.
- **Specifically:**
 - During the tape application process, C1 moves the label holder to different vertical positions corresponding to the two tape strips that need to be applied on the label.
 - Each tape strip is 5.5 cm long, placed near the two outer edges of the label (as detailed in the design).
- The use of cylinder C1 ensures high positional accuracy and reliable adhesive bonding, while also optimizing space within the system.

Design of Sliding Cylinder C2:

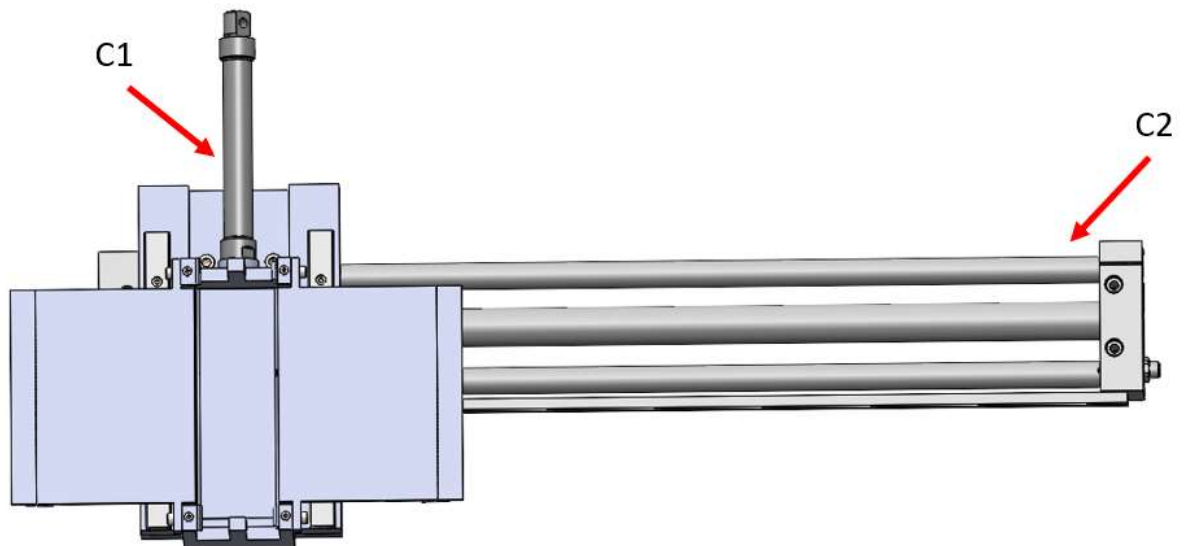


Figure 4.37 Position of C1 tape-pressing cylinder and D2 sliding cylinder

Sliding Cylinder C2 Design:

- To allow the label holder unit to move from the tape application area to the label pickup area, the team has added a horizontal sliding cylinder (length: 50 cm).
- Function of the sliding cylinder (C2): Moves the label holder assembly from left to right.

Movement Details:

- The initial position of the sliding cylinder is where tape is applied onto the label (i.e., the tape application mechanism operates here).
- The end position is where the suction cups approach to pick up the label and attached tape, preparing for the labeling operation on the tire.

This marks the phase in the design process where the system is ready to proceed to the labeling stage.

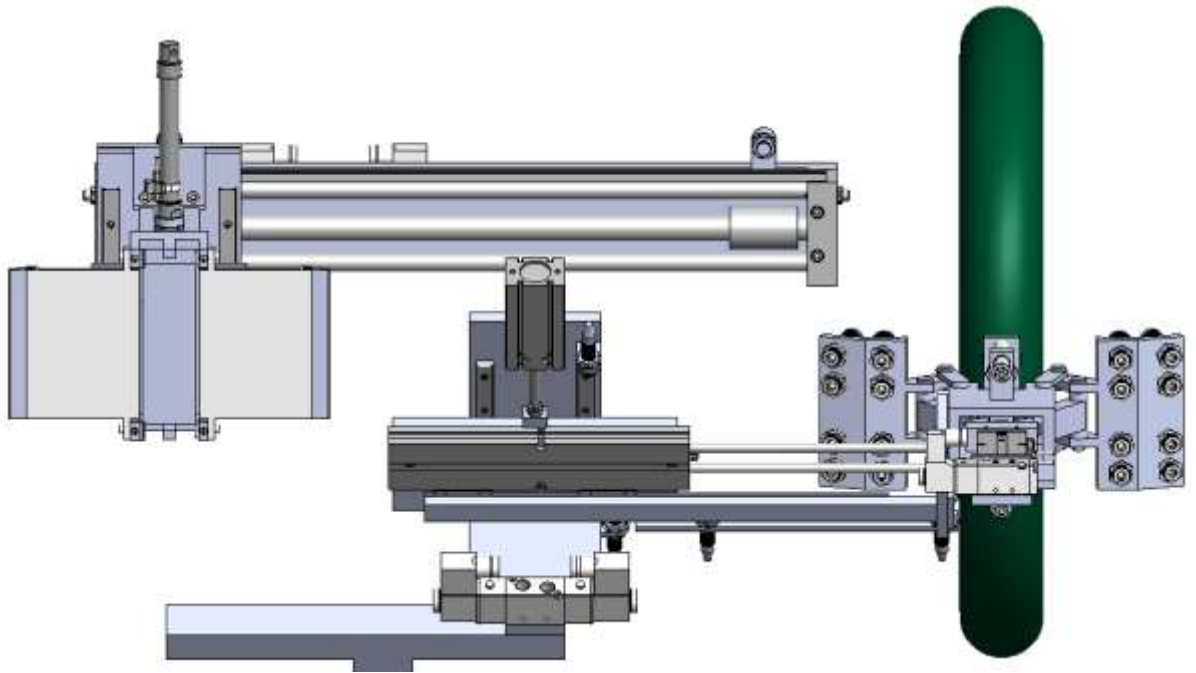


Figure 4.38 Model after designing label sticking and storing mechanism (a)

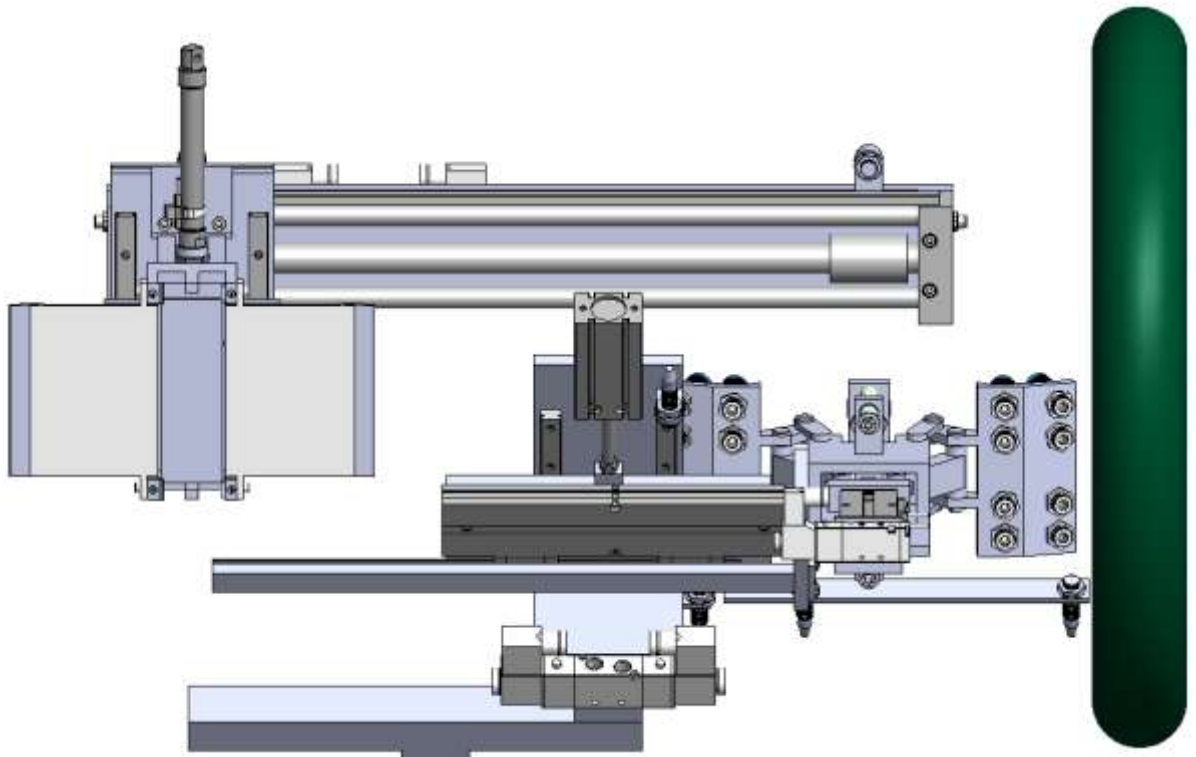


Figure 4.38 Model after designing label sticking and storing mechanism (b)

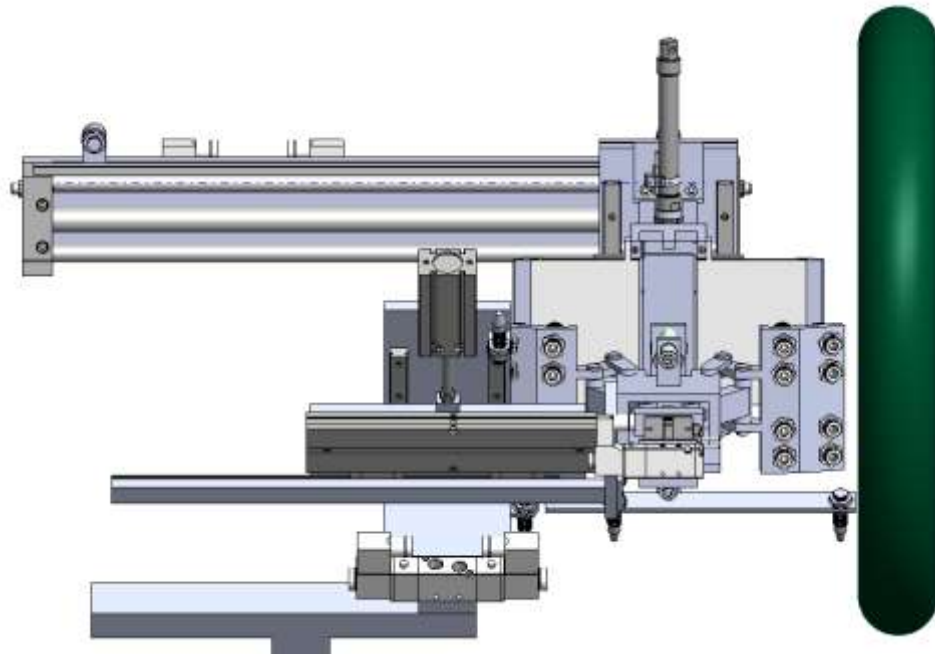


Figure 4.38 Model after designing label sticking and storing mechanism (c)

Design of the Adhesive Tape Application Mechanism onto the Label Surface

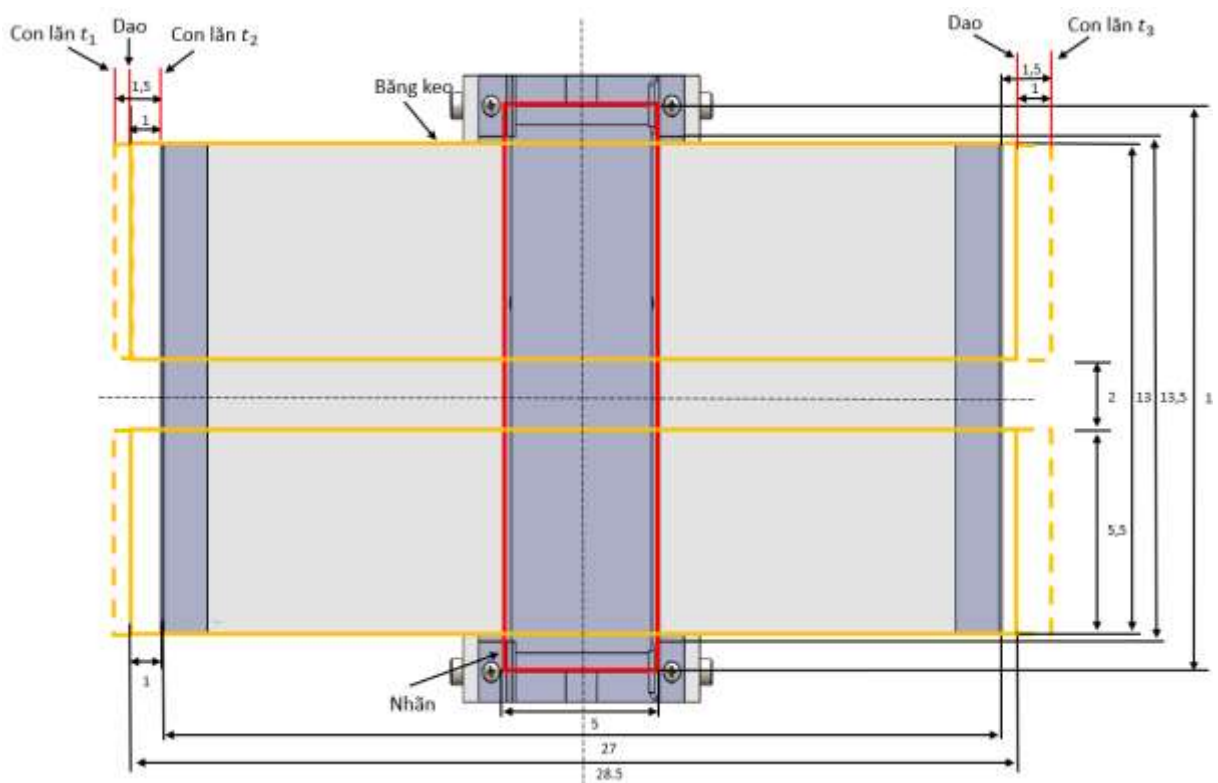


Figure 4.39 Actual position where tape is applied to label surface

Requirements:

- Two strips of yellow tape must be applied to the surface of the label, each with a length of 27 cm.
- Therefore, the team chose to use a sliding cylinder (B2) with a stroke of 30 cm (since the manufacturer only provides 25 cm and 30 cm options).
- The sliding cylinder B2 will be responsible for moving the tape applying mechanism horizontally from left to right, in order to apply the tape along the full required length of the label.

Thus, it is necessary to design the tape applying mechanism to be mounted on the body of the sliding cylinder (B2), which will move linearly to bring the mechanism to the label surface. The design of the tape applying mechanism is mounted on the sliding cylinder (B2):

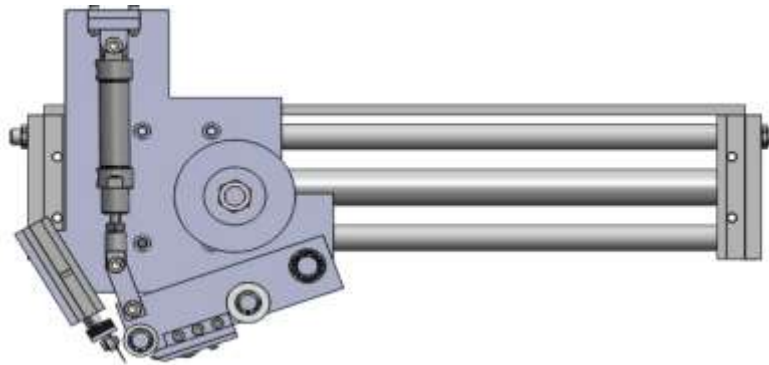


Figure 4.40 Tape sticking mechanism mounted on B2 sliding cylinder

The tape applying mechanism is directly mounted on the body of the sliding cylinder B2, and consists of the following main components:

- **Tape roll:** Fixed onto the frame of the mechanism and used to continuously supply tape.
- **Tape guiding system:**
 - The tape is guided through a shaping roller, which stabilizes and accurately directs the tape strip.
 - Then, the tape passes through a slot with a width of 5.7 cm, ensuring a snug fit with the tape width of 5.5 cm (the bottom side of the tape uses a FEFT non-stick layer to prevent premature adhesion to other parts).
- **Tape pressing mechanism:**
 - At the tape's output end, a pressing roller is installed.
 - When cylinder B1 operates and moves the roller towards the label surface (specifically the edge of the label-holding mechanism), the roller presses the tape down, ensuring it adheres well to the label surface.

- Since the sliding cylinder has a stroke of 30 cm while the required tape length is only 27 cm, there will be excess travel. Therefore, the design ensures that when cylinder B1 moves forward, the tape is not yet pressed onto the outer edge of the label-holding mechanism. Only after cylinder B2 begins sliding will the roller press the tape onto the outer edge of the label mechanism. At the end of the stroke, a tape cutting blade is activated (the distance from the blade to the outer edge of the label mechanism is 0.5 cm).

Operation sequence:

- Cylinder B1 moves downward (the tape is not yet adhered to the outer edge of the label-holding mechanism; the roller only presses the tape once cylinder B2 begins sliding).
- Sliding cylinder B2 moves from left to right, carrying the entire tape applying mechanism.
- During the movement, the pressing roller continuously presses the tape down onto the outer edges and flaps of the label, ensuring an even, precise, and secure application of tape along both edges.
- When cylinder B2 reaches the end of its stroke (detected by a cylinder sensor), cylinder B3 is activated to cut the tape.
- After cutting, cylinders B1 and B3 both retract to their original positions.

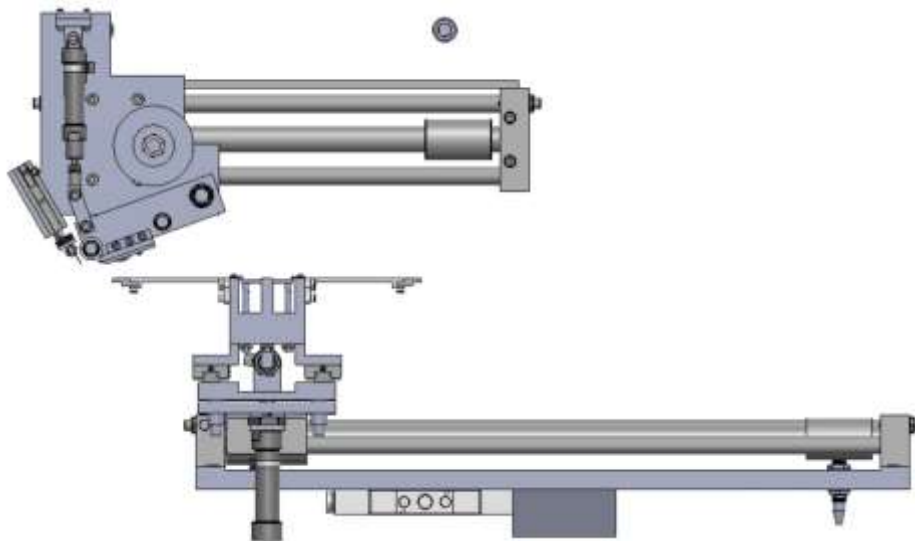


Figure 4.41 Tape sticking mechanism to label holder

With this design, the system ensures:

- Precise application of tape on both outer edges of the label.
- Exact tape length of 27 cm is applied.
- Synchronized operation between the three cylinders (B1, B2, B3), optimizing space and streamlining the process.

The tape applying mechanism is designed using SolidWorks.

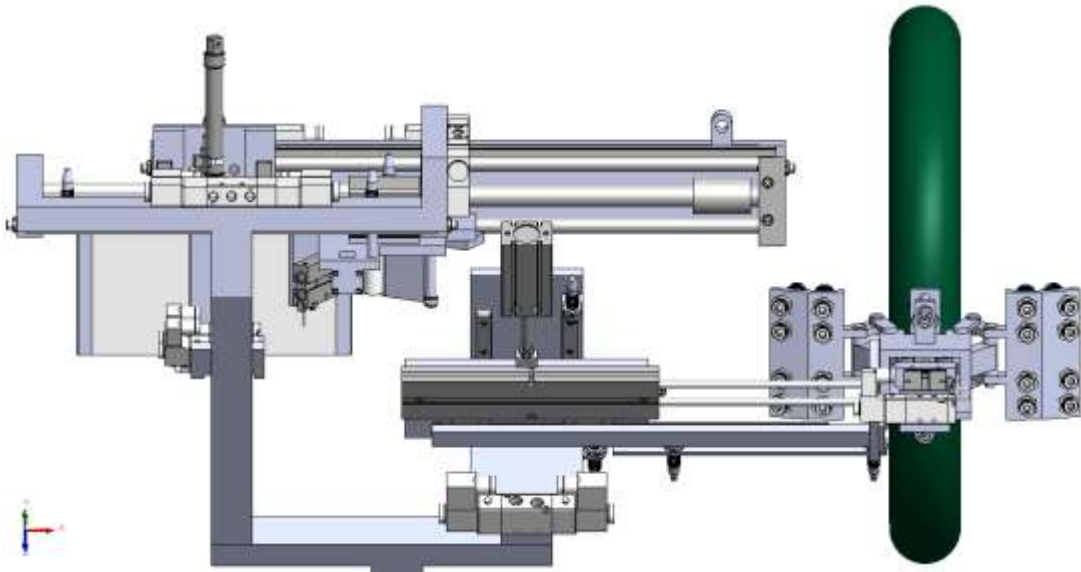


Figure 4.42 Overall design model of labeling mechanism

4.3.2 Calculation and Design of the Label Applying Mechanism:

4.3.2.1 Calculation and Design of the Label Application Assembly

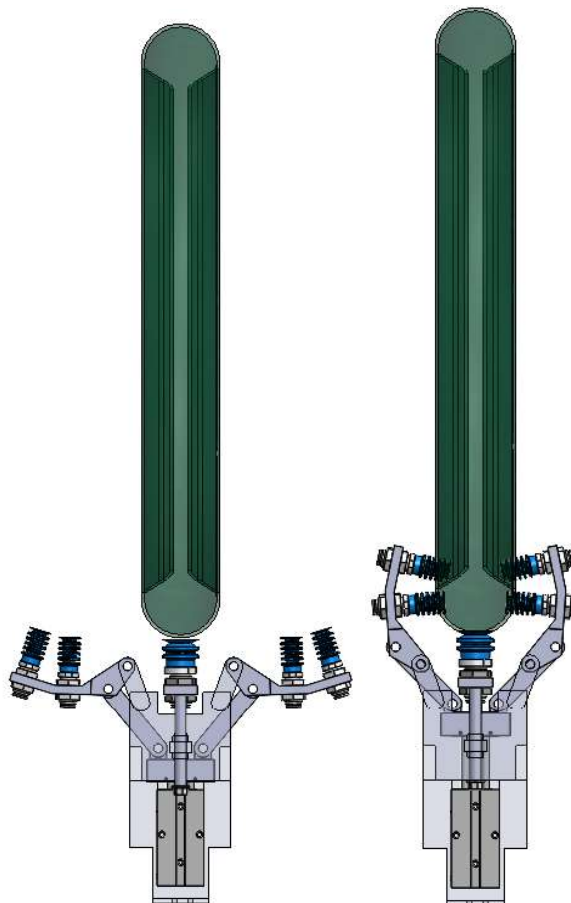


Figure 4.43 Position before and after label sticking(a)

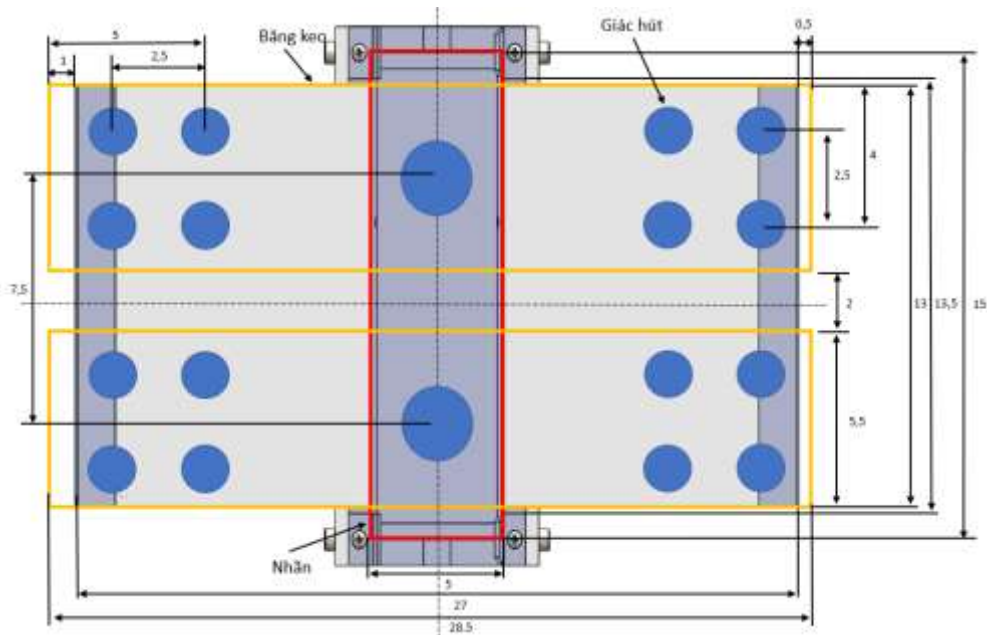


Figure 4.43 Suction cup positions on label and tape surface(b)

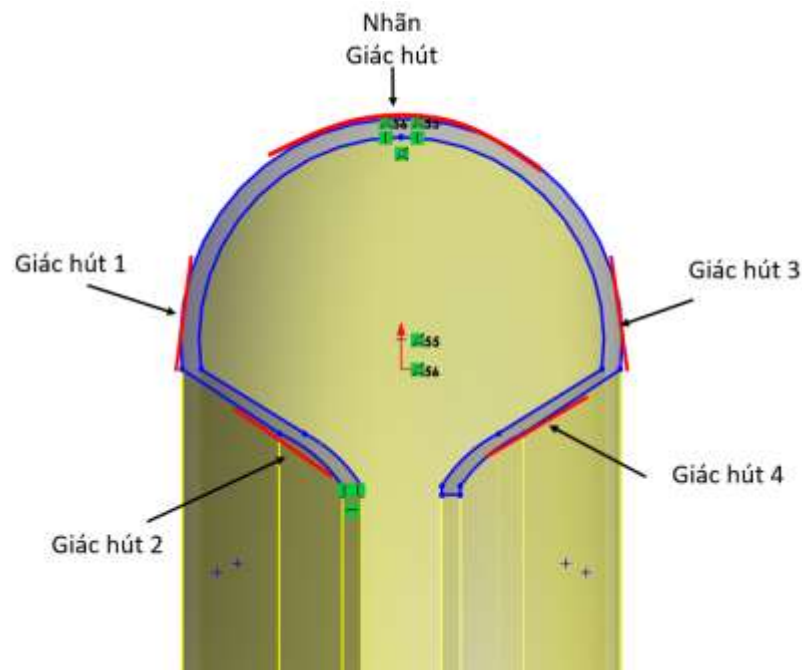


Figure 4.43 Suction cup positions on label and tape surface(c)

A gripper arm integrated with suction cups is used, capable of picking up both the label and tape simultaneously. This gripper is actuated by a cylinder, which moves it forward to press the label and tape onto the tire surface. Before pressing onto the tire, the suction cups holding the label and tape must be positioned approximately 1 cm away from the tire surface.

The design includes two central suction cups, each with a diameter of 3 cm, positioned to suction the center of the label and tape. Additionally, four smaller suction valves (each with a diameter of 2 cm) are arranged to evenly distribute suction across

the tape, ensuring full contact and firm adhesion along the circumference of the tire frame.

Two springs are incorporated into the design. Their function is to allow the suction cups to press the label and tape onto the tire surface only after the cylinder moves forward by 3.5 cm. When the cylinder retracts by 1.5 cm, the springs return the mechanism to a balanced state, maintaining the suction cups in a neutral, ready position.

The cylinder will push the labeling mechanism into the center of the tire (where the two gripper arms press against the tire surface, applying the label and tape). Once a signal from a magnetic sensor is received, the mechanism retracts. The cylinder body is equipped with two magnetic sensors at the start and end positions to control this motion precisely.

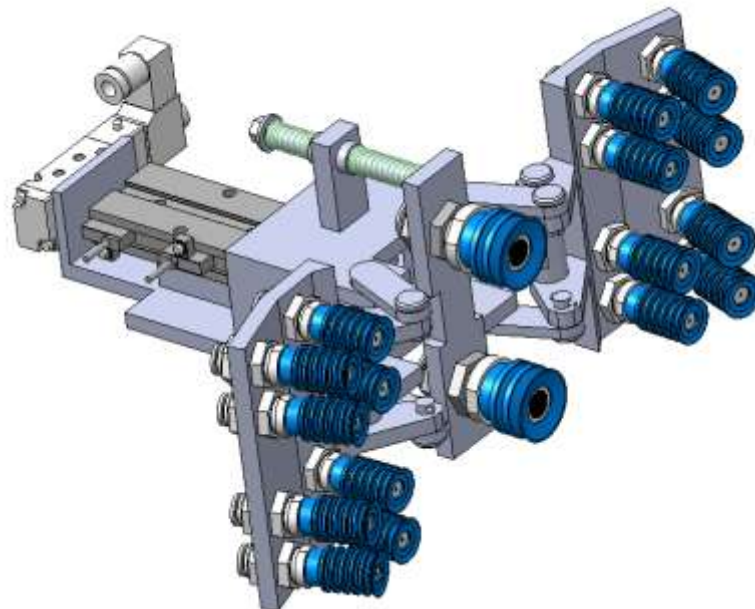


Figure 4.44 Labeling mechanism

Selection of the Cylinder for Driving the Labeling Mechanism:

The cylinder is responsible for pushing the labeling mechanism to apply the label onto the tire, with a load of 3.6 kg, transmitted through two intermediate joints. Required stroke length: $S = 40 \text{ mm}$

To move the load, the cylinder must generate a force of at least 36 N. Compressed air pressure: $p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$

To calculate the minimum required piston area:

$$F = p \times A \Rightarrow A = \frac{F}{p} = \frac{36}{0,6} = 60 \text{ mm}^2$$

Piston surface area formula:

$$A = \pi \times \left(\frac{D}{2}\right)^2 \Rightarrow D = \sqrt{\frac{4 \times A}{\pi}} = \sqrt{\frac{4 \times 60}{\pi}} = 8,7 \text{ mm}$$

Thus, the selected cylinder diameter is $D = 10 \text{ mm}$, which is a standard size commonly supplied by manufacturers.

The maximum pushing force the cylinder can generate is:

$$F = p \times A = p \times \pi \times \left(\frac{D}{2}\right)^2 = 0,6 \times \pi \times \left(\frac{10}{2}\right)^2 = 47 \text{ N}$$

Therefore, the chosen model is the TN10-40 cylinder, which features dual guides on both sides for improved alignment and stability.

Table 10 – TN10-40 Cylinder Parameters[9]

Parameter	Specification
Cylinder Model	TN10-40
Piston Diameter (Bore)	10 mm
Stroke Length	40 mm
Type of Action	Double Acting
Number of Rods	2 Guide Rods (Parallel)
Operating Pressure	0.1 ~ 1.0 MPa (1 ~ 10 bar)
Maximum Pressure	1.2 MPa
Operating Temperature	0 ~ 60°C
Operating Speed	50 ~ 500 mm/s
Working Medium	Compressed Air (non-lubricated or lightly lubricated)
Air Port Size	M5

Maximum Force Generated by Cylinder TN10-40:

$$F_t = 2 \times F = 2 \times 47 = 94 \text{ N}$$

The maximum pushing force of the cylinder is 94 N, which is well above the required 36 N, ensuring safe and reliable operation with an appropriate safety margin.

Time required for the cylinder to complete its stroke: $t = 0,3 \text{ s}$

⇒ Cylinder extension speed:

$$v = \frac{L}{t} = \frac{0,04}{0,3} = 0,13 \text{ m/s}$$

Cylinder speed (based on flow rate and area): $v = \frac{Q}{A}$

Required air flow to operate the cylinder:

$$\Rightarrow Q = v \times A = 0,13 \times 0,000078 = 0,9 \times 10^{-5} m^3/s = 0,6 \text{ l/phút}$$

The cylinder provides sufficient thrust for the allowable load.
⇒ Low required compressed air flow → energy-efficient, suitable for compact pneumatic systems.

Shock - absorbing spring design when the cylinder presses the label onto the tire:

Two springs are designed so that the cylinder only pushes the two suction cups to stick onto the tire surface after moving forward 3.5 cm. When retracting 1.5 cm, it returns to a balanced state, maintained by the two **springs above and below**.

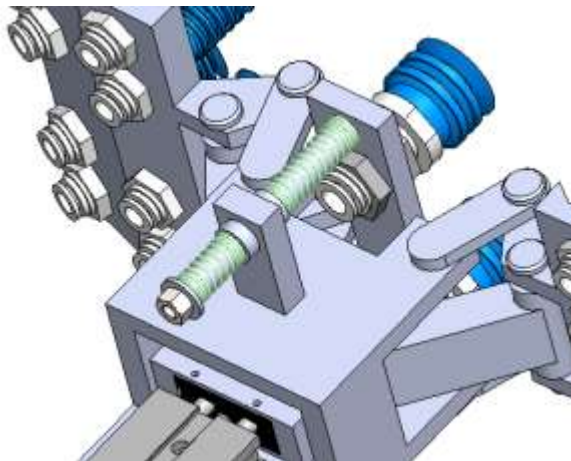


Figure 4.45 Label pressing spring design

Compressive force on each spring: $F = 47 \text{ N}$

Spring deflection (compression) $\Delta l = 5 \text{ mm}$

Inner diameter: $D_t = 10 \text{ mm}$

Free length: $l_0 = 25 \text{ mm}$

Modulus of rigidity for 65Mn spring steel: $G = 79300 \text{ MPa}$

Tensile strength: $850 \div 1200 \text{ Mpa}$

Elastic limit: $600 \div 1000 \text{ Mpa}$

Allowable shear stress: $346 \div 577 \text{ MPa}$

Selected spring wire diameter: $d = 1,8 \text{ mm}$

Mean coil diameter:

$$D = D_t + d = 11,8 \text{ mm}$$

Spring constant (stiffness):

$$k = \frac{F}{\Delta l} = \frac{47}{8} = 5,9 \text{ N/mm}$$

Number of active coils:

$$n = \frac{G \times d^4}{8 \times D^3 \times k} = \frac{79300 \times 1,8^4}{8 \times 11,8^3 \times 5,9} = 10,7 \text{ vòng}$$

Chosen number of active coils: $n = 11$

Check spring length:

$$l_0 = (n + 2) \cdot d = (11 + 2) \cdot 1,8 = 23,4 \text{ mm}$$

⇒ Chosen $n = 12$, as the spring can be slightly longer since it is pre-compressed in the frame..

To achieve a spring length of 25 mm, the number of active coils is selected as:

$n = 12$

$$l_0 = (n + 2) \cdot d = 14 \cdot 1,8 = 25,2 \text{ mm}$$

⇒ $n = 12$ is chosen, as the spring can be slightly longer since it is pre-compressed within the frame.

Spring index:

$$C = \frac{D}{d} = \frac{11,8}{1,8} = 6,5$$

Wahl correction factor:

$$K_w = \frac{4C - 1}{4C - 4} + \frac{0,615}{C} = 1,24$$

Shear stress in the spring:

$$\tau = \frac{8 \cdot F \cdot D}{\pi \cdot d^3} \cdot K_w = \frac{8 \times 47 \times 11,8}{\pi \times 1,8^3} \times 1,24 = 300 \text{ MPa}$$

Selected safety factor 1,5:

$$\tau = 300 \times 1,5 = 450 \text{ MPa}$$

The calculated shear stress is within the allowable shear stress range for 65 Mn spring steel.

⇒ The two front springs are selected to be identical to the two rear springs to ensure balanced force and elasticity. These front springs are not subjected to tensile or compressive loads but are intended to maintain the balanced position of the dual suction cup mechanism.

Design of Two Types of Vacuum Suction Cups:

In the design of the labeling and taping mechanism on the tire surface, the following technical requirements must be met:

- The tire surface is not flat and has a curved profile.
- The label and tape must be held precisely without misalignment or dropping during operation.
- The suction gripper must be able to make good contact with the curved surface and withstand the pressing force during application.

Based on the working position and application, a suction cup with an extended nipple is selected. This allows for greater angular flexibility when applying the tape onto the tire surface, enabling better conformity to the curved shape and ensuring secure adhesion.

To meet these requirements, the team selected the **ZP3P series vacuum pads** from **SMC**, which are known for their **soft bellows design**. This design provides excellent adaptability to uneven surfaces and ensures stable performance even under slight vibrations.

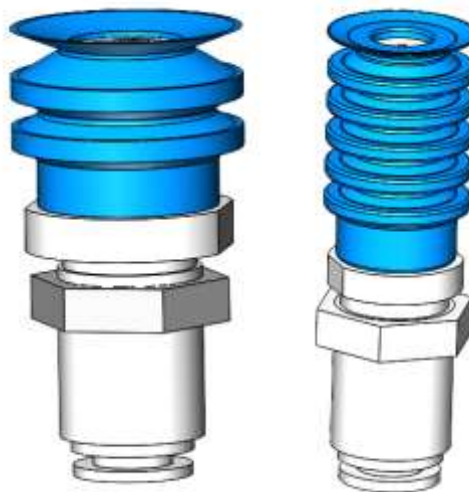


Figure 4.46 Vacuum pad for picking up tape and labels

Central Label Suction Cup (wide suction area, central contact)

- Model: ZP3P-T32JT2SF-WM-A20
- Diameter: Ø32 mm
- Pad Type: Soft, 2.5 bellows, deformation-resistant during suction
- Application: Suction at the center of the label with a large contact area to ensure stability during labeling.

Outer Tape Edge Suction Cup (small suction area, high flexibility required)

- Model: ZP3P-T20JT5SF-WM-A16

- Diameter: Ø20 mm
- Pad Type: 5 bellows – provides excellent contact on tape edges
- Application: Suction at both edges of the label tape, ensuring even adhesion on both sides.

Reasons for Choosing the ZP3P Series:

- **Bellows structure** compensates for surface misalignment — ideal for curved tire surfaces.
- **Stable suction force**, maintains shape during motion without deformation.
- **Soft pad material** protects thin labels and tape, preventing tearing at the edges under strong suction.
- **Available in multiple sizes and connection types**, making it suitable for compact and space-limited fixture designs.

Table 11 – Parameters of SMC ZP3P Vacuum Pad[10]

Specification	ZP3P-T32JT2SF-WM-A20	ZP3P-T20JT5SF-WM-A16
Pad Diameter	Ø 32 mm	Ø 20 mm
Bellows Type	2.5-stage	5.5-stage
Material	Silicone rubber (FDA-compliant)	Silicone rubber (FDA-compliant)
Soft Pad	Yes	Yes
Air Supply Method	Thread M20 × 1 plate mounting	Thread M16 × 1 plate mounting
Vacuum Connection	Rc1/4	Rc1/8
Weight	~61 g	~25.8 g
Operating Temperature	-30 °C to 90 °C (soft pad: -5 °C to 60 °C)	-30 °C to 90 °C (soft pad: -5 °C to 60 °C)
Application	Center label suction on tire	Edge tape suction

Design and Calculation of Vacuum Suction Valve:

Based on the mechanism for labeling tires, the design uses 10 vacuum suction cups that are appropriately positioned to ensure accurate and precise label application.

Area of a 2 cm suction cup:

$$A_1 = \pi \times r^2 = \pi \times 1^2 = 3,14 \text{ cm}^2$$

Total area of eight 2 cm suction cups:

$$A_{1t} = 8 \times 3,14 = 25,12 \text{ cm}^2$$

Area of a 3 cm suction cup:

$$A_2 = \pi \times r^2 = \pi \times 1,5^2 = 7,07 \text{ cm}^2$$

Total area of eight 3 cm suction cups:

$$A_{2t} = 8 \times 3,14 = 14,14 \text{ cm}^2$$

Total suction area

$$A_{tt} = 25,12 + 14,14 = 39,26 \text{ cm}^2$$

Required air flow rate (based on manufacturer's reference):

For applications with leakage (such as suction through adhesive tape), select a flow rate of:

$$Q = 3 \div 6 \text{ lít/phút/cm}^2$$

Choose the average: $Q = 3 \frac{\text{lít}}{\text{phút}} \times 39,26 = 120 \text{ l/phút}$

⇒ Recommended vacuum valve (pneumatically operated type): **CV- 25 HS**



Figure 4.47 CV25HS pneumatic vacuum valve

Table 12 – Parameters of SMC Vacuum Solenoid Valve VXA21/22[11]

Type	2/2 – Direct-Acting Pneumatic Valve (Piston Type)
Operation Mode	N.C. (Normally Closed), N.O. (Normally Open)
Port Sizes (Inlet/Outlet)	1/4" (ø6 mm) / 3/8" (ø10 mm) / 1/2" (ø15 mm)
Pilot Pressure	0.25 – 0.7 MPa (2.5 – 7 bar)
Max Differential Pressure	1.0 MPa (10 bar)
Vacuum suction flow	160 L/min at 6 bar
Compressed air consumption	265 L/min at 6 bar
Body Material	Brass (C37) or Stainless Steel
Applicable Media	Air, Vacuum, Water, Oil
Vacuum Pressure Resistance	Supports up to approx. –100 kPa (deep vacuum) with "V" seal
Operating Temperature	–5 to +60 °C

Selected valve: 5/2 Pneumatic Solenoid Valve AirTac 4V210-08B

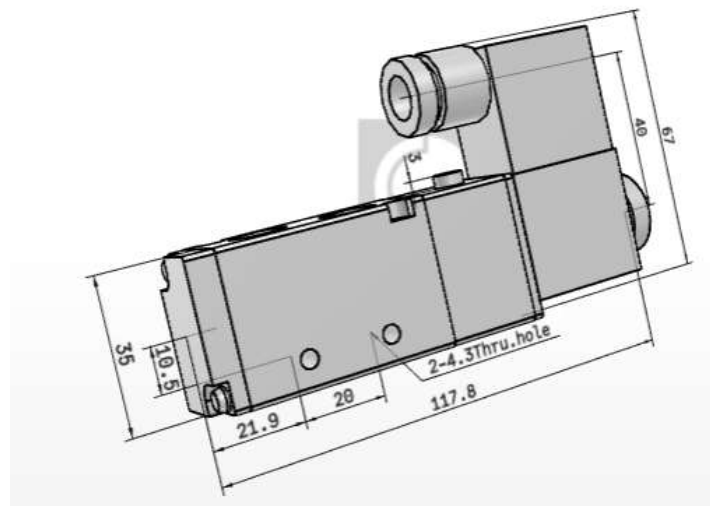


Figure 4.48 AirTac 4V210-08B 5/2 solenoid valve

Table 13 – Specifications of Pneumatic Solenoid Valve 5/2 AirTac 4V210-08B[12]

Valve Type	5-Port, 2-Position (5/2), Pneumatically Piloted
Port Size	G1/4"
Flow Rate (Cv)	~1.0 (Approx. 890 L/min at 6 bar)
Operating Pressure	0.15 – 0.85 MPa (1.5 – 8.5 bar)
Maximum Pressure	1.2 MPa (12 bar)
Coil Voltage	24 VDC
Coil Power	3 W
Response Time	≤ 50 ms
Operating Temperature	–20 °C to +70 °C
Weight	Approx. 0.2 kg

After calculating the total suction cup area and the required compressed air flow to maintain a stable vacuum pressure, the system requires a vacuum generator capable of producing sufficient vacuum strength and an airflow rate ≥ 120 liters/min at 6 bar pressure.

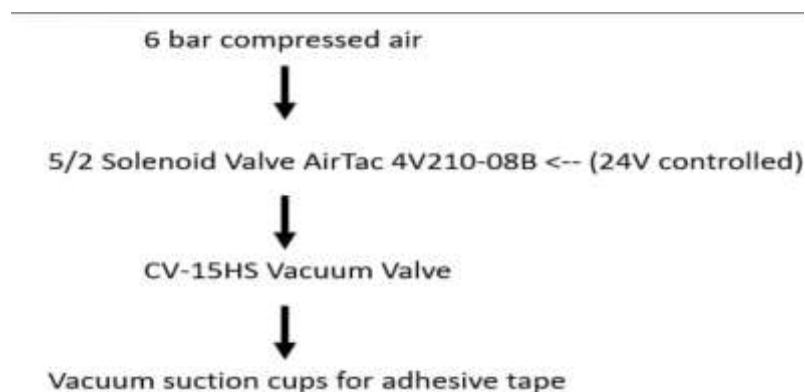
The SMC VXA21/22 vacuum generator was selected as it meets these requirements well, offering an appropriate flow rate, suitable port size (1/4" or 3/8"), and fully pneumatic operation without the need for electricity, ensuring reliable and stable vacuum generation for the system.

To control this vacuum generator, the AirTac 4V210-08B pneumatic solenoid valve (5/2 valve, 1/4" port) was chosen. It provides a high airflow capacity (~890 liters/min at 6 bar), supplying sufficient compressed air to quickly actuate the vacuum generator. It also features fast response time and a 24VDC coil voltage, compatible with the system's automation controls.

This combination ensures efficient and durable vacuum system operation, meeting technical requirements and the industrial environment of the adhesive tape handling line.

Operating Procedure Description

- Compressed air at 6 bar is supplied from the main pneumatic system.
- When a 24VDC signal is sent to the coil of the AirTac 4V210-08B solenoid valve, the valve switches to the open position, allowing compressed air to flow to the vacuum generator.
- The **SMC VXA21/22 vacuum generator** receives the compressed air and generates vacuum at the suction cups (8 cups of 2 cm diameter + 2 cups of 3 cm diameter), lifting the adhesive tape from a flat surface.
- When the 5/2 solenoid valve is energized, it supplies air to activate the vacuum.
- When the 24VDC signal is turned off, the solenoid valve closes the air supply, cutting off the compressed air. The vacuum generator stops operating, and the suction cups release the adhesive tape.



4.3.2.2 Calculation and Design of the Horizontal Motion Mechanism for the Label-Pushing Assembly into the Tire

To perform the task of labeling the tire, cylinder D1 is used to push the entire labeling mechanism to move horizontally from left to right:

- Cylinder D1 is mounted on a base to generate linear force in the horizontal direction, allowing the labeling assembly to reach the working position.
- The labeling mechanism includes several moving parts with significant weight, so stability and precision during movement must be ensured.
- Therefore, to support and enhance the rigidity of the movement driven by cylinder D1, the team designed two sliders fixed on a guide rail:
 - These two sliders function as a linear guiding system, ensuring smooth, aligned, and vibration-free movement.
 - At the same time, the slider system also absorbs auxiliary forces, helping to reduce the load on cylinder D1, thereby increasing the lifespan and stability of the system.
- Two proximity sensors are mounted on the base to transmit the start and end position signals of cylinder D1's stroke.

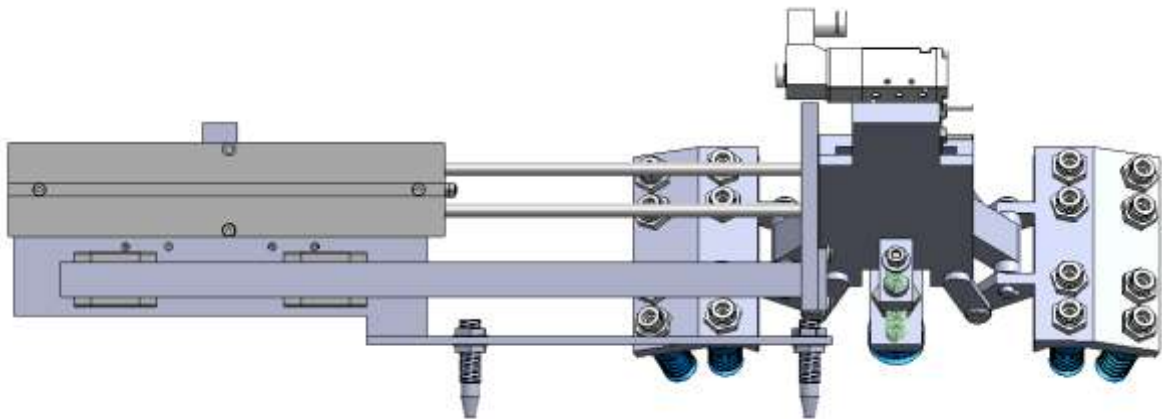


Figure 4.49 Sensor position at the start and end of cylinder stroke (horizontal motion)

Based on the applied force from the large load (6.3 kg), and considering the design space constraints, a suitable stroke length for the cylinder is selected as 200 mm (20 cm).

The desired time for the cylinder to push the labeling assembly is $t = 1 \text{ s}$ over a stroke $S = 200 \text{ mm}$, with the distance between two sliders on the guide rail being $d = 70 \text{ mm}$. To move the load, the cylinder must generate a force of at least 62 N .

Compressed air pressure is given as:

$$p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$$

Minimum required pushing force by the cylinder:

$$F = p \times A \Rightarrow A = \frac{F}{p} = \frac{62}{0,6} = 103 \text{ mm}^2$$

Piston surface area: $A = \pi \times \left(\frac{D}{2}\right)^2 \Rightarrow D = \sqrt{\frac{4 \times A}{\pi}} = \sqrt{\frac{4 \times 103}{\pi}} = 11,4 \text{ mm}$

Select a **cylinder diameter D = 16 mm**, which is a standard size commonly used by manufacturers.

Maximum pushing force of the cylinder:

$$F = p \times A = p \times \pi \times \left(\frac{D}{2}\right)^2 = 0,6 \times \pi \times \left(\frac{16}{2}\right)^2 = 120 \text{ N}$$

⇒ **Selected cylinder: TN16-200, which has a dual-rod design to aid in guiding movement.**

Table 14 – TN16-200 Cylinder Parameters[13]

Cylinder Model	TN10-40
Piston Bore	16 mm
Stroke	200 mm
Actuation Type	Double Acting
Rod Type	Dual Guide Rods (Parallel)
Operating Pressure	0.1 ~ 1.0 MPa (1 ~ 10 bar)
Maximum Pressure	1.2 MPa
Operating Temperature	0 ~ 60°C
Operating Speed	50 ~ 500 mm/s
Working Medium	Compressed Air (Lubricated or Non-lubricated)
Port Size	M5

Required Time for Cylinder to Complete Stroke: $t = 1 \text{ s}$

$$\rightarrow \text{Cylinder Extension Speed: } v = \frac{L}{t} = \frac{0,2}{1} = 0,2 \text{ m/s}$$

Using the relationship $v = \frac{Q}{A}$ we determine

Required air flow to control the cylinder:

$$\Rightarrow Q = v \times A = 0,2 \times 0,0002 = 0,4 \times 10^{-4} \text{ m}^3/\text{s} = 2,4 \text{ l/phút}$$

⇒ The cylinder provides a pushing force that meets the required load.

→ The required air flow is low → energy efficient and suitable for compact pneumatic systems.

Design of Linear Guide and Sliders

Gravitational force acting on the load:

$$F = m \cdot g = 6,2 \times 10 = 62 \text{ N}$$

Assuming uniformly accelerated motion from rest:

$$a = \frac{2s}{t^2} = \frac{2 \times 0.2}{2^2} = 0,1 \frac{m}{s^2}$$

Inertial force:

$$F_t = ma = 6,2 \times 0,1 = 0,62 \text{ N}$$

Total force acting on each slider:

$$F_{t\delta ng} = F + F_t = 62 + 0,62 = 62,6 \text{ N}$$

The eccentric moment is the moment generated due to the load being offset from the center of the sliding system (d = 380 mm, from the load center to the center of the two sliders)

$$M = F \times d = 62,8 \times 0,07 = 4.396 \text{ N.m}$$

This **eccentric moment** is the torsional force that the two sliders on the guide rail must withstand due to the load being off-centered.

Forces acting on the two sliders:

Front slider (closer to the load): $F_1 = \frac{F}{2} + \frac{M}{L}$

$$F_t = \frac{F}{2} = \frac{62,6}{2} = 31,3 \text{ N}$$

Moment around the horizontal axis:

$$M_p = F \times L = 62,8 \times 0,1 = 6,28 \text{ N.m}$$

ince the labeling unit is offset toward the front, when the cylinder pushes forward, this unit tends to “tilt downward,” generating a “head-drop” type moment.

Moment around the vertical axis My=0: The load does not clearly shift left/right, so this moment can be neglected or considered negligible.

Moment around the motion axis (rolling moment): If the mechanism tends to roll around the sliding direction, then M_r would be significant. However, the labeling unit does not rotate around the rail axis. $M_r = 0$

⇒ **Selected slider type: LRM7L**



Figure 4.50 Slider selection table

Table 15 – Specifications of Linear Slide LRM7L[14]

Specification	LRM7L Value
Rail Width	7 mm
Block Dimensions (A × B)	32.5 × 21.7 mm
Block Size (C × C1)	13 × 12 mm
Mounting Hole Pitch (P)	15 mm
Mounting Screw (J)	M3 × 0.5
Dynamic Load (C_{100B})	9.27 kN
Static Load (C_0)	7.96 kN
Moment Load (M^R)	7.96 kN·mm
Weight (Block/Rail)	0.014 kg / 0.22 kg/m

4.3.2.3 Calculation and Design of the Longitudinal Motion Mechanism for the Label-Pushing Unit into the Tire

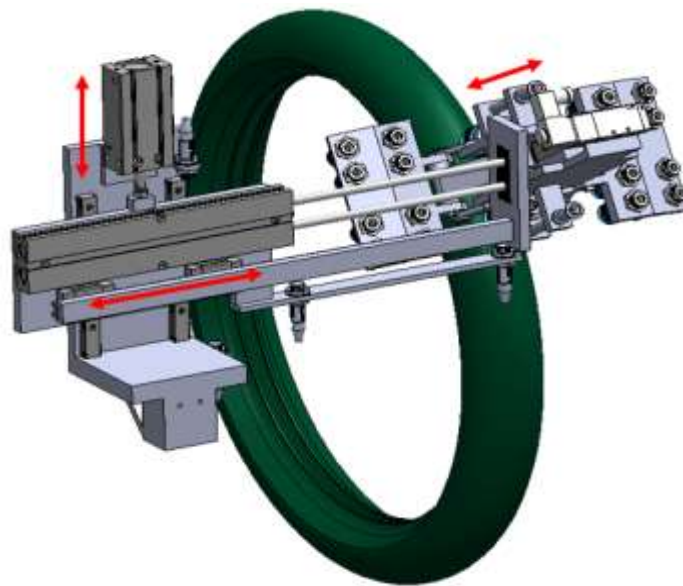


Figure 4.51 Vertical motion mechanism for label pressing unit

The **D2 cylinder mechanism** is equipped with **two proximity sensors** positioned at the start and end of the stroke.

- These sensors are responsible for **detecting the exact position of the cylinder piston** at its initial maximum position (start of stroke) and its final maximum position (end of stroke).
- Signals from the sensors enable the control system to **determine the operating state**, ensuring **safety and synchronization** of the mechanism's movement.

The **labeling mechanism** is mounted **off-center on the fixture assembly**, resulting in an **asymmetric load** during vertical movement. The entire assembly is raised and lowered **vertically** by a **single cylinder (D2)**.

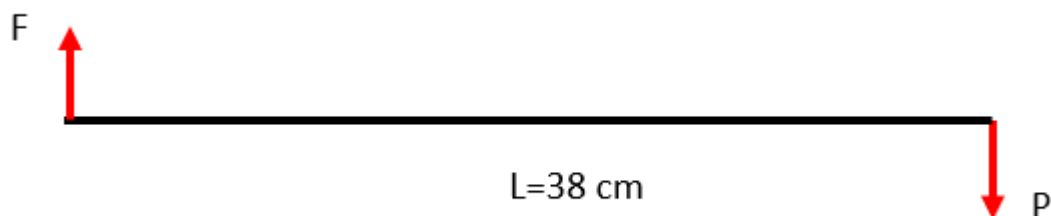


Figure 4.52 Simplified problem diagram

Due to the **eccentric design**, the entire lifting force must be borne by the cylinder. The required force is calculated as follows:
The **load of the tire labeling mechanism** is offset to one side, so the force P is the load due to gravity:

$$P = mg = 6,2 \times 10 = 62 \text{ N}$$

The **load from the fixture slider**:

$$N = mg = 3,25 \times 10 = 32,5 \text{ N}$$

Since the **cylinder bears the full lifting load**:

$$\Rightarrow F \geq N + P = 94,5 \text{ N}$$

The required **stroke length** is:

$$S = 60 \text{ mm}$$

As the cylinder **lifts an off-center load**, a **safety factor of 1.5** is applied:

$$F_{\text{tối thiểu}} \geq 1,5 \times 93,88 = 141 \text{ N}$$

Given **pneumatic pressure**:

$$p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$$

To generate this force, the required **piston area** is:

$$F = p \times A \Rightarrow A = \frac{F}{p} = \frac{141}{0,6} = 235 \text{ mm}^2$$

From the piston area, the **piston diameter** is calculated:

$$A = \pi \times \left(\frac{D}{2}\right)^2 \Rightarrow D = \sqrt{\frac{4 \times A}{\pi}} = \sqrt{\frac{4 \times 235}{\pi}} = 17,3 \text{ mm}$$

Therefore, a cylinder diameter of $D = 20 \text{ mm}$ is selected — a standard size commonly provided by manufacturers.

The maximum pushing force the cylinder can generate is:

$$F = p \times A = p \times \pi \times \left(\frac{D}{2}\right)^2 = 0,6 \times \pi \times \left(\frac{20}{2}\right)^2 = 188,5 \text{ N}$$

⇒ Selected cylinder: MD20-60

Given that the labeling mechanism operates in a limited space and requires a short vertical stroke ($S = 60 \text{ mm}$), the MD-series cylinder is an optimal choice.

Table 16 – MD20-60 Cylinder Parameters [15]

Specification	Value
Cylinder Model	MD20-60
Piston Bore	20 mm
Stroke	60 mm
Actuation Type	Double Acting
Rod Type	Single Guide Rod
Operating Pressure	0.1 ~ 1.0 MPa (1 ~ 10 bar)
Max Thrust (at 6 bar)	188.5 N
Maximum Pressure	1.2 MPa
Operating Temperature	0 ~ 60°C
Operating Speed	50 ~ 500 mm/s
Working Medium	Compressed Air (Lubricated or Non-lubricated)
Port Size	M5

Required time for the cylinder to complete its stroke: $t = 0,2 \text{ s}$

Cylinder extension speed: $v = \frac{L}{t} = \frac{0,06}{0,2} = 0.3 \text{ m/s}$

Cylinder velocity relation: $v = \frac{Q}{A}$

Required air flow rate to operate the cylinder:

$$\Rightarrow Q = v \times A = 0,3 \times 0,0003 = 0,9 \times 10^{-4} \text{ m}^3/\text{s} = 5,4 \text{ l/phút}$$

The cylinder provides sufficient thrust force for the required load.

⇒ The required pneumatic flow rate is low, which helps save energy and makes it suitable for compact pneumatic systems.

4.3.2.4 Calculation and Design of the Label Storage Mechanism

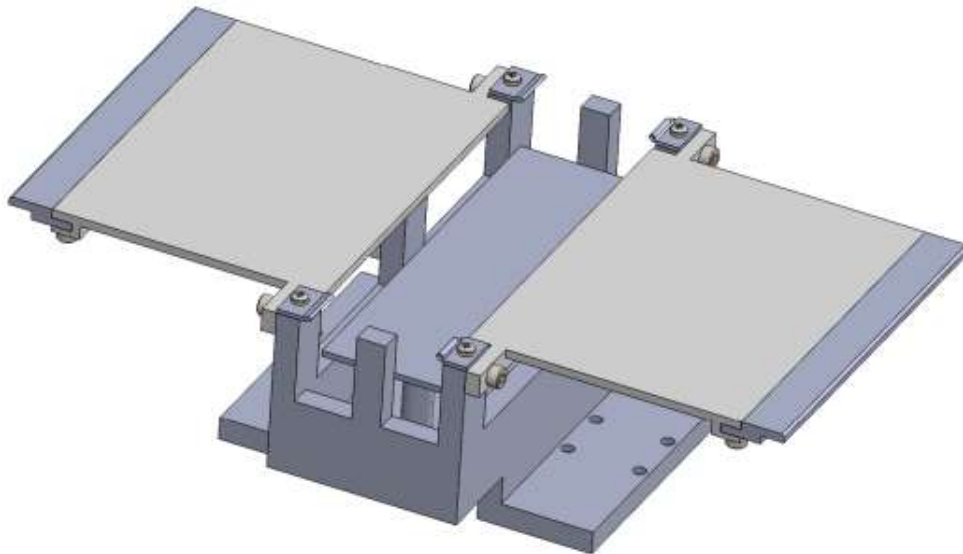


Figure 4.53 Label and tape container mechanism

The label storage box has an internal area of 15×5 cm, designed to hold labels. It serves two main functions: storing the labels and supporting two side flaps that integrate the tape-applying mechanism.

Each label is secured by four clips at the corners to ensure accurate positioning, leaving space in the center for two suction cups to easily pick up the label.

Structure of the Label Storage Box:

- Box height: 2 cm, with a capacity of 100 labels.
- The bottom of the box contains three spring-loaded shafts that continuously push the labels upward, enabling one-by-one dispensing.
- The two side flaps are made of FEFT plastic, a material that prevents tape adhesion, avoiding unwanted sticking.
- The outermost edges are made of aluminum, which allows tape to adhere, thereby holding the start and end of the tape strip applied to the label.

4.3.2.5 Calculation and Design of the Translational Cylinder Mechanism for Tape Application

The C1 cylinder is responsible for moving the label storage unit vertically (up and down). This motion allows the storage unit to reach precise positions, facilitating accurate tape placement on the label surface by the tape-application mechanism.

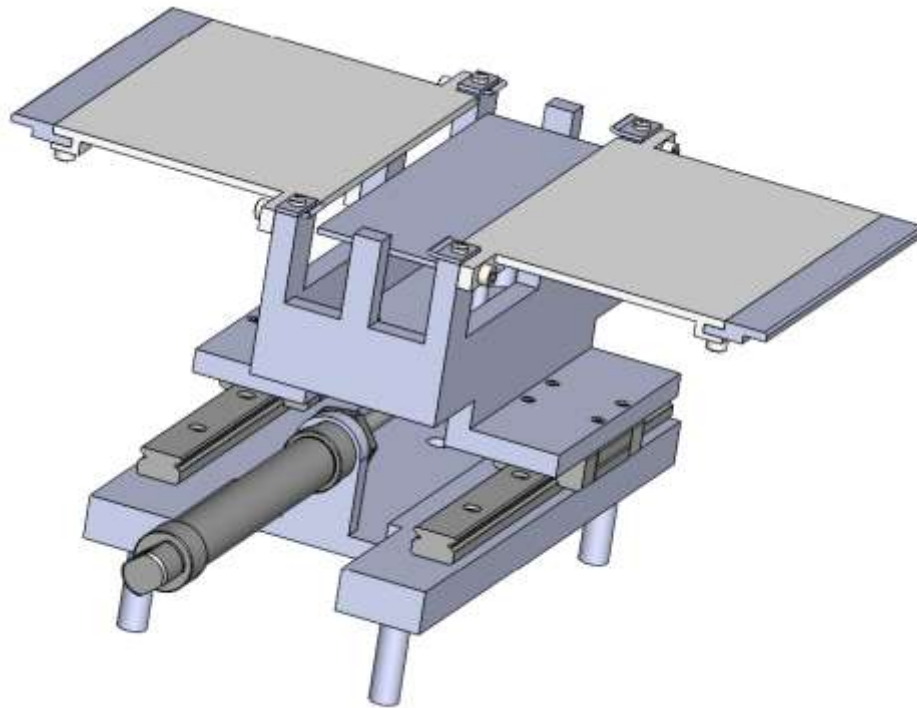


Figure 4.53 Tape pressing cylinder and label container mechanism

Operating Principle:

- During the tape application process, Cylinder C1 moves the label storage unit to specific positions corresponding to two tape strips, each 5.5 cm long, applied near the outer edges of the label.
- Applying the tape at designated positions increases precision, ensures aesthetic alignment, and improves adhesion quality of the label on the tire.

Translational Support Structure:

- Cylinder C1 is centrally mounted within the mechanism and acts as the main actuator.
- Additionally, the system is equipped with two linear guide rails and two sliders, positioned on both sides of the cylinder.
- These guide rails help:
 - Reduce friction
 - Stabilize motion
 - Minimize load on the cylinder

→ This enhances durability and ensures smooth and precise movement of the entire structure.

Advantages:

- Ensures precise positioning at each taping location.
- Space-efficient design, suitable for compact automation systems.
- Improves adhesion quality and promotes system synchronization in automated operation.

Inclined Installation Design:

To fit the limited space and synchronize with other components like the label suction arm and tape applicator, the label storage unit is tilted at a 60° angle from the ground.

- Cylinder C1 is also mounted at a 60° angle to the horizontal plane, allowing it to move the label holder in the required inclined direction.
- This angled movement enables the suction head to access and pick up the label and tape from an optimal angle, avoiding collisions and conserving space.
- This inclined design is especially well-suited for the label pushing mechanism, which requires a precise angle of contact to apply the label and tape accurately to the curved surface of the tire.

➤ **Cylinder Selection for Pulling the Label Holder for Tape Application**

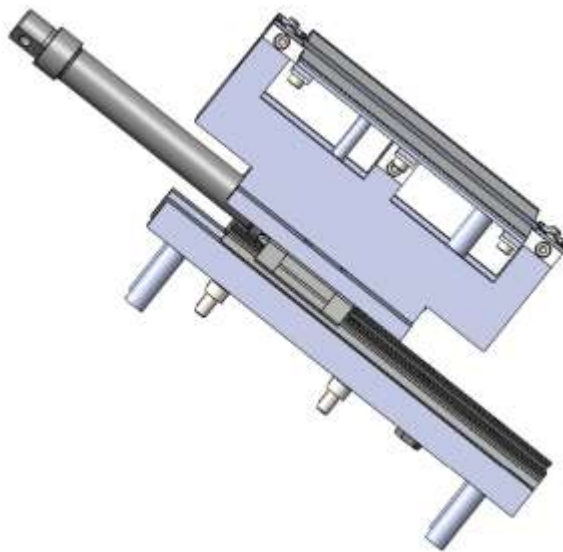


Figure 4.54 Actual tilted view of tape pressing cylinder and label container

A 4.6 kg load is pulled by a cylinder at a 60° incline. The system is assisted and friction is reduced by two guide rails (for safety considerations, the two sliders are disregarded).

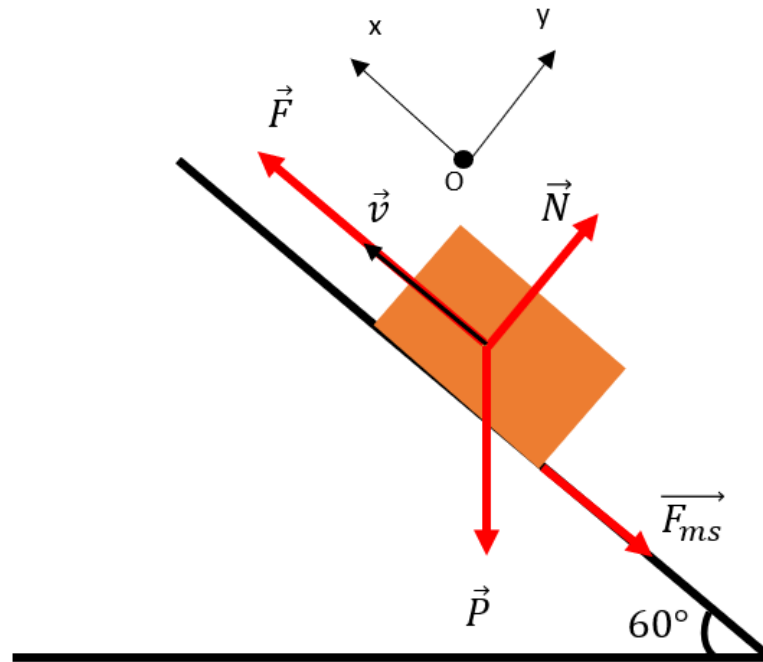


Figure 4.55 Simplified problem design of cylinder

The stroke length is 75 mm.

Required Time for Cylinder Stroke Completion: $t = 0,2 \text{ s}$

$$\Rightarrow \text{Piston speed (extension): } v = \frac{L}{t} = \frac{0,075}{0,2} = 0,375 \text{ m/s}$$

$$\Rightarrow \text{Acceleration: } a = \frac{v}{t} = \frac{0,375}{0,2} = 1,875 \text{ m/s}^2$$

Hệ số ma sát con lăn $\mu = 0,003$

Reduce it to a load-pulling problem.

According to Newton's Second Law:

It is given that,
$$a = \frac{\vec{F} + \vec{F}_{ms} + \vec{N} + \vec{P}}{m}$$

Along the positive Oy direction :

$$N = P \times \cos 60^\circ = m \times g \times \cos 60^\circ = 10 \times 4,6 \times 0,5 = 23 \text{ N}$$

Along the positive Ox direction:

$$a = \frac{F - F_{ms} - \sin 60^\circ \times P}{m}$$

$$F = ma + \sin 60^\circ \times P + \mu \times N = 4,6 \times 1,875 + 0,87 \times 10 \times 4,6 + 0,003 \times 23 = 48,7 \text{ N}$$

Greater than or equal to 48.7 N.

Pneumatic pressure: $p = 6 \text{ bar} = 0,6 \text{ N/mm}^2$

Minimum pushing force of the cylinder: $F = p \times A \Rightarrow A = \frac{F}{p} = \frac{48,7}{0,6} = 81,2 \text{ mm}^2$

Cross-sectional area of the piston $A = \pi \times \left(\frac{D}{2}\right)^2 \Rightarrow D = \sqrt{\frac{4 \times A}{\pi}} = \sqrt{\frac{4 \times 81,2}{\pi}} = 10,2 \text{ mm}$

\Rightarrow Cylinder Selection: 12MA-75 Due to the limited space in the labeling mechanism and the requirement for a short linear stroke ($S = 75 \text{ mm}$), the MA series cylinder is the optimal choice.

Table 17 – 12MA-75 Cylinder Parameters[16]

Specification	Value
Cylinder Model	12MA-75
Piston Bore	12 mm
Stroke	75 mm
Actuation Type	Double Acting
Rod Type	Single Guide Rod
Operating Pressure	0.4 ~ 0.7 MPa
Operating Temperature	0 ~ 60°C
Operating Speed	50 ~ 500 mm/s
Working Medium	Compressed Air (Lubricated or Non-lubricated)
Port Size	M5

Required air flow rate to operate the cylinder:

$$\Rightarrow Q = v \times A = 0,375 \times 0,0001 = 0,4 \times 10^{-4} m^3/s = 2,4 \text{ l/phút}$$

The cylinder provides sufficient pushing force for the allowable load.
Low required air flow → energy-efficient, suitable for compact pneumatic systems.

➤ **Guide Roller Design:**

Mass of the load supported by the sliders: 4,6 kg

Load weight:

$$F = m \cdot g = 4,6 \times 10 = 46 \text{ N}$$

Force component acting on the rail (parallel to the rail inclined at 60°):

$$F_s = F \cdot \cos 60^\circ = 46 \times 0.5 = 23 \text{ N}$$

Since the two guide blocks share the load equally due to symmetric placement:

$$F_{s1} = \frac{F_s}{2} = \frac{23}{2} = 11,5 \text{ N}$$

The load is uniformly distributed → the center of mass lies on the axis → no offset distance.

There is no moment generated (due to symmetry and even load distribution).

Each guide roller bears a load of 11.5 N from the applied force.

Since the load is small, LRM5N linear guide is selected.

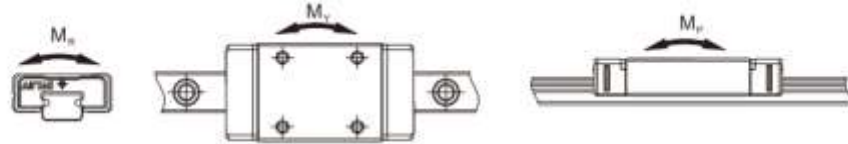
Static load factor calculation:: $f_{sl} = \frac{C_0}{P} = \frac{550}{11,5} = 47,8 \text{ N}$

This is highly safe (far exceeds the recommended value of $f_{sl} > 2,5$)

Moment and moment load factor calculation:

Since the load is evenly and symmetrically applied:

$$d = 0 \Rightarrow M = P \times d = 0 \text{ N.m}$$



Model/Item	Mounting Screw	Dynamic Load Rating(kN)	Static Load Rating(kN)	Static Rated Moment (N.m)			Weight	
		C_{100B}	C_0	M_s	M_v	M_p	Block(kg)	Rail(kg/m)
LRM5N	M2	0.33	0.55	1.68	0.99	0.99	0.0035	0.114

Table 18 – LRM5N Cylinder Parameters

Specification	LRM5N Value
Block Height (H)	5 mm
Block Dimensions (A × B)	6 mm
Block Size (C × C1)	7 × 8 mm
Mounting Hole Pitch (P)	15 mm
Mounting Screw (J)	M2 × 0.4
Dynamic Load (C_{100}^B)	1.68 kN
Static Load (C_0)	0.99 kN
Moment Load (M^R)	0.99 kN·mm
Weight (Block/Rail)	0.0035 kg / 0.114 kg/m

4.3.2.6 Calculation and Design of the Linear Cylinder Mechanism for Label and Tape Suction Using a Vacuum Cup

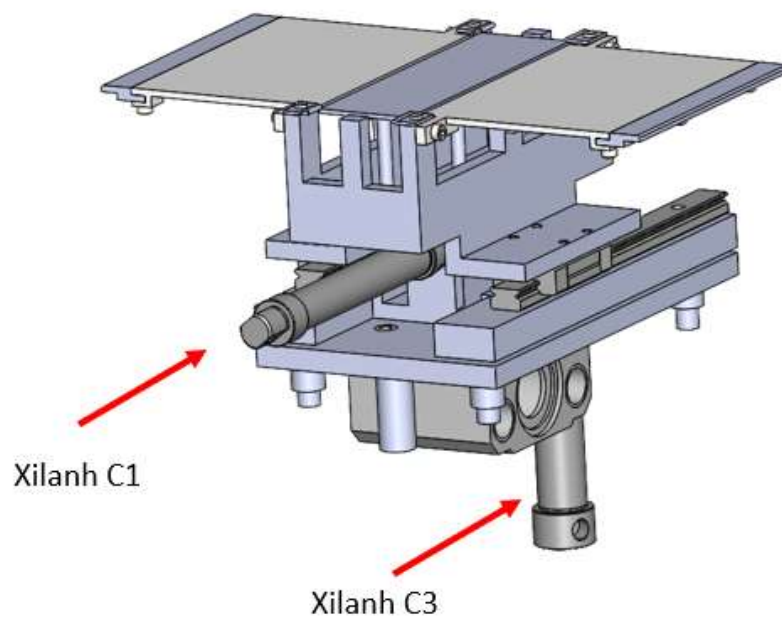


Figure 4.56 Design of C3 cylinder

The cylinder (C3) pushes and lifts the label holder assembly vertically (from bottom to top), operating in parallel with the movement direction of the gripper cylinder. At the stage when the suction cup picks up the label and adhesive tape, the label holder assembly will be temporarily lifted so the suction cup can pick up the label and tape. After the suction cup has successfully picked up the label and adhesive tape, the C3 cylinder will lower the label holder assembly back to its original position. The extended state of cylinder C3 is to allow the suction cup to pick up the label and tape, while the retracted state is for safety.

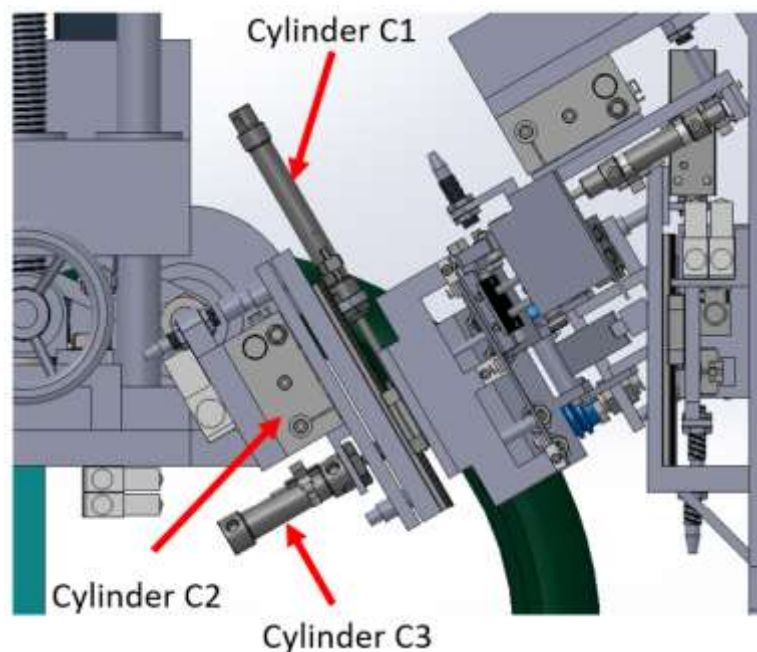


Figure 4.57 Cylinder positions in label container mechanism

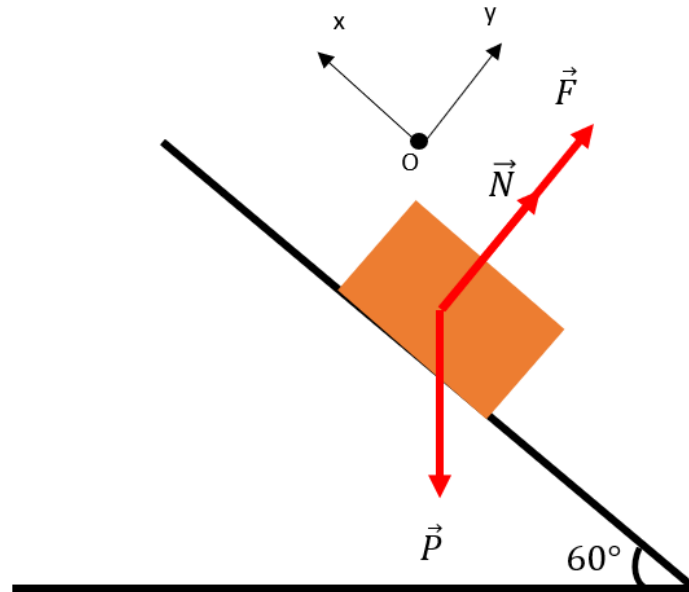


Figure 4.58 Simplified calculation of C3 cylinder

Calculation for selecting a cylinder to lift a load of 6.8 kg. The cylinder is mounted perpendicular to an inclined plane, and the inclined plane makes an angle of 60° with the ground. The cylinder lifts and lowers the load over a distance of 2 cm in 0.5 seconds, starting from zero initial velocity, with negligible friction (friction is ignored).

Stroke length:

$$S = 20 \text{ mm}$$

Time to lift the load:

$$t = 2 \text{ s}$$

Load mass:

$$m = 6.8 \text{ kg}$$

Initial velocity:

$$v_0 = 0$$

Neglect friction

Using the equation of motion with constant acceleration (because the pulling force F causes uniform acceleration):

$$s = \frac{1}{2}at^2$$

$$a = \frac{2s}{t^2} = \frac{2 \cdot 0.02}{2^2} = 0.01 \text{ m/s}^2$$

According to Newton's Second Law:

$$a = \frac{\vec{F} + \vec{F}_{ms} + \vec{N} + \vec{P}}{m}$$

Along the upward y-axis:

$$a = \frac{F - \cos 60^\circ \times P}{m}$$

(N=0 because it does not cause acceleration)

$$F = ma + \cos 60^\circ \times m \times g = 6,8 \times 0,01 + 0,5 \times 10 \times 6,8 = 32 \text{ N}$$

To push the load, the cylinder must generate a force $F \geq 32$.

Given pneumatic pressure $p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$

Minimum pushing force of the cylinder:

$$F = p \times A \Rightarrow A = \frac{F}{p} = \frac{32}{0,6} = 53,3 \text{ mm}^2$$

Area of the piston surface:

$$A = \pi \times \left(\frac{D}{2}\right)^2 \Rightarrow D = \sqrt{\frac{4 \times A}{\pi}} = \sqrt{\frac{4 \times 53,3}{\pi}} = 8,2 \text{ mm}$$

However, in practice, manufacturers only provide standard sizes such as 12 mm, 16 mm, 20 mm, 25 mm, etc. Therefore, to ensure the required safety factor, a size larger than the calculated 8.2 mm must be selected.

In this case, the nearest standard size of 12 mm can be chosen. However, to ensure higher safety because the cylinder is mounted at a 60° incline, the load is bulky, and to allow practical installation

Select diameter D=16 mm

\Rightarrow Choose cylinder type **16MA-20**. Because the labeling mechanism has limited space and requires a short stroke ($S = 75 \text{ mm}$), the MA series cylinder is the optimal choice.

Specifications of cylinder 16MA-20:

Table 19 – 16MA-20 Cylinder Parameters[17]

Specification	Details
Cylinder Model	16MA-20
Piston Diameter (Bore)	16 mm
Stroke Length	20 mm
Cylinder Type	Round Type
Acting Type	Double Acting
Rod Number	1 Guide Rod
Operating Pressure	0.1 ~ 0.7 MPa
Operating Temperature	-10 ~ 70°C
Operating Speed	50 ~ 750 mm/s (0.05 ~ 0.75 m/s)
Cushioning	Rubber cushions at both ends
Air Port Connection	M5 × 0.8

Required time for the cylinder to complete the stroke: $t = 0,2 \text{ s}$

\Rightarrow Therefore, cylinder extension speed: $v = \frac{L}{t} = \frac{0,02}{0,2} = 0.1 \text{ m/s}$

Cylinder extension speed relation:

$$v = \frac{Q}{A}$$

Required airflow to operate the cylinder:

$$\Rightarrow Q = v \times A = 0,1 \times 0,0002 = 0,2 \times 10^{-4} m^3/s = 1,2 \text{ l/phút}$$

The cylinder provides a pushing force suitable for the allowable load.

The required compressed air flow rate is low \rightarrow energy saving, suitable for compact pneumatic systems.

4.3.2.7 Calculation and design of sliding cylinder (C2) for the label holding assembly:

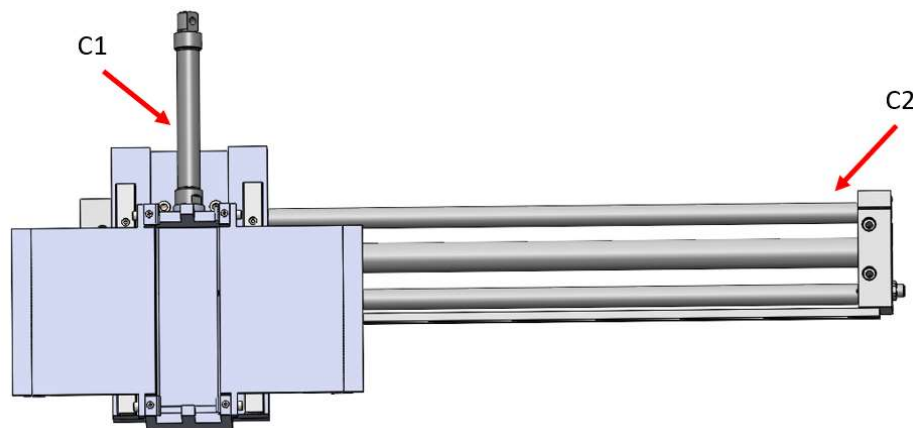


Figure 4.59 Design of sliding cylinder (C2) for mounting label container and label mechanism

To allow the label holding mechanism to move its position from tape application to the suction gripper, the design team added a horizontal sliding cylinder (50 cm long).

Function of the sliding cylinder: to move the label holding unit from left to right.

- The initial position of the sliding cylinder is where the tape is applied to the label (the tape application mechanism operates here).
- The final position is where the suction cup approaches to pick up the label and tape, preparing for the tire labeling operation.

On the sliding cylinder mounting mechanism D2, there are 2 proximity sensors to send signals for the start and end of the cylinder D2 stroke.

In this mechanism, the tape-applied label is designed to be inclined at 60° to fit the position and angle of labeling onto the tire, so the design approach is to mount the sliding cylinder tilted at a 60° angle relative to the ground. A load of 8.4 kg is attached on the slider and moves along the piston axis with a stroke length of 500 mm.

Although the cylinder is installed inclined at 60° to the horizontal, the movement of the load itself remains horizontal. Then, the gravitational force component "pulling" the slider down along the inclined plane will be:

$$W = m \times g = 8,4 \times 10 = 84 \text{ N}$$

Because the mechanism is inclined at 60° :

$$F_{t\grave{a}i} = W \times \sin(60^\circ) = 82,2 \times 0,866 = 73,1 \text{ N}$$

\Rightarrow This is the minimum force the cylinder must generate to push the load.

To push the load, the cylinder must generate a force $\geq 73.1 \text{ N}$.

The sliding cylinder stroke length is 500 mm.

Time required to move from start to end of stroke is 2 seconds.

Working speed of the cylinder:

Working speed of the cylinder:

$$v = \frac{S}{t} = \frac{0,5}{2} = 0,25 \text{ m/s}$$

Since the cylinder moves at a high speed, cushioning is needed at both ends of the sliding cylinder.

Stroke length $S = 30 \text{ cm}$

Pneumatic pressure: $p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$

Minimum pushing force of the cylinder:

$$F = p \times A \Rightarrow A = \frac{F}{p} = \frac{73,1}{0,6} = 121,8 \text{ mm}^2$$

$$\text{Piston surface area: } A = \pi \times \left(\frac{D}{2}\right)^2 \Rightarrow D = \sqrt{\frac{4 \times A}{\pi}} = \sqrt{\frac{4 \times 121,8}{\pi}} = 8,2 \text{ mm}$$

However, in reality, manufacturers only provide common standard sizes such as 12 mm, 16 mm, 20 mm, 25 mm, etc. Therefore, to ensure the necessary safety factor, we must choose a size larger than the calculated 8.2 mm.

In this case, the nearest standard size is 12 mm. However, to ensure higher safety -due to the cylinder being installed at a 60-degree incline, the bulky load, and to ensure practical installation

Choose size $D = 16 \text{ mm}$.

⇒ The maximum pushing force the cylinder can generate:

$$F = p \times A = 0.6 \times \pi \times \left(\frac{16}{2}\right)^2 = 120 \text{ N}$$

Airflow needed to operate the cylinder:

$$\Rightarrow Q = v \times A = 0,25 \times 0,0002 = 0,5 \times 10^{-4} \text{ m}^3/\text{s} = 3 \text{ l/phút}$$

⇒ **Choose sliding cylinder RMT16x500**



Figure 4.60 RMT16x500 sliding cylinder

Table 20 – Specifications of Slide Cylinder RMT16x500 [18]

Specification	Details
Product Code	RMT16x500
Piston Diameter	16 mm
Stroke Length	500 mm
Operation Type	Double acting
Working Pressure	0.15 – 0.7 MPa
Maximum Pressure	1.2 MPa
Stroke Speed	50 – 400 mm/s
Operating Temperature	–20°C to 70°C (non-freezing)
Working Medium	Clean, filtered compressed air
Air Port Thread	M5 x 0.8
Cylinder Body Material	Aluminum alloy

4.3.2.8 Design of the Tape Applying and Cutting Mechanism

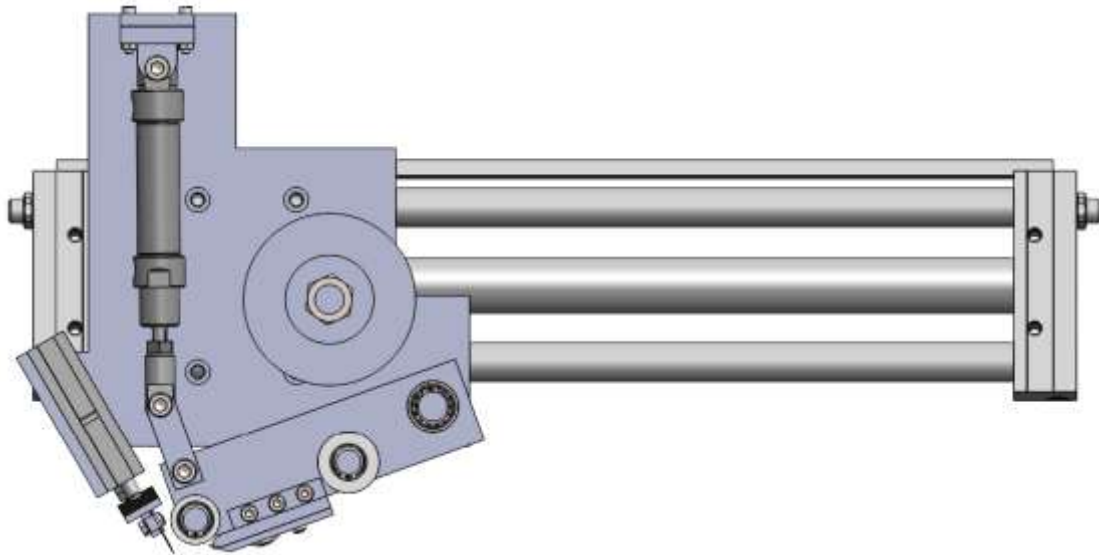


Figure 4.61 Tape sticking and cutting mechanism

The tape application mechanism is directly mounted onto the body of the sliding cylinder B2 and includes the following main components:

- Tape roll: fixed on the frame of the mechanism, used to supply continuous tape.
- Tape guiding system:
 - The tape is guided through a shaping roller, which helps stabilize and precisely align the tape strip.
 - Next, the tape passes through a groove with a width of 5.7 cm, ensuring a snug fit for the 5.5 cm-wide tape (the underside of the tape uses a non-stick FEFT layer to prevent premature adhesion to other components).
- Tape pressing mechanism:
 - At the tape's output end, a pressing roller is installed.

The **cutting blade** is positioned 1 cm away from the **roller**, and the roller is 0.5 cm away from the **leading edge of the output tape**.

At the initial position of the sliding cylinder B2, when **cylinder B1** descends, the roller is at position t_1 (the edge surface of the label-holding mechanism has not yet had tape applied). After the cylinder moves 1.5 cm, the roller reaches position t_2 (the edge surface begins to be taped). When the sliding cylinder reaches the **final position**, the roller is at position t_3 , which is 2 cm from the outer edge of the label-holding mechanism, and the blade is 0.5 cm from the outer edge at the moment of cutting.

The tape is mounted through a **guide roller**, and then passed through a **shaping roller** to ensure proper alignment and prevent deviation. Afterward, the tape is fed into a **non-stick FEFT material groove**. At the output, there is a roller that ensures the tape is evenly pressed down onto the surface of the label-holding mechanism when the cylinder advances for application.

The entire tape application mechanism is mounted on a **roller shaft** and **moves translationally via the cylinder**.

Cylinder Selection for the Tape Application Mechanism:

The cylinder is mounted above the structure but includes a pivot joint allowing it to oscillate. If the cylinder were fixed rigidly, it would not be able to operate effectively. Therefore, the design problem is reduced to selecting a cylinder oriented perpendicular to the X-axis, with the load being the tape application mechanism, which is mounted on a bearing (rotational support).

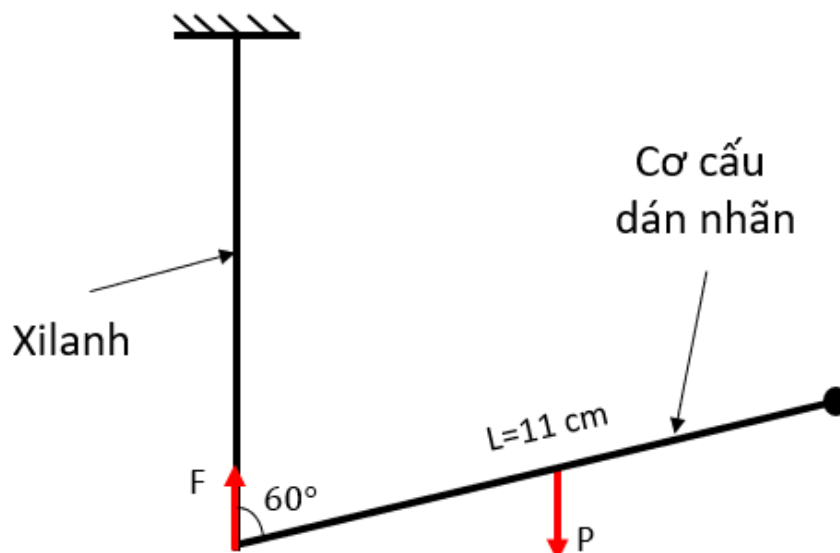


Figure 4.63 Selection of tape-sticking cylinder simplified mechanism

Cylinder Selection Based on Torque Balance for the Tape Application Mechanism:

The problem is modeled as a rod (mass = 1.2 kg) mounted onto a roller shaft. The total length of the arm is 12.75 cm, but since it's mounted on the roller, the distance from

the roller's center to the end of the lever arm is 11 cm. The center of mass is located at the midpoint of the arm.

Using the **torque balance equation**:

$$M = P \cdot L = F \cdot r \cdot \sin(\theta)$$

Where:

gravitational force

$$P = m \times g = 10 \times 1,2 = 12 \text{ N}$$

Distance from pivot to center of mass:

$$L = 5.5 \text{ cm} = 0.055 \text{ m}$$

Distance from pivot to point of cylinder force application $r = 0.11 \text{ m}$

$$\text{Angle } \alpha = 60^\circ \Rightarrow \sin(60^\circ) = 0.866$$

$$\text{Required cylinder force: } F = \frac{PL}{r \sin(\alpha)} = \frac{12 \times 0.055}{0.11 \times 0.866} = 7 \text{ N}$$

Although the actual force the cylinder needs to pull the object is only about 7 N, we should not select a cylinder that only meets this exact force when designing. The reason is that very small cylinders often have short strokes, weak bodies, are prone to vibration or bending during operation, and may not fit well within the actual installation space. Additionally, small cylinders often lack the rigidity necessary to ensure accuracy, durability, and ease of maintenance. Therefore, when choosing a cylinder, we also need to consider factors such as the required stroke (in this case, 20 mm), available installation space, and the mechanical assembly's rigidity.

Thus, even though the required force is small, we should select a cylinder with a larger piston diameter such as 16 mm to ensure proper fit, increase stability, and enhance durability during long-term operation.

Cylinder diameter: $D = 16 \text{ mm}$

Compressed air pressure: $p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$

Piston surface area: $A = \pi \times \left(\frac{D}{2}\right)^2 = 201 \text{ mm}^2$

Maximum pushing force of the cylinder (denoted as F) : $F = p * A = 0.6 * 201 = 120 \text{ N}$

Converted to mass: $P = \frac{F}{g} = \frac{120}{10} = 12 \text{ Kg}$

Required time for the cylinder to complete its stroke: $t = 0,2 \text{ s}$

\Rightarrow Cylinder extension speed: $v = \frac{L}{t} = \frac{0.02}{0,2} = 0.1 \text{ m/s}$

Cylinder extension speed (again): $v = \frac{Q}{A}$

Air flow required to control the cylinder:

$$\Rightarrow Q = v \times A = 0,1 \times 0,0002 = 0,2 \times 10^{-4} m^3/s = 1,2 \text{ l/phút}$$

Table 21 – 16MA-20 Cylinder Parameters[19]

Specification	Details
Cylinder Model	16MA-20
Piston Bore Diameter	16 mm
Stroke Length	20 mm
Cylinder Type	Round type
Acting Type	Double acting
Number of Rods	Single rod
Working Pressure	0.1 ~ 0.7 MPa
Operating Temperature	-10 ~ 70°C
Operating Speed	50 ~ 750 mm/s (0.05 ~ 0.75 m/s)
Cushion	Rubber cushion on both ends
Air Port Thread	M5 × 0.8 Select the 16MA-20 pneumatic cylinder

⇒ Selecting the 16MA-20 pneumatic cylinder is the optimal solution in terms of pulling force, stroke length, and installation space. It ensures stable operation, is easy to integrate mechanically, and meets practical working requirements in space-constrained environments.

Bearing selection for the rotating assembly (support bearing for the rotating shaft

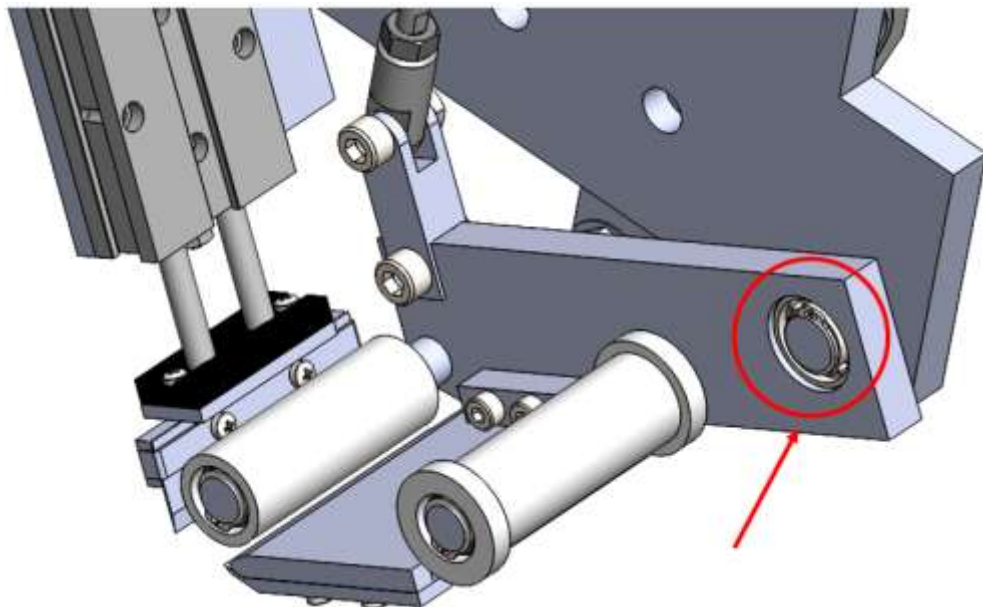


Figure 4.64 Bearing selection for rotating unit in tape sticking mechanism

A 1.2 kg mass is mounted on a mechanism with a bearing and rotates as the cylinder pushes up and down. The shaft diameter is 12 mm, and the rotational speed is very low with a light load.

The maximum load applied to the bearing is: $F = m \times g = 12 \text{ N}$

⇒ Selected bearing model: 6701ZZ"

Table 22 – Parameters of Deep Groove Ball Bearing 6701ZZ[20]

Specification	Details
Bearing Model	6701ZZ
Bearing Type	Deep groove, ultra-thin, double shielded (ZZ)
Inner Diameter (d)	12 mm
Outer Diameter (D)	21 mm
Width (B)	5 mm
Speed Limit (Grease)	30,000 rpm
Dynamic Load Rating (C)	1,100 N
Static Load Rating (Co)	430 N
Dimensional Tolerance	ISO 492, P0 (standard class)
Lubrication Type	Pre-lubricated with grease, maintenance-free

⇒**Friction roller selection for the tape system:**

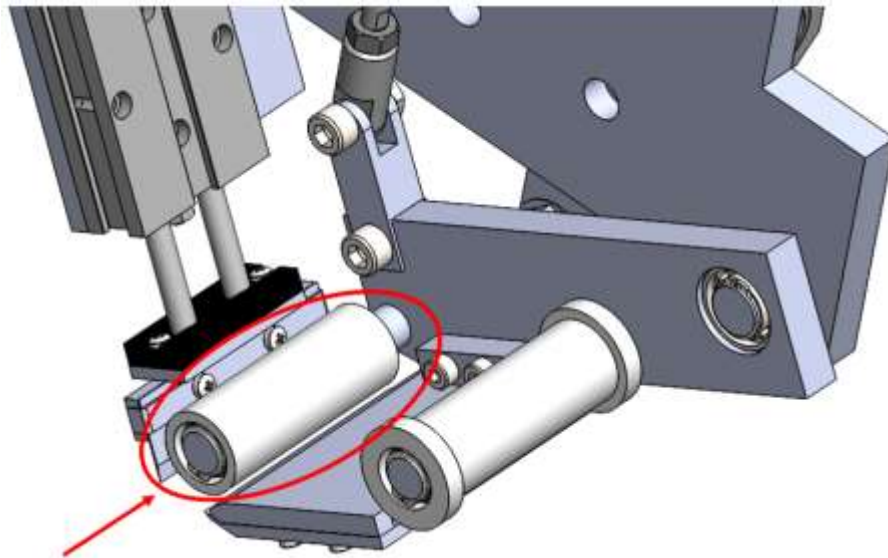


Figure 4.65 Friction roller selection for rotating unit in tape sticking mechanism

- Assume a roller with a shaft diameter of 1 cm and an outer diameter of 2 cm.
- It operates 16 hours per day over a period of 6 months
- The friction force acting on the roller during rotation is calculated as:

$$f = \frac{kN}{R} = \frac{0.001 \times 0.2 \times 10}{0.01} = 0,2N$$

Where: k is the coefficient of friction

$$N \text{ is the normal force: } N = P = m \cdot g = 10 \times 0,2 = 2 \text{ N}$$

- Rotational speed: $v = 0.18 \text{ m/s}$

$$\omega = \frac{v}{r} = \frac{0.18}{0.01} = 18 \frac{\text{rad}}{\text{s}} = 171 \text{ vòng/phút}$$

Friction torque:

$$M = F \times r = 0.2 \times 0.01 = 0.002 \text{ Nm}$$

$$\text{Power loss due to friction: } P_{\text{loss}} = M \times \omega = 0.002 \times 18 = 0.036 \text{ W}$$

$$\text{Impact on lifespan: } 171 \cdot 60 \cdot 2880 = 29548800 \text{ vòng}$$

Recommended roller type: PU Ø20 × 10mm

Table 23 – Parameters of PU Roller[21]

Specification	Details
Roller Specification	PU Ø20 × Shaft Ø10 mm
Outer Diameter (D)	20 mm
Shaft Diameter (d)	10 mm
Roller Length (L)	30 mm
Roller Cover Material	Polyurethane (PU), Shore 85A–95A
Shaft Material	Zinc-plated carbon steel
Bearing Type	Ball bearing 626-2RS (sealed, pre-lubricated)
Dynamic Load Rating (C)	1.1 kN
Static Load Rating (Co)	0.5 kN
Maximum Rotational Speed (n max)	2800–3000 rpm
Rolling Friction Coefficient (k)	0.001 m
Roller Weight	Approx. 50–70 grams
Operating Temperature Range	-20°C to +80°C
Theoretical Bearing Life (ISO 281)	> 100,000 hours
Expected Use Duration (your case)	2,880 hours (16 hrs/day × 6 months)

Forming roller selection for the tape system:

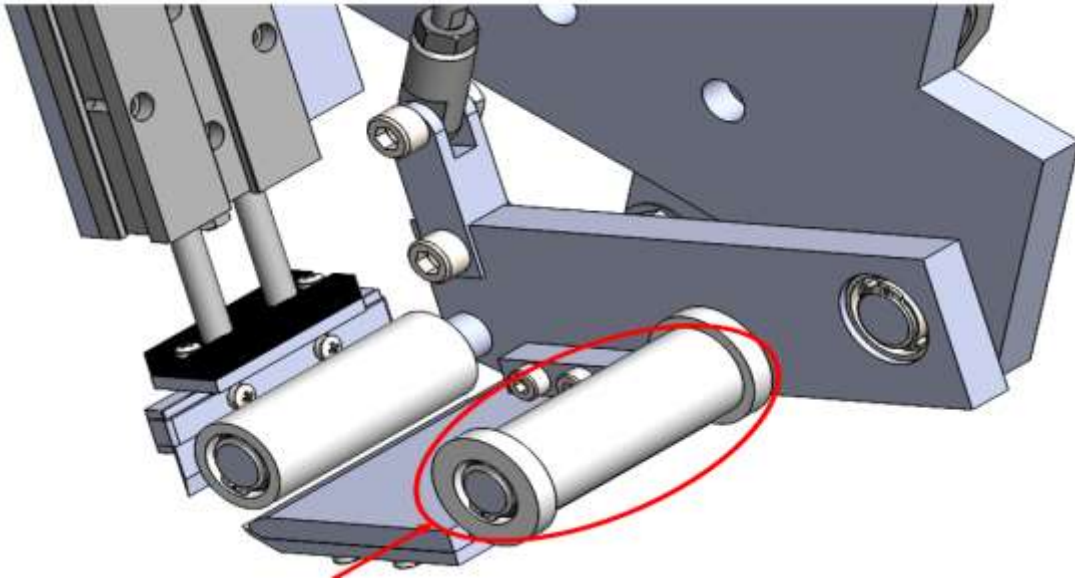


Figure 4.66 Tape guide roller selection for rotating unit in tape sticking mechanism

Forming roller selection:

- Based on the actual design, the roller is only used to guide tape at low speed and is not subjected to heavy loads; therefore, a PTFE roller is selected.
- A PTFE roller is designed with either a coating or a full body made of PTFE (Teflon) – a material known for its excellent non-stick properties.
- Roller shaft: Made of stainless steel to ensure durability.
- Outer coating: Thin layer of PTFE (Teflon) – completely non-stick to adhesive and tape.
- Bearing housing: Precisely machined for smooth rotation, vibration resistance, and wear resistance.
- Stable motion: The combination of a stainless steel shaft and precision bearings ensures smooth and stable roller operation.

Table 24 – Shaping Roller Specifications

Specification	Details
Material	PTFE (Teflon)
Outer Diameter	20 mm
Inner Diameter	10 mm
Roller Length	65 mm
Weight	33.7 g
Rotational Speed	10 rpm (very slow)
Bearing Type	Press-fit on shaft (tight fit)
Load Condition	Very light load

Design and selection of tape-cutting cylinder

Stroke: $S = 20\text{mm}$

Assumed piston diameter: $D = 10 \text{ mm}$

Pneumatic pressure: $p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$

Piston surface area:

$$A = \pi \times \left(\frac{D}{2}\right)^2 = \pi \times \left(\frac{10}{2}\right)^2 = 78 \text{ mm}^2$$

Maximum pushing force of the cylinder (F):

$$F = p * A = 0.6 * 78 = 46 \text{ N}$$

Equivalent load:

$$P = \frac{F}{g} = \frac{46}{10} = 4,6 \text{ kg}$$

Desired stroke time: $t = 0,1 \text{ s}$

⇒ Piston speed (forward):

$$v = \frac{L}{t} = \frac{0.02}{0,1} = 0.2 \text{ m/s}$$

Piston speed (forward motion): $v = \frac{Q}{A}$

Required air flow rate to operate the cylinder:

$$\Rightarrow Q = v \times A = 0,2 \times 0,000078 = 0,16 \times 10^{-4} \text{ m}^3/\text{s} = 0,96 \text{ l/phút}$$

⇒ Selected cylinder model: TN10-30

⇒ Compact design, suitable for narrow spaces dual rods → anti-rotation, good guidance. Suitable for precise clamping.

TN10-30 Cylinder Specifications

Table 25 – TN10-30 Cylinder Parameters[23]

Specification	Details
Cylinder Model	TN10-30
Piston Bore Diameter	10 mm
Stroke Length	30 mm
Acting Type	Double acting
Number of Rods	2 guide rods (parallel type)
Working Pressure Range	0.1 ~ 1.0 MPa (1 ~ 10 bar)
Maximum Pressure	1.2 MPa
Operating Temperature	0 ~ 60°C
Operating Speed	50 ~ 500 mm/s
Working Medium	Compressed air (dry or lightly lubricated)
Air Port Size	M5

Design and selection of sliding cylinder for tape sticking application

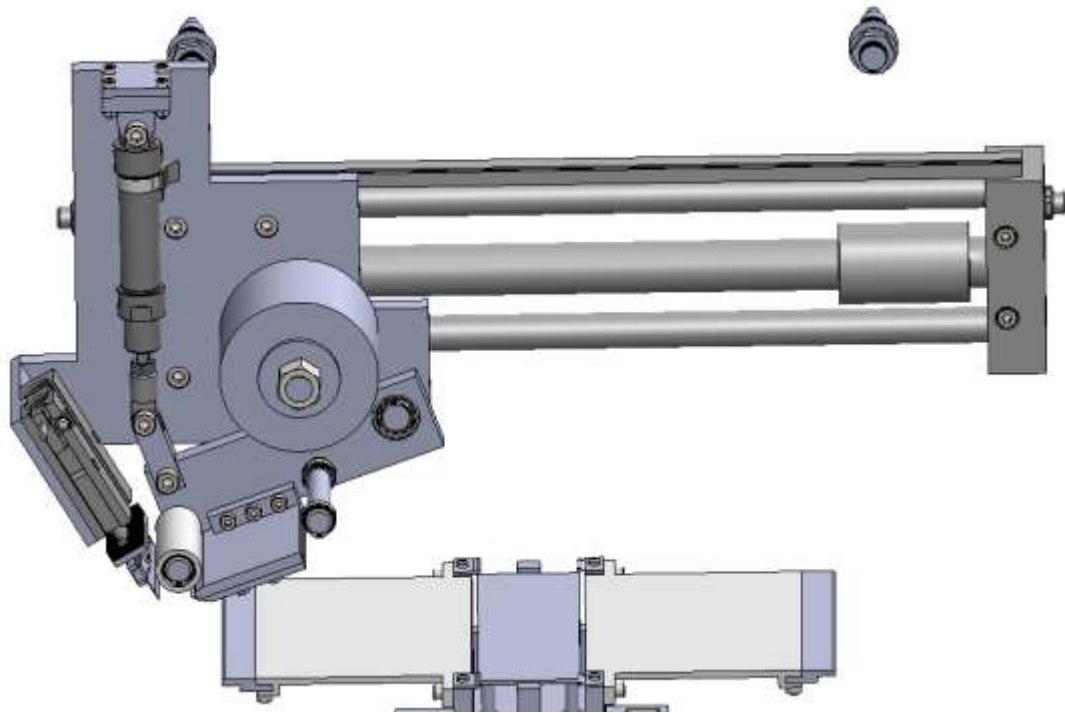


Figure 4.67 Tape and label sticking mechanism via sliding cylinder

Sliding Cylinder – Stroke Length: 30 cm

Required travel time from start to end of stroke 1,5s

Operating speed of the cylinder: $v = \frac{S}{t} = \frac{0,3}{1,5} = 0,2 \text{ m/s}$

Since the cylinder operates at high speed, shock absorbers are needed at both ends of the sliding cylinder.

Load force required for the cylinder to pull 4,3 kg

Stroke length: $S = 30 \text{ cm}$

Proposed cylinder diameter: $D = 20 \text{ mm}$

Compressed air pressure: $p = 6 \text{ bar} = 0.6 \text{ N/mm}^2$

Piston surface area: $A = \pi \times \left(\frac{D}{2}\right)^2 = 314 \text{ mm}^2$

Maximum pushing force of the cylinder (denoted as F):

$$F = p * A = 0.6 * 314 = 188 \text{ N}$$

Converted to mass equivalent: $P = \frac{F}{g} = \frac{188}{10} = 18 \text{ Kg}$

Air flow required to operate the cylinder:

$$\Rightarrow Q = v \times A = 0,2 \times 0,000188 = 0,38 \times 10^{-4} \text{ m}^3/\text{s} = 2,3 \text{ l/phút}$$

⇒ Compared to the required load force of 43 N, the available force exceeds the requirement by approximately 4 times.

Choose a larger cylinder diameter because:

- Under normal conditions, the cylinder is mounted horizontally, with the load placed on top. The main force acts horizontally → the load does not apply gravitational force on the piston rod.
- According to the design and limited working space, when the cylinder is rotated 180°, it remains horizontal, but the load-carrying platform hangs underneath. In this position, the load pulls the piston rod downward due to gravity → meaning gravity now acts directly along the piston rod's axis.
- With the load hanging below, gravitational force pulls the piston rod down along its axis, requiring the piston to continuously bear the load — it's no longer only driven by pneumatic force.
- Gravity causes the piston to press against the cylinder wall → leading to greater friction and faster seal wear.
- If the guiding mechanism is weak, and the load is heavy and hanging below → the piston may sag or become misaligned, which could cause rod or cylinder scratching.

Solution: Choose a cylinder with a larger diameter

Increases the piston area → reduces the required pressure to generate sufficient force → lowers the stress on seals. → Provides surplus pushing/pulling force → offsets the gravitational pull from the load → ensures smoother motion.

Table 26 – Parameters of Slide Cylinder RMT20-300[23]

Specification	Details
Piston Diameter	20 mm
Stroke	300 mm
Working Pressure	0.1 – 1.0 MPa
Pushing Force (at 0.6 MPa)	188.5 N
Pulling Force (at 0.6 MPa)	150 – 160 N
Permissible Load	~3–7 kg (depending on slide type and mounting direction)
Operating Speed	50 – 500 mm/s
Position Repeatability	±0.1 mm
Ambient Temperature	0 – 60°C
Guiding System	Slide or roller bearing guide
Load Mounting Option	Load can be mounted directly on the slider

4.4 Solenoid Valve Selection and Calculation

Table 27 – Cylinder Components in the System

Cylinder	D (mm)	Stroke (mm)	Flow rate (L/min)	Time (s)	Air port (mm)	solenoid valve
Tire pressing cylinder (SC50×75)	50	75	28,8	0,2	1/4	Van 5/2 1 coin 4V110-M5
PE film clamping cylinder (A1) (TN16-175)	16	175	4,2	0,5	M5×0,8	Van 5/3 4V130C-M5
Line applying cylinder (A2) (TN10-30)	10	30	0,47	0,3	M5×0,8	Van 5/2, 1 coin 4V110-M5
Line cutting cylinder (A3) (TN10-50)	10	50	1,2	0,2	M5×0,8	Van 5/2, 1 coin 4V110-M5
Tape applying cylinder (B1) (16MA-20)	16	20	1,2	0,2	M5×0,8	Van 5/2, 1 coin 4V110-M5
Tape cutting cylinder (B3) (TN10-30)	10	30	0,96	0,2	M5×0,8	Van 5/2, 1 coin 4V110-M5
Sliding cylinder (B2) (RMT20-300)	20	300	2,3	1,5	M5×0,8	Van 5/3 4V130C-M5
Pushing cylinder for tape application (C1) (12MA-75)	12	75	2,4	0,2	M5×0,8	Van 5/2, 1 coin 4V110-M5
Sliding cylinder (C2) (RMT16×500)	16	500	3	2	M5×0,8	Van 5/3 4V130C-M5
Pushing cylinder for vacuum pad suction (C3) (16MA-20)	16	20	1,2	0,2	M5×0,8	Van 5/2, 1 coin 4V110-M5
Horizontal motion cylinder (D1) (TN16-200)	16	200	2,4	1	M5×0,8	Van 5/2, 1 coin 4V110-M5

Vertical motion cylinder (D2) (MD20-60)	20	60	5,4	0,2	M5×0,8	Van 5/2, 1 coin 4V110-M5
Gripper arm cylinder (D3) (TN10-40)	10	40	0,13	0,3	M5×0,8	Van 5/2, 1 coin 4V110-M5

In a pneumatic system, selecting the appropriate solenoid valve is a key factor to ensure stable airflow, meet the cylinder speed requirement, and match the connection type of each mechanism.

System characteristics:

- The cylinders used in the mechanism have small piston diameters, mainly ranging from Ø10 mm to Ø25 mm, except for the tire labeling pressing cylinder.
- The air inlet threads of the cylinders follow the M5×0.8 standard, corresponding to small-size connectors.
- The required airflow for each cylinder typically ranges from 110–150 L/min, ensuring stable operation without pressure drop.

Advantages of the V100 valve series:

- Suitable output airflow: The SMC V100 solenoid valve series provides an airflow range from 110 to 150 L/min, ideal for small cylinders operating at moderate speed.
- Built-in M5 connection: The V100 is designed with a standard M5×0.8 thread, easily integrated directly into cylinders without the need for adapters.
- Compact size: Suitable for limited-space machine designs, especially in layouts requiring compactness, such as the labeling module in your design.
- Energy-saving and quick response: The valve operates with low power consumption (~0.5W), enabling fast response and energy efficiency in continuously operating pneumatic systems.

4.4.1 Airtac Valve 4V130C-M5 (for 3-position stop cylinder A1 and sliding cylinders B2, C2)

- 5/3 Valve – controls 3 positions (start – middle – end of stroke):
 - + The valve has 5 ports (2 supply ports, 2 exhaust ports, and 1 inlet port) and 3 control positions, suitable for controlling a cylinder to stop at three points.
 - + The middle position of the valve is a hold-stop state, which means cutting off the air supply to the cylinder and closing both exhaust ports, keeping the piston stationary at its current position (especially necessary when stopping mid-stroke).
- Suitable for precise control requirements:
 - + Valve 5/3 allows the cylinder to stop mid-stroke without drifting, which is particularly important when fixing the mechanism at an intermediate position.
 - + Combined with a flow control valve, the user can adjust the cylinder's movement speed as required.
- Appropriate size and flow capacity:

- + The Airtac 4V130 series uses M5 threaded ports, suitable for small to medium pneumatic systems.
- + The required airflow of approximately 4.2 liters/min is relatively low → this valve provides more than enough capacity, ensuring stable operation at 0.6 bar pressure.

Reputable manufacturer – easy to replace and maintain: Airtac is a widely used pneumatic equipment brand in Vietnam, with easily available components, saving maintenance time and replacement costs.



Figure 4.68 Airtac 4V130C-M5 valve

Table 28 – Parameters of Airtac Solenoid Valve 4V130C-M5[24]

Parameter	Value
Model	4V130C-M5
Valve Type	5/3 Solenoid Valve (5 ports, 3 positions)
Center Position Type	Closed center (air supply and exhaust blocked)
Port Size (Threading)	M5 × 0.8
Working Pressure Range	0.15 ~ 0.8 MPa (approx. 1.5 ~ 8 bar)
Maximum Pressure	1.0 MPa (10 bar)
Control Voltage	24V DC
Coil Power Consumption	~2.5 W (DC)
Response Time	≤ 0.05 s
Operating Temperature Range	5°C ~ 50°C
Rated Flow Coefficient (Cv)	0.15
Actuation Method	Electromagnetic (solenoid operated)
Valve Body Material	Aluminum alloy
Average Service Life	> 15 million cycles

4.4.2 Van Airtac 4V110-M5:



Figure 4.69 Airtac 4V110-M5 valve

- A 5/2 valve has 5 ports (1 air supply port, 2 output ports to the cylinder, 2 exhaust ports), and it controls 2 positions: the beginning and end of the stroke.
- This valve allows the cylinder to perform forward–backward movement clearly and stably.
- Unlike the 5/3 type, this valve does not have a mid-stroke stop state, so it is commonly used for continuous movements that do not require intermediate stops.
- Suitable applications in the system:
 - + Suitable for double-acting cylinders in mechanisms such as: label picking, label pushing, label applicator movement – cases that do not require mid-stroke stops.
 - + Combined with a flow control valve, the cylinder's movement speed can be adjusted, ensuring smooth and precise operation.
- Highlighted technical specifications:
 - + Air thread port: M5×0.8 → directly compatible with small cylinders, no adapter needed.
 - + Rated air flow: ~110 L/min at 0.6 MPa → sufficient for small to medium cylinder diameters (Ø10 – Ø25).
 - + Working pressure: 0.15 ~ 0.8 MPa → stable operation within the common pressure range of industrial pneumatic systems.
 - + Flexible control voltage: typically uses DC24V for the control system.

4.4.3 Use of PC4-M5 Fitting

After selecting a 5/2 solenoid valve to control the pneumatic cylinder, the next step is to choose a suitable fitting to connect the valve to the air tubing. In this case, the PC4-M5 pneumatic fitting is selected for the following reasons:

- Thread Compatibility with Valve:
 - The 5/2 valve used in the system features M5 × 0.8 threaded ports.

- The PC4-M5 fitting has a matching M5 × 0.8 male thread, ensuring a proper seal and tight fit without the need for additional adapters.
- **Tubing Size Compatibility:**
 - The PC4-M5 is designed for pneumatic tubing with an outer diameter of Ø4 mm, a compact tubing size suitable for systems with low air flow and limited installation space.
- **Quick and Easy Connection:**
 - The PC4-M5 is a straight push-to-connect fitting, using a spring-loaded collet to securely grip the tubing.
 - This allows for quick installation and disassembly, improving assembly efficiency and simplifying maintenance.



Figure 4.70 PC4-M5 connector

Table 29 – Parameters of Fitting PC4-M5[26]

Parameter	Specification
Model	PC4-M5
Type	Push-in straight fitting
Thread Size	M5 × 0.8 (external metric thread)
Compatible Tubing Diameter	Ø4 mm (PU, PE, or nylon tubes)
Working Pressure Range	0 – 1.0 MPa (up to 10 bar)
Max Withstanding Pressure	~1.5 MPa (15 bar)
Operating Temperature Range	0 – 60°C (depending on seal material)
Body Material	Nickel-plated brass or engineering plastic (varies by brand)
Collet Material	Stainless steel
Compatible Tubing Types	PU, PE, Nylon (outer diameter Ø4 mm)
Function	Connects M5 thread port to Ø4 mm pneumatic tubing via push-in mechanism

4.4.4 Throttle Valve - Sang-A GNSE04M5

The Sang-A GNSE04M5 throttle valve is installed at the exhaust port of the pneumatic cylinder to regulate the airflow released from the cylinder. This control mechanism helps manage the piston's movement speed effectively.

Function and Advantages:

- **Controls Exhaust Flow for Speed Adjustment:**
 - By adjusting the exhaust air, back pressure is increased inside the cylinder, resulting in smoother and slower piston movement.
 - This method ensures better control compared to regulating inlet flow, particularly in reducing vibration or jerky motion during operation.
- **Precise Manual Adjustment:**
 - The throttle valve features an adjustable screw knob that allows users to fine-tune the exhaust flow, thus making it easy to adjust the cylinder speed according to the application's specific requirements.
- **Improved Stability and Responsiveness:**
 - Exhaust-side throttling provides more consistent speed control, especially under varying loads, and helps maintain system stability.

Typical Applications:

Used widely in automation, robotics, and pneumatic actuators where precise speed control and smooth operation are essential.



Figure 4.71 SL M5 and PT1/4 flow control valves

Table 30 – Parameters of Flow Control Valve SL M5 and SL PT1/4[26]

Parameter	Specification
Connection Type	M5 × 0.8 (male thread)
Orifice Size	4 mm
Working Pressure Range	0 – 150 psi (0 – 9 kgf/cm ² / 0 – 900 kPa)
Operating Temperature	0 – 60°C
Fluid Medium	Air (compressed, dry)
Overall Dimensions	10.4 × 24.5 × 29.5 mm
Weight	8 g

CHAPTER V: DESIGN OF CONTROL CIRCUIT DIAGRAM

5.1 Selection of Devices for the System

5.1.1 Selection and Calculation of Sensors for the System:

5.1.1.1 Autonics PRDL12-8DN Proximity Sensor

- **Electrical Safety:** The 24VDC power supply is considered low voltage, which is classified as safe for human interaction according to industrial standards. This minimizes the risk of electric shock during operation, maintenance, or in the event of unexpected incidents, making it particularly suitable for environments where operators frequently interact with the equipment.
- **Compatibility with Control Devices:** Most commonly used industrial control devices—such as limit switches, proximity sensors, pneumatic solenoid valves, and intermediate relays—are designed to operate at 24VDC. Using a single power standard simplifies circuit design, reduces the number of required power sources, and enhances overall system stability.
- **Convenient Connection to Frequency Inverters:** Modern frequency inverters typically feature digital input terminals that operate at 24VDC, allowing direct connection with relay contacts in the control circuit without the need for additional interface or isolation circuits. This reduces component count, saves panel space, and increases signal transmission reliability.
- **Ease of Maintenance, Installation, and Expansion:** A system utilizing a 24VDC power supply ensures safer and easier installation. Furthermore, when system expansion is required (e.g., adding sensors, valves, indicator lights), maintaining a consistent voltage standard ensures a fully integrated control system, simplifying wiring and maintenance for technicians.

Design and Selection of Sensors: Limit Sensor for Cylinder Stroke (Proximity Sensor)

In a control system using a relay logic circuit, sensors are installed at the end positions of the cylinder's stroke (both extended and retracted). Their purpose is to accurately detect when the cylinder has reached the desired position.

When the cylinder completes its stroke, the sensor detects this condition and sends an electrical signal (typically in the form of contact closure or opening) to the relay circuit. Once the relay is activated, it allows current to flow, thereby energizing the coil of the solenoid valve, enabling the subsequent cylinder to operate.

Thus, the sensor not only monitors the status of the cylinder but also serves as an intermediate triggering condition - meaning that the next cylinder will only be activated once the previous cylinder has completed its operation. This ensures that the process follows the correct sequence and enhances system reliability.

To ensure operator safety during system operation and maintenance, a 24VDC control power supply is selected. A 24VDC voltage level is a widely adopted standard in modern industrial control systems, offering high safety by minimizing the risk of

electric shock - especially in humid environments or when operators are working near moving equipment.

In addition, using 24VDC is well-suited for control devices such as sensors, relays, and solenoid valves, which are commonly designed to operate reliably at this voltage level. Moreover, DC power supplies are less susceptible to electromagnetic interference (EMI) compared to AC power, resulting in more reliable control signals.

Due to the low voltage level, in the event of short circuits or open circuits, the risk of electrical hazards to operators is very low, meeting industrial electrical safety standards.

During the design of the control system, two types of sensors are typically considered: inductive proximity sensors and capacitive sensors, both used to detect objects and transmit signals. The selection of the appropriate sensor depends on factors such as the material properties of the detected object, the operating environment, reliability requirements, and cost considerations.

Comparison Table: Inductive Proximity Sensor vs. Capacitive Sensor

Table 31 – Parameters of Proximity Sensor Autonics PRDL12-8DN (8mm)

Criteria	Inductive Proximity Sensor	Capacitive Sensor
Detectable Materials	Metals	Metals and non-metals (wood, plastic, liquids, etc.)
Detection Range	Shorter, but more stable	Longer, but more susceptible to interference
Sensitivity & Stability	High, less affected by environmental factors	Easily affected by humidity and dust
Durability & Lifespan	High, rugged industrial design	Lower in harsh environments
Cost	Common, cost-effective	Higher
Typical Applications	Industrial machinery, metal components	Detecting a wide range of materials

Since all components in the system that come into contact with the sensor are made of metal, the use of an inductive proximity sensor is the most suitable and optimal choice. This type of sensor operates reliably when detecting metallic materials, offering high accuracy and being less affected by environmental factors such as dust or humidity—common conditions in industrial mechanical systems.

In addition, inductive proximity sensors offer high durability, are easy to install, and are generally more cost-effective compared to capacitive sensors. They have been widely adopted in systems using pneumatic cylinders to detect stroke positions.

Selected sensor model: Autonics PRDL12-8DN - 8mm sensing distance, NO-NPN output, 12–24VDC.



Figure 5.11 Autonics PRDL12-8DN - 8mm sensor

Table 32 – Parameters of Proximity Sensor DMSG-N020[27]

Specification	Value
Wiring & Power Supply	3-wire DC, 12–24VDC
Sensing Face Diameter	M12
Sensing Distance	8 mm
Installation	Non-flush (non-shielded) mounting
Standard Sensing Target	25 × 25 × 1 mm (iron)
Response Frequency	400 Hz
Current Specifications	Current consumption: Max. 10 mA
Control Output	NPN Normally Open (NO)
Material	Brass (nickel-plated)
Cable Standard / Material	Standard cable
Protection Rating	IP67
Body Length	Long body
Ambient Temperature	Operating: -25 to 70°C; Storage: -30 to 80°C
Ambient Humidity	Operating: 35 to 95% RH; Storage: 35 to 95% RH
Hysteresis	Max. 10% of sensing distance
Residual Voltage	Max. 1.5V
Weight	Approx. 92 g

5.1.1.2 Cylinder Body Sensor 16MA (DMSG-N020)

The DMSG-N020 travel sensor belongs to the DMS series. It is a magnetic proximity switch recommended by the manufacturer for use with cylinders that have a sensor mounting slot, typically the 16MA cylinder.

- The 16MA cylinder is designed with a round body or with a slot suitable for mounting DMS series sensors.
- The DMSG-N020 has a compact size, making it easy to install into the slot or mount directly onto the cylinder body using the included clamp.
- Electrical specifications compatible with control systems:

- Power supply: NPN/PNP: 5V ~ 30V DC
- Output signal: selectable NPN or PNP type, compatible with the control system input circuit.
- Low current consumption and power: low power consumption ensures safe operation with digital inputs.

Stable and Durable Performance:

- Switching Frequency 1000 Hz: Suitable for high-speed applications.
- Wide Operating Temperature Range: -10°C ~ 70°C, adaptable to various industrial environments.
- Excellent Water and Dust Resistance (IP64/IP68): Ensures long-term durability and stable operation.

Safety and Circuit Protection: Integrated protective features such as reverse polarity protection and surge protection.

Quality Certification: Complies with international standards: CE marking, RoHS ensuring reliability in industrial environments..



Figure 5.2 Proximity Sensor DMSG-N020

Table 33 – Parameters of Proximity Sensor DMSJ-N020[28]

Parameter	Specification
Product Code	DMSG-N020
Manufacturer	AIRTAC
Sensor Type	Magnetic Switch Sensor
Output Type	NPN Normally Open (NO)
Operating Voltage	5V – 30V DC
Maximum Load Current	100 mA
No-load Current Consumption	≤5 mA
Switching Frequency	1000 Hz
Internal Voltage Drop	≤0.7 V
Leakage Current	≤0.01 mA
Operating Temperature Range	-10°C ~ +70°C
Protection Features	Reverse Polarity Protection, Surge Protection
Status Indicator	Yes (LED Indicator)
Standard Cable Length	2 meters

5.1.1.3 Cylinder-Mounted Sensor for TN Cylinder (AIRTAC DMSJ-N020):

After calculating and selecting the appropriate AIRTAC TN double-rod guided cylinder that meets the technical requirements (thrust force, stroke, working conditions, etc.), the magnetic proximity sensor selected is the AIRTAC DMSJ-N020. The selection of this sensor is based on the following factors:

Compatibility in design and installation:

- The TN cylinder is designed with a dedicated sensor slot along its body.
- The DMSJ-N020 sensor belongs to the magnetic sensor series specifically designed for AIRTAC cylinders, with the TN series being one of the directly compatible models.
- Sensor installation is simple using a standard mounting clamp or by sliding directly into the cylinder slot.

Compatibility with magnetic piston structure:

- The TN cylinder uses a piston integrated with a permanent magnet → The DMSJ-N020 magnetic sensor can detect the piston's position without physical contact, ensuring durability and eliminating wear.

Output signal compatibility with the control system:

- The DMSJ-N020 sensor offers either NPN or PNP output and operates within a voltage range of 5–30VDC, making it suitable for direct connection to relay inputs in the automatic control system.
- High sensitivity and stable performance, with a switching frequency up to 1000 Hz → ensures precise monitoring of piston stroke position in fast-cycle operations.

- Durability and suitability for industrial environments:

- The sensor meets IP64/IP68 protection standards, offering resistance to dust and moisture.
- Integrated protective functions such as reverse polarity protection and surge protection enhance system safety.

⇒ The selection of the DMSJ-N020 magnetic sensor for the TN-16 cylinder is fully technically appropriate, ensuring synchronization, accuracy, and safety in cylinder position monitoring, while also complying with the recommendations of the manufacturer, AIRTAC.

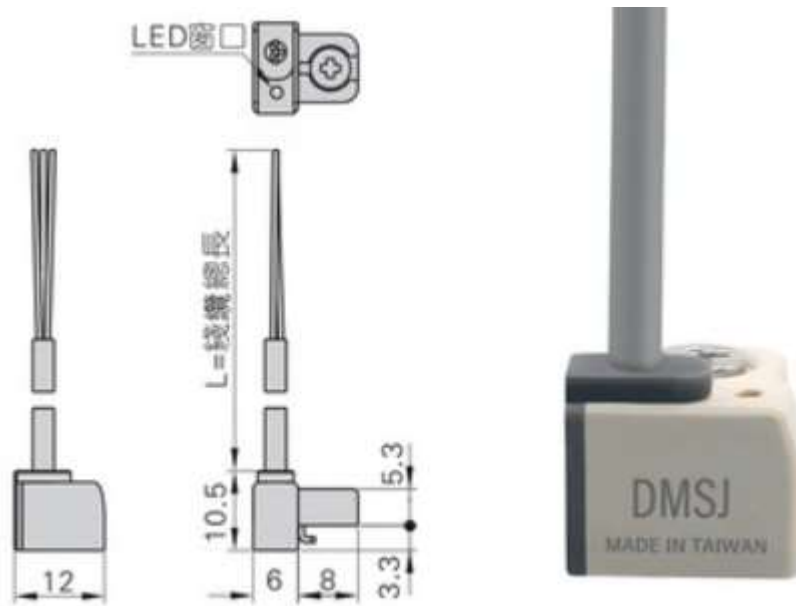


Figure 5.3 Proximity Sensor DMSJ-N020

Table 34 – Parameters of Proximity Sensor DMSJ-N020

Parameter	Specification
Product Code	DMSJ-N020
Manufacturer	AIRTAC
Sensor Type	Magnetic Switch Sensor
Output Type	NPN Normally Open (NO)
Operating Voltage	5V – 30V DC
Maximum Load Current	100 mA
No-load Current Consumption	≤5 mA
Switching Frequency	1000 Hz
Voltage Drop	≤0.7 V
Leakage Current	≤0.01 mA
Operating Temperature Range	-10°C ~ +70°C
Protection Features	Reverse Polarity Protection, Surge Protection
Status Indicator	Yes (LED Indicator)
Standard Cable Length	2 meters

5.1.2 Selection of Control Push Buttons:

5.1.2.1 START, STOP, RUN Push Buttons

In a 24VDC control circuit using relay logic to control motors and cylinders, control buttons such as Start, Stop, and Run should be momentary push buttons of the Normally Open (NO) type. This type of button is suitable for use with latching circuits, ensuring safety, ease of operation, and compliance with industrial standards.

Operation Principle – Compatible with Latching Circuit:

- A momentary push button only closes the circuit while the operator is pressing it. When combined with an intermediate relay or contactor with a self-holding

circuit, the system maintains its operating state after the button is released. This ensures automation and reduces manual effort.

- Industrial Standard and Easy Replacement:
- Standard 22mm NO momentary push buttons are commonly included in control cabinets, widely available, easy to replace, and simple to install.
- Start/Run buttons typically use NO contacts, while Stop buttons use NC (Normally Closed) contacts to ensure immediate circuit interruption in case of wire breakage or button failure.

Select momentary push buttons with LED indicator: IDEC YW1L-MF2E10Q4G (Green), YW1L-MF2E10Q4R (Red), 24VAC/DC, 22mm mounting, 1NO contact



Figure 5.4 Push button with LED indicator

Table 35 – Parameters of IDEC YW1L-MF2E10Q4G / YW1L-MF2E10Q4R[29]

Parameter	Specification
Product Code	YW1L-MF2E10Q4G (Green), YW1L-MF2E10Q4R (Red)
Button Type	Momentary Push Button
Brand	IDEC (Japan)
Contact Type	1NO (1 Normally Open Contact)
LED Indicator Color	Green (MF2E10Q4G), Red (MF2E10Q4R)
LED Voltage	24VDC
LED Type	Built-in high-brightness LED
Housing Material	Plastic
Number of Terminals	2
Button Head Diameter	Φ28.2 mm
Mounting Hole Diameter	Φ22.3 mm
Button Style	Flat head with protective bezel

Front Protection Rating	IP65 (dustproof, water-jet resistant – suitable for industrial environments)
Contact Rated Current	8A at 24VDC
Mechanical Durability	≥ 5,000,000 operations
Electrical Durability	≥ 500,000 operations (with rated load)
Wiring Method	Screw terminal
Operating Temperature Range	-25°C to +55°C
Overall Width	30 mm
Overall Height	49.3 mm
Overall Depth	64.8 mm
Certifications	CCC, CE, UL

5.1.2.2 Emergency Stop Button:

The emergency stop (E-stop) button operates on the principle of interrupting the control circuit through a Normally Closed (NC) contact. During normal system operation, the NC contact of the E-stop button allows current to flow, maintaining the operation of devices such as relays, contactors, or variable frequency drives (VFDs).

When the operator presses the emergency stop button:

- The NC contact opens, interrupting the control circuit.
- This causes relays or contactors to de-energize, cutting off power to motors or the operating system.
- If a VFD is used, the interruption of the control signal causes the VFD to stop supplying power to the motor.

After being pressed, the emergency stop button remains in a latched state (pressed and held) until the operator performs a reset action (typically by twisting or pulling the button), ensuring that the system does not automatically restart in an unsafe manner.

Select emergency stop button: IDEC YW1B-V4E01R, 22mm (D22) mounting



Figure 5.5 IDEC YW1B-V4E01R Emergency Stop Button

Table 36 – Parameters of Emergency Stop Button IDEC YW1B-V4E01R

Parameter	Specification
Product Code	YW1B-V4E01R
Manufacturer	IDEC (Japan)
Button Type	Emergency Stop Push Button (Push-Lock, Twist-Release)
Contact Configuration	1NC (1 Normally Closed Contact)
Mounting Hole Diameter	22 mm
Button Head Diameter	Approx. 40 mm (mushroom head)
Button Color	Red
Illumination	Non-illuminated (no LED)
Front Protection Rating	IP65 (dustproof, water jet resistant — suitable for industrial environments)
Contact Rated Current	10A at 250VAC / 8A at 24VDC
Mechanical Durability	≥ 300,000 operations
Electrical Durability	≥ 100,000 operations (with rated load)
Operating Temperature Range	-25°C to +55°C
Reset Method	Twist-to-release
Wiring Method	Screw terminals
Certifications	CE, UL, CCC

5.1.3 Power Supply

The system utilizes multiple devices operating at 24VDC, including solenoid valves, sensors, and intermediate relays. To select an appropriate power supply, it is necessary to calculate the total current consumption of all devices as follows:

Solenoid valve: with a power rating of 3W and an input voltage of 24VDC:

$$\Rightarrow I_{van} = \frac{P}{U} = \frac{3}{24} = 0,125A$$

Total number of valves 14 valves:

$$\Rightarrow I_{vant} = 14 \times 0.125 = 1,75A$$

Maximum current per sensor: 0,1A

Total number of sensors 21 sensors:

$$\Rightarrow I_{sensor} = 21 \times 0.1 = 2,1 A$$

Maximum current per relay: 0,04A

Total number of relays 34 relays:

$$\Rightarrow I_{rl} = 34 \times 0,04 = 1,36 A$$

⇒ To ensure stable operation, with a safety margin to account for current fluctuations, inrush currents, and potential future device expansions, a power supply with a rated current higher than the calculated total current is required.

$$I_t = 0,125 + 1,75 + 2,1 = 5,21 A$$

Selected power supply: 24VDC/10A

⇒ Model: Switching Power Supply 24V 10A (S-250-24)



Figure 5.6 24V 10A Power Supply

Table 37 – Parameters of 24V 10A Power Supply

Parameter	Specification
Input Voltage	AC 220V (Terminals L and N)
Output Voltage	DC 24V 10A
Rated Power	240W
Output Voltage Adjustment Range	±10%
Input Voltage Range	85 ~ 132VAC / 180 ~ 264VAC
Input Current	2.6A @ 115V, 1.3A @ 230V
Leakage Current	<1mA @ 240VAC
Vibration Resistance	10 ~ 500Hz, 2G 10 min. / cycle, 60 min. per axis
Operating Temperature & Humidity	-10°C ~ +60°C, 20% ~ 90% RH
Storage Temperature & Humidity	-20°C ~ +85°C, 10% ~ 95% RH
Dimensions	199 × 109 × 50 mm
Weight	0.68 kg

5.1.4 Intermediate Relay

5.1.4.1 Intermediate Relay for 24VDC Control Circuit

- The control system includes 13 solenoid valves, each with a power rating of 2.5W at 24VDC. The current consumption per valve is relatively low, approximately 0.104A.
- The selected intermediate relay is the IDEC RN4S-NL-D24, a 4-pole relay with a contact rating of 3A at 24VDC.
- Although the actual load current of each solenoid valve is only about 0.104A, selecting a relay with a 3A contact rating is a practical and suitable choice for the following reasons:

- + Safety and durability: Using a relay with a significantly higher current rating than the actual load reduces the risk of contact wear or burning due to overload or arcing during switching operations. This ensures a longer service life and higher reliability for the relay during long-term operation.
- + Provision for abnormal conditions: In practical applications, current may increase due to inrush, load fluctuations, or electrical noise. Selecting a relay with surplus current capacity helps maintain stable system operation and prevents equipment failure.
- + Compliance with technical standards and design: Relays with a 3A contact rating are commonly used, easy to source, cost-effective, and compatible with most 24VDC control systems in industrial applications. This facilitates standardization and simplifies maintenance and replacement.
- + Meets control circuit requirements: With a 24VDC coil voltage, the 3A relay ensures easy integration and effective operation in the control circuit, guaranteeing accurate and safe transmission of control signals.

Technical Specifications of Relay RN4S-NL-D24 IDEC

Table 38 – Parameters of Relay RN4S-NL-D24 IDEC[30]

Parameter	Specification
Product Series	RN4S
Number of Poles	4
Number of Pins	14 flat pins
Maximum Contact Current	3A
Coil Voltage	24V DC
Power Consumption	0.9W
Contact Resistance	Max. 100 mΩ
Contact Material	Silver
Humidity Range	5% – 85% RH
Mechanical Life (min.)	AC: 50,000,000 DC: 100,000,000
Electrical Life (min.)	200,000 operations
Operating Temperature	-55°C to +60°C
Weight	35g

5.1.4.2 Intermediate Relay for Contactor Control:

In the control system for a 3-phase 380VAC contactor with a rated current of 6A, the use of an intermediate relay is essential to isolate the control circuit from the power circuit, ensuring system safety and extending the service life of the input control devices.

Specifically, the coil of the contactor operates at a 220VAC control voltage. Instead of sending the control signal directly to the contactor coil, an intermediate relay is used to act as a signal intermediary.

The selected intermediate relay is the LY2N-J 220VAC 10A, with the following characteristics:

- Coil Voltage: 220VAC, suitable for the control voltage.

- Contact Current Rating: 10A, higher than the contactor's rated current of 6A, ensuring safe and reliable relay operation.
- Contact Type: 2 contacts (DPDT – Double Pole Double Throw), allowing for additional control or monitoring of auxiliary circuits if needed.

The selection of the LY2N-J 220VAC 10A relay ensures:

- Compliance with the system's technical requirements.
- Enhanced reliability and safety in the control process.
- Easy replacement and maintenance, thanks to the widespread availability of this popular relay model on the market.



Figure 5.7 LY2N-J 220VAC 10A Relay

Table 39 – Parameters of Relay LY2N-J 220VAC 10A[31]

Parameter	Specification
Product Model	LY2N-J
Coil Voltage	220VAC
Number of Contacts	2 (DPDT - Double Pole Double Throw)
Contact Configuration	2NO + 2NC (2 Normally Open + 2 Normally Closed)
Contact Current Rating	10A
Contact Voltage Rating	250VAC / 30VDC

Coil Power Consumption	Approx. 1.2 VA
Contact Material	Silver alloy
Insulation Resistance	$\geq 100 \text{ M}\Omega$ (at 500VDC)
Dielectric Strength	2000VAC for 1 min between coil and contacts
Mechanical Life	$\geq 10,000,000$ operations
Electrical Life	$\geq 100,000$ operations at rated load
Operating Temperature	-25°C to +55°C
Mounting Type	Plug-in (with socket)
Socket Type	Compatible with PYF08A or equivalent
Indicator Light	Built-in LED indicator
Weight	Approx. 90g

5.1.3 Selection of Timer T38N-01C

Total cycle time: 30 seconds

After the start of the cycle, a delay of 6 seconds is required, after which the cylinder should advance by sending a control signal (via relay or solenoid valve).

The cylinder will then continue operating for the remainder of the cycle.

Therefore, the timer only needs to generate a single output signal after exactly 6 seconds, each time a new 30-second cycle begins.

⇒ Selected Timer: T38N/T48N, type C timer, with the time set to 6 seconds. The 5–8 contact of the timer will be used to trigger the cylinder advance signal after a 6-second delay from the start of each 30-second cycle.



Figure 5.8 T38N-01C Timer

■ Loại C

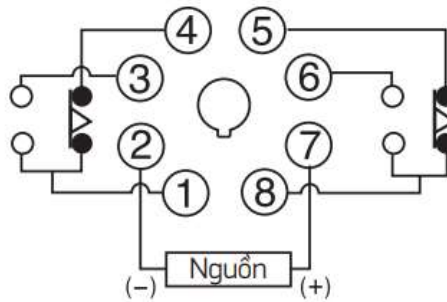


Figure 5.9 Timer T38N-01C pin configuration

Table 40 – Parameters of Timer T38N-01C[32]

Parameter	Specification
Power Supply Voltage	24–240V AC/DC, 50–60 Hz
Power Consumption	4.5VA (240V AC 60 Hz); 1.5W (24V DC)
Display Method	Rotary dial
Terminal Type	8-pin round socket
Output Signal	Power On Delay
	2 × SPDT (1c) contacts
	250VAC 3A (resistive load)
Reset Time	max. 0.1s
Relay Mechanical Life	> 10 million operations
	> 100,000 operations
Operating Temperature Range	-10°C to +50°C (non-condensing) -20°C to +65°C
Ambient Humidity	35% to 85% RH
Product Dimensions	40.5 × 50.5 × 83 mm

5.1.4 Rexroth Inverter VFC3210-1K50-1P2

Technical Specifications Table of Motor JO₂

JO ₂	22-4	1410 RPM
Kw: 2HP	CONN: Δ/Y	50Hz
220/380V	0,81	6,64/3,48A
NO	INS.CL E	20kg

The motor used in the system is a 3-phase asynchronous motor with a rated power of P = 1.5 kW, rated voltage U = 380V, and power factor cos(φ) = 0.81.

Power consumption:

$$P = \sqrt{3}UI \cos(\varphi)$$

Rated current:

$$I = \frac{P}{\sqrt{3}U \cos(\varphi)} = \frac{1492}{\sqrt{3} \times 380 \times 0,81} = 2,8(A)$$

Based on the motor power of $P = 1,5\text{kW}$

The rated current of the motor $I_{dm} = 2,8\text{ A}$

Selection of Rexroth Inverter VFC3210-1K50-1P2

The Rexroth VFC3210-1K50-1P2 inverter is used to control electric motors in the system. It is a 1.5 kW inverter with a 3-phase 380VAC power supply, supporting precise and efficient speed and torque control of the motor..

Key features of this inverter include:

- Speed control from 0 to 60 Hz.
- Motor protection against overload, short circuit, and phase loss.
- Supports communication with other automation control devices such as PLCs.
- Energy saving and reduces mechanical wear.
- Easy installation and operation.

This inverter is suitable for industrial applications requiring accurate and stable motor speed control.



Figure 5.10 VFC3210-1K50-1P2 Inverter

Table 41 – Parameters of VFC3210-1K50-1P2 Inverter[33]

Product Code	Rexroth VFC3210-1K50-1P2
Control Display	Built-in fixed 5-digit LCD screen
Control Technology	Intelligent V/f control with multiple functions
	PID Controller
	Asynchronous motor control
	Cooling fan control: constant speed
Product Code	Rexroth VFC3210-1K50-1P2
Control Display	Built-in fixed 5-digit LCD screen

Control Technology	Intelligent V/f control with multiple functions
PID Controller	
Asynchronous motor control	
Cooling fan control: constant speed	
Communication	Standard Modbus RTU
Input Voltage	Single-phase 200VAC $\pm 5\%$, 50/60 Hz; AC 200~240V
Output Frequency	0 ~ 400 Hz
	Analog Input (AI1): 0(2) to 10 V / 0(4) to 20 mA
	Analog Output (AO1): 0(2) to 10 V
	Digital Inputs (DI1...DI4): 50 mA; NPN wiring, 24VDC, 8 mA/12 VDC, 4 mA
	Relay Output (RO1): 250 VAC 3 A / 30 VDC 3 A
Ambient Humidity	$\leq 90\%$ (non-condensing)
Protection Class	IP20
Material	High-quality material with good heat dissipation, durable and long lifespan
Dimensions (W x H x D)	95 x 206 x 170 mm
Weight	1.8 Kg

Wiring Diagram: Rexroth VFC3210-1K50-1P2 Inverter - Single-phase 1.5 kW, 2

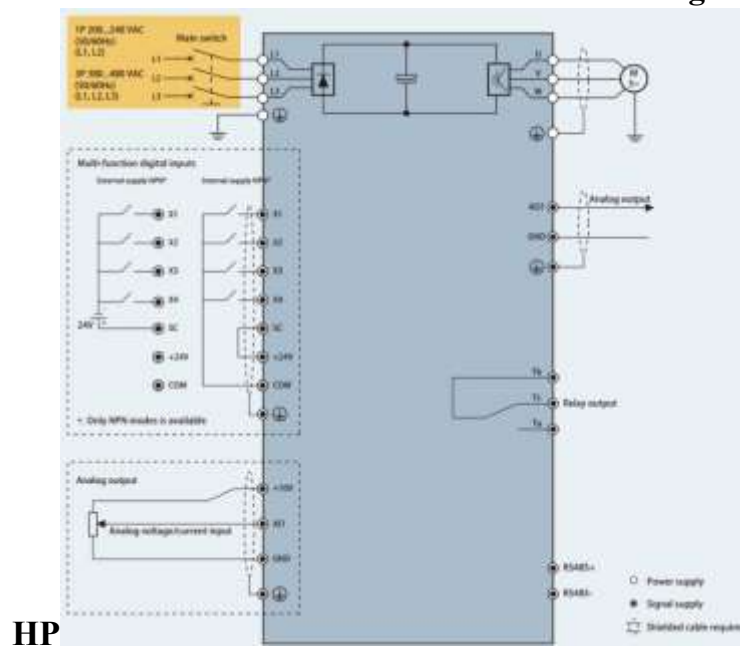


Figure 4.11 VFC3210-1K50-1P Inverter Circuit

5.1.5 Thermal Overload Relay LS MT-32 (4-6A)

The thermal overload relay is used to protect the motor from overload conditions by interrupting the circuit when the current exceeds the allowable limit for a prolonged period. The selection of the thermal relay is based on the motor's rated current. However,

to avoid nuisance tripping during normal motor operation or startup, the rated current of the thermal relay is usually chosen to be slightly higher than the motor's rated current, with a multiplying factor ranging from 1.2 to 1.3. This ensures the thermal relay only operates during actual overload situations, protecting the motor while preventing unnecessary interruptions caused by false trips.

Calculation of power consumption for the rotary motor:

$$P = \sqrt{3}UI \cos(\varphi)$$

Rated current of the rotary motor:

$$I_{dm} = \frac{P}{\sqrt{3}U \cos(\varphi)} = \frac{2200}{\sqrt{3} \times 380 \times 0,8} = 4,2(A)$$

Based on the motor power of

$$P = 2,2 \text{ kW}$$

The rated current is

$$I_{dm} = 4,2 \text{ A}$$

Thermal overload relay selection:

The rated current is :

$$I_{dm} = \frac{P}{\sqrt{3}U \cos(\varphi)} = \frac{2200}{\sqrt{3} \times 380 \times 0,8} = 4,2(A)$$

Thermal overload relay selection:

$$I_{RLN} = (1,2 \div 1,3)I_{dm} = (5,04 \div 5,46)A$$

⇒ Therefore, select the thermal relay with a rated current of approximately: $I_{RLN} = 5A$

⇒ **Selected relay: LS MT-32 (4-6A)**



Figure 5.12 LS MT-32 Relay (4-6A)

Table 42 – Parameters of LS MT-32 Thermal Overload Relay (4–6 A)[34]

Model:	LS 3P 4-6A
Adjustable Current Range:	4-6A
Number of Phases:	3-phase
Protection Type:	Overload protection (thermal overload)
Rated Voltage for Power Circuit:	Up to 690V AC
Common Voltage Usage:	380V 3-phase – standard in Vietnam
Compatible Contactor Models:	LC1-D09 to LC1-D18

5.1.6 Contactor LS MC-6a 220VAC 6A 3kW 1NO

To select a suitable contactor for the motor, first calculate the motor's rated current using the formula:

$$I_{dm} = \frac{P}{\sqrt{3}U \cos(\varphi)} = \frac{2200}{\sqrt{3} \times 380 \times 0,8} = 4,2(A)$$

The contactor current rating is calculated as: $I_{contactor} = I_{rate} \times \text{Starting factor}$ (where the starting factor ranges from 1.2 to 1.5)

⇒ Choose a contactor with a current rating of: $I_{CTT} = 1,5 \times I_{dm} = 1,5 \times 4,2 = 6,3 A$

Therefore, the contactor must have a current capacity of at least 6.3A. Considering available contactors on the market, the LS MC-6a contactor with a rated current of 6A is a suitable choice, ensuring safe operation and high durability for this motor.

⇒ **Selected contactor: LS MC-6a 220VAC 6A 3kW 1NO**



Figure 5.13 LS MC-6a 220VAC 6A 3kW 1NO Contactor

Table 43 – Parameters of Contactor LS MC-6a 220VAC 6A 3kW INO[35]

Manufacturer:	LS Electric (South Korea)
Control Voltage:	220VAC
Number of Poles:	3 poles
Current Rating:	6A
Rated Frequency:	50/60Hz
Rated Impulse Withstand Voltage (Uimp):	690VAC
Motor Power:	3kW at 380VAC

5.1.7. Selection of MCB for Total Load

Total load current: $I_t = 7,3 + 4,2 + 10 = 21,5 A$

Selection of MCB current rating: To ensure safety and account for inrush current and other transient conditions, the MCB is selected with a safety factor of 1.5 to 2 times the total load current:

$$I_{total} = (1,5 \div 2)I_t = (32,25 \div 43)A$$

⇒ Selected MCB current rating: $I_{total} = 32 A$

⇒ **Choose MCB LS BKN-b 32A 3P 10kA**



Figure 5.14 LS BKN-b 32A 3P 10kA MCB

Table 44 – Parameters of MCB LS BKN-b 32A 3P 10kA[36]

Specification	Details
Manufacturer	LS Electric
Model	BKN-B
Rated Current	32A
Number of Poles	3P (3-phase)
Short-circuit Breaking Capacity	10kA
Tripping Characteristic	B-type (fast trip)
Rated Voltage	AC 240/400VAC
Frequency	50/60 Hz
Maximum Residual Current	Not applicable (not RCCB)
Operating Temperature Range	-5°C to +60°C
Standards	IEC 60947-2; IEC/EN 60898-1

5.2 Inverter Connection and Parameter Configuration

Table 45 - JO2 motor parameters.

JO ₂	22-4	1410 RPM
Kw: 2HP	CONN: Δ/Y	50Hz
220/380V	0,81	6,64/3,48A
NO	INS.CL E	20kg

Motor Control Using VFC3210 Inverter with Two-Speed Levels for Tire Winding Process:

- Speed Level 1 (X1) → Runs at high speed for fast winding.
- Speed Level 2 (X2) → Runs at low speed when approaching the sensor, allowing for accurate stopping and transition to the next stage.

Motor Specifications:

- Wiring type: Star connection
- Rated voltage: 380V
- Rated frequency: 50Hz
- Number of pole pairs: $p = 2$ → Synchronous speed $n = 1500$ rpm
- Motor power: 1.5kW
- Rated current: 2.8A

Speed Calculation:

Table 46 - motor speeds

Speed Level	Set Frequency	Motor Speed (rpm)	Winding Speed (rpm)
Level 1 (X1)	50 Hz	1500 rpm	750 rpm
Level 2 (X2)	5 Hz	150 rpm	75 rpm

Note: The winding speed is half the motor speed due to the transmission ratio.

The purpose of using the second speed level is to allow the winding drum to rotate slowly when approaching the sensor, so it can stop immediately and proceed to the next step accurately.

❖ Inverter Setup Procedure:

Use internal supply with NPN logic:

Step 1: Factory Reset the Inverter:

Set P9.01 = 1 → then press Set → The inverter will reset to factory default.

Step 2: Motor Parameter Configuration

Press Func twice → Find and set the following parameters:

C1.05 → Motor power → 1.5 kW

C1.06 Motor voltage → 380V

C1.07 → Motor current → 2.8A

C1.08 → Motor frequency → 50Hz

C1.09 → Motor speed → 1500 rpm

Step 3: Set External Control Mode

Func → group E0:

E0.00 → select E0.01 → set value to 1 → Enables external control via terminals.

Step 4: Frequency Range Configuration

E0.08 → Max frequency: 400 Hz

E0.09 → Output max frequency: 400 Hz

E0.10 → Minimum frequency: 0 Hz

Step 5: Acceleration/Deceleration Time

E0.26 → Acceleration time: 1s

E0.27 → Deceleration time: 1s

Step 6: Configure Input Terminals

X1 → E0.01 → 1 → Speed level 1 (50Hz)

X2 → E0.02 → 2 → Speed level 2 (50Hz)

X3 → E0.03 → 3 → Forward run

Step 7: Set Speed for Each Level

Func → E3:

E3.40 → Speed level 1 → 50 Hz

E3.41 → Speed level 2 → 5 Hz

Conclusion:

With the above configuration, the VFC3210 inverter controls the motor operation as required:

- High speed (50Hz) for fast winding.
- Low speed (5Hz) for accurate sensor detection, allowing the motor to stop instantly, ensuring safety and precision for the next stage of the process.

5.3. System Operation Cycle

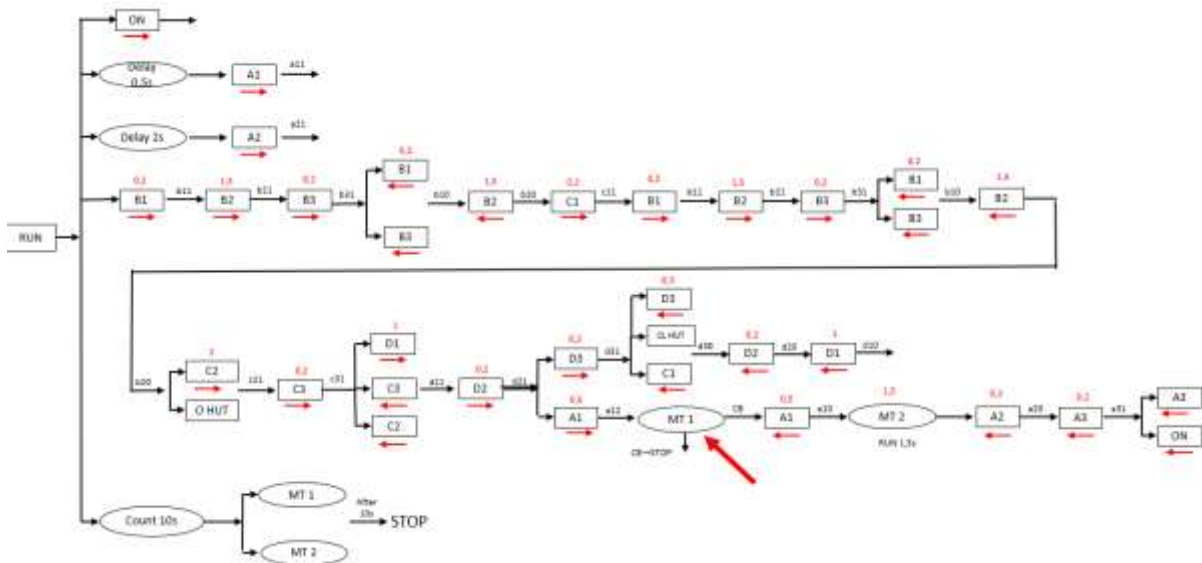


Figure 5.15 Operating cycle of tire wrapping machine

The system is designed to operate in an automated cycle, divided into four main groups of mechanisms: A, B, C, and D, to facilitate labeling, identification, and to avoid confusion during installation or maintenance.

The operating sequence is as follows:

- After the tire is placed in the system and initial steps are completed, cylinder A2 (for PE film cutting) is activated and moves forward until it reaches the end of its stroke.
- → A proximity sensor (mounted at the end position) detects the cylinder's arrival and sends a signal to trigger the next action.
- The film wrapping motor is then activated at speed level 2, corresponding to a control frequency of $f_2 = 5$ Hz.
- At this frequency, the wrapping ring rotates at 75 rpm, which is approximately 1.25 revolutions per second.
- → Therefore, the time required to complete one full rotation is less than 1 second, ensuring accurate position detection by the next sensor.
- The total time from the start of the cycle until cylinder A2 reaches its end position is measured at 11.1 seconds.
- The maximum duration for the wrapping motor to run is 1 second.
- After the motor stops (once the sensor confirms one full rotation), the labeling and finalizing mechanisms operate for an additional 2.5 seconds to complete the cycle.

Total Designed Operating Time per Cycle: $T_{total} = 14,6$ s

Comparison of Improvement Efficiency:

- Original manual operation time per cycle: 30 seconds
- Improved semi-automated operation time: 14.6 seconds

As a result, the cycle time has been reduced by nearly 50%, leading to:

- Nearly double the productivity,
- Reduced worker fatigue,

Higher consistency and precision in each production cycle.

CHAPTER VI: CONCLUSION

6.1 Conclusion

After nearly four months of dedicated work and in-depth research, our student group has successfully completed the graduation thesis titled: “Design of an Automatic PE Film Wrapping System for Motorcycle Tires.” The project originated from real production needs at Đắp Lốp Workshop and DRC Rubber Company, where manufacturing processes are increasingly transitioning toward automation and modernization. In this context, reducing manual labor, improving efficiency, and enhancing the accuracy of machinery have become essential requirements.

Through field surveys on the production line, we identified that in each PE film wrapping cycle, workers must manually perform three repetitive tasks:

- Holding and wrapping the PE film around the tire,
- Applying and cutting the positioning line to secure the film,
- Labeling the product and securing it with adhesive tape.

These manual tasks not only consume time but also reduce consistency and stability across products.

Based on this assessment, we developed a semi-automated system integrating mechanical, electrical, and pneumatic components to replace manual labor with synchronized and precise automation. The proposed system includes three independent mechanical modules, each responsible for a specific task within the wrapping process. While the system still requires human assistance for loading and unloading the tires, all internal steps have been fully automated.

- The mechanical design was undertaken by student Nguyễn Đức Nam.
- The electrical and control system design was carried out by student Nguyễn Tấn Hậu.

Through detailed design, simulation, and performance evaluation, we demonstrated that the cycle time per tire could be reduced from 30 seconds to approximately 20 seconds, thereby increasing productivity, reducing worker fatigue, and contributing to standardized product quality.

This project not only meets real-world demands from manufacturers, but also enabled our team to develop and strengthen essential technical skills such as:

- Precise mechanical design thinking
- Automated control programming,
- Interdisciplinary integration of mechanics – electronics – control,
- And particularly, the ability to solve practical engineering problems aligned with industrial automation trends.

This marks an important milestone in helping us get closer to the actual requirements of modern manufacturing environments.

6.2 Future development direction

The current PE film wrapping machine model has reached a semi-automated level, where workers are only required to assist in two stages: loading and unloading the tire. However, to meet the increasing demand for full automation in modern production lines, the system still holds significant potential for further development.

In the future, our team aims to:

- Integrate a conveyor system or robotic arm to automatically deliver tires to the wrapping position, eliminating the need for manual handling.
- Design an automated tire unloading mechanism to transfer the finished tire to the next production stage or onto a classification conveyor.
- Connect the control system to an industrial network (PLC/SCADA) for real-time monitoring, production data logging, and centralized process control.
- Enhance control algorithms by incorporating smart sensors (such as vision sensors, encoders, force sensors) to improve positional accuracy and optimize the speed of each mechanical component.
- Progress toward a fully-automated machine model, where no operator intervention is required, ensuring higher productivity, consistent operation, and improved safety for large-scale manufacturing environments.

6.3 Project Outcomes and Value Gained

After a thorough process of research, field analysis, and technical design, our team has successfully completed the key components of the project, with the following results:

Completed the improved mechanical design for the PE film wrapping machine, focusing on three main subsystems:

- PE film wrapping and cutting,
- Line application and cutting,
- Labeling and adhesive tape wrapping.
- These mechanisms were designed based on mechanical principles, utilizing transmission systems, gears, rollers, and pneumatic cylinders suitable for actual manufacturing conditions.

Simulated the machine's operation using technical software, allowing for evaluation of the improved process cycle time.

Simulation results showed that the wrapping cycle time was reduced from approximately 30 seconds to 15 seconds, thereby increasing productivity and reducing physical labor for workers.

Completed the design of the control circuit and power circuit for the system:

- The control circuit incorporates sensors, relays, push buttons, and a PLC/microcontroller to handle control signals throughout each operational phase.
- The power circuit manages the operation of motors, solenoid valves, pneumatic cylinders, and other actuators safely and efficiently.

6.4 Acknowledgements

On the occasion of completing our graduation thesis, we would like to express our sincere gratitude to:

- The Board of Rectors and all lecturers of the Faculty of Mechanical Engineering – University of Science and Technology – The University of Danang, especially the faculty members of the Mechatronics Department, for their dedicated teaching, guidance, and for imparting invaluable knowledge to us throughout our five years of study.

- Dr. Doan Le Anh, who has wholeheartedly mentored, advised, and supported us from the initial stages of forming our project idea to the completion of every mechanical drawing, electrical schematic, and control circuit.
- Danang Rubber Joint Stock Company (DRC), for providing our team with the opportunity to observe real-world manufacturing processes and for allowing us to carry out this graduation project.
- We would like to extend our heartfelt thanks to MSc. Cao Thanh Khanh for his direct guidance, constructive feedback, and technical support throughout the entire duration of the project.

Although we have done our utmost, due to limited time and experience, the project may still contain shortcomings. We sincerely welcome feedback and suggestions from lecturers and industry experts so that we can continue to improve—both the project and ourselves—as we pursue our future careers in engineering.

Thank you all very much!

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