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POLYTECHNIC UNIVERSITY OF BUCHAREST

DOCTORAL SCHOOL

from the Faculty of Industrial Engineering and Robotics

Robots and Production Systems Department

No. Decision .... **from** ....

DOCTORAL THESIS

RESEARCH INTO INCREASE THE PERFORMANCE OF PNEUMATIC ACTUATION SYSTEMS

SUMMARY

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Content

Foreword

This PhD thesis is the culmination of more than five years of intensive study, meticulous research and continuous experimentation in the fascinating field of pneumatic systems. These years have been dedicated to the joint efforts carried out at PLASTOR S.A., with the National University of Science and Technology POLITEHNICA Bucharest as a reliable partner.

The time spent on this project represents not only a segment of time in my academic development, but also a milestone in my personal and professional development. It has been a journey full of challenges, discoveries and memorable encounters with people who have positively influenced the direction and quality of my research.

In this context, I would like to express my deep gratitude to my distinguished scientific supervisor, Prof. Dr. Eng. Ștefan Velicu. Without his trust, guidance and valuable advice, this work would not have reached the level of excellence it has today.

I could not go on without mentioning the essential contribution of the directors Dr. Ing. Seres Ioan, Eng. Milas Gavril, Eng. Horia Ungur and Eng. Adrian Prada. They are the pillars on which the impressive structure of Plastor S.A. rests. Grateful for their uninterrupted support, the resources made available and the confidence shown, I would like to thank them for their decisive role in the materialization of this work.

Sincere thanks to the technical staff, colleagues in the Engineering department and the device development design team. The interaction and collaboration with each of them was essential, providing fertile ground for new ideas, experimentation and further research.

I would like to express my sincere appreciation to the management of the faculty, the department and the Doctoral School. My deepest thanks go to Prof.dr.eng. Miron ZAPCIU, Prof.dr.eng. Constantin Dogariu, and Dr.dipl.-eng. Mihai GHINEA for their constant support and encouragement throughout this endeavour.

Last but not least, I want to express my deep gratitude to my family. They have been my refuge, my inspiration and the force that has pushed me forward in moments of doubt and exhaustion. I owe them everything.

Thank you to everyone who contributed to this achievement and trusted me. This thesis is not only a reflection of my effort, but also of the community that has supported me unconditionally.

INTRODUCTION

In today's technological landscape, the development and optimisation of pneumatic drive systems is not only a necessity but also a major priority for the advancement of industry. In a context where every element of a machine and every detail of a process matters, it is essential to explore the possibilities for improvement and, above all, to identify those components that are essential but could be improved.

The thesis entitled "RESEARCH ON IMPROVING THE PERFORMANCE OF PNEUMATIC DRIVE SYSTEMS" is not just a simple presentation of pneumatic systems as they are today, but an ambitious journey into the heart of the mechanisms, a rigorous exploration of the points of resistance and vulnerability. In the course of the research, we have managed to identify a niche, a key component of pneumatic systems, which, although widely used, has so far been little touched by the hand of innovation.

The revelation of this niche was just the beginning. The work continued with meticulous analysis of the component's functionality, identifying vulnerabilities and designing solutions to increase its efficiency. Delving deeper into this evolutionary direction, we found that improving the performance of this component would not only generate a quantum leap in the operation of pneumatic systems, but could also represent a revolution in the way the industry perceives and uses pneumatics.

In this thesis, I have compiled a detailed collection of data and analysis, aiming to reveal the depths of this component. By analysing each technical aspect in detail, I will demonstrate how, through an innovative and meticulous approach, I have optimised the performance of the respective component in a significant manner.

This work, then, is not only a contribution to the existing literature, but a step forward, a boldness, a challenge to the present state of affairs. With each chapter, I aim to offer a new perspective, an original contribution and a clear vision of the potential for innovation in the field of pneumatic drive systems.

So we invite you on a journey of discovery, where theory meets practice, where innovation is the order of the day, and where every page will bring you closer to the future of pneumatic systems.

CHAPTER 1: STATE OF PLAY ON PNEUMATIC DRIVE

In a world of technological expansion, this chapter sheds light on the impressive progress of pneumatic drive, tracing a clear timeline of its evolution. The objectives of the thesis are deployed with precision, arguing the need for such research in the current technological context.

CHAPTER 2: THEORETICAL METHODS OF ANALYSIS OF PNEUMATIC DRIVE SYSTEMS

This is not a simple review of principles. Here, pneumatics is revealed in all its complexity, from the laws of hydrostatics to sophisticated control mechanisms. Methods of regulation and control are examined under the magnifying glass of expertise, giving the reader a clear view of the potential of this field.

CHAPTER 3: ASSUMPTIONS AND MATHEMATICAL MODELLING OF ASSUMPTIONS

Through a meticulous approach, the hypotheses that will guide the research are established. The aim is not only to identify problems, but also to provide solutions, through rigorous mathematical modelling and innovative experimental design.

CHAPTER 4: EXPERIMENTAL CONTRIBUTIONS ON THE DESIGN AND REALIZATION OF A UNIDIRECTIONAL CONTROL ELECTRODE

Going beyond theory, this chapter offers a practical approach, presenting the design and implementation of a revolutionary electro-soup. The experimental bench is not just a tool, it represents the future of innovation in pneumatics.

CHAPTER 5: PNEUMATIC SYSTEM DESIGN AND SIMULATION IN AUTOMATION STUDIO

Enter the digital world with Automation Studio. This chapter illustrates not only the ability to design, but also to simulate and test in a controlled environment, highlighting the accuracy and efficiency of the proposed pneumatic system.

CHAPTER 6: ANALYSIS AND VALIDATION OF EXPERIMENTAL RESULTS OBTAINED ON THE TEST BENCH

Research becomes tangible here. Every test, every result is analysed and validated, confirming hypotheses and objectives. This thorough validation demonstrates the robustness and relevance of the research.

CHAPTER 7: DATA ANALYSIS AND CONFIRMATION OF HYPOTHESES AND OBJECTIVES

The evidence is clear and the data speak for themselves. Through a detailed analysis, this chapter consolidates the findings and corroborates them with the research objectives, thus establishing a close link between theory and practice.

CHAPTER 8: FINAL CONCLUSIONS AND PERSONAL CONTRIBUTIONS

This chapter provides a reflection on the whole journey, highlighting personal values and contributions. Recommendations for the future are presented not as mere suggestions, but as logical steps in the evolution of the pneumatics field.

The paper presented provides detailed and well-structured information accompanied by 192 images. These images show pneumatic and electrical diagrams, graphs, codes, instruments, tables and drawings, all chosen for clarity and to emphasise the ideas discussed.

The bibliography presented in this thesis is extensive and rigorously selected, consisting of 151 technical and scientific papers, 24 published and forthcoming scientific articles, 33 links to web pages that were accessed between 2015 and 2023 and appendices with technical documents.

CHAPTER 1 STATE OF PLAY ON PNEUMATIC DRIVE

This chapter provides an overview of the current state of the art in pneumatic actuation, based on a review of the literature. Pneumatic actuation has undergone a significant evolution in recent decades, with a number of innovations and improvements aimed at optimising performance and efficiency.

Various research activities in the field of pneumatics by researchers from different parts of the world present methods for the design and testing of pneumatic systems for industrial automation (Design and Test of Pneumatic Systems for Production Automation - Giorgio Figliolini, Pierluigi Rea, Universita degli studi di Cassino e del Lazio Meridionale, Italy)[44], Trends in Energy-saving of Pneumatic Systems (Approach for Energy-saving of Pneumatic Systems, Yukio Kawakami, Shibaura Institute of Technology, Japan)[92], Development of Electropneumatic Systems for Industrial Automation by Remote Experimentation in a Web-based Learning Environment (Electropneumatic system for industrial automation: a remote experiment within a web-based learning environment - Farah Helúe Villa-López, Jesús García-Guzmán, Jorge Vélez Enríquez, Simón Leal-Ortíz and Alfredo Ramírez-Ramírez, Facultad de Ingeniería Mecánica Eléctrica, Universidad Veracruzana, Zona Universitaria, Xalapa, México [139], new methods for controlling pneumatic and electro-pneumatic systems (Teaching control pneumatic and electro-pneumatic circuits - a new method, António Ferreira da Silva, Adriano A. Santos, Polytechnic Institute of Porto, Portugal) [39], control of pneumatic systems using various methods such as the waterfall method in the LabView platform (Control a Pneumatic Sequence using waterfall method in the LabVIEW platform, Jose Domingos Senra Simoes, Andre Monteiro Fernandes, Enrico Augusto Rodrigues de Sebra, [108], improving the control of pneumatic and electropneumatic systems in the context of Industry 4.0 (The pneumatic and electropneumatic systems in the context of 4th industrial revolution, K. Foit, W. Banas, G. Cwikla, Silesian University of Technology Automation and Integrated Manufacturing Systems, Gliwice, Poland) [47].

A remarkable aspect, which I have observed in the numerous works studied, is a convergence in terms of the tools and methodologies used for research. Many of these studies were based on the use of advanced software and technologies similar to those adopted in the research presented in this thesis. For example, Matlab has proven to be essential for most researchers due to its ability to model and analyse the complexity of pneumatic systems. In addition, software such as Catia and Automation Studio are frequently cited as leading tools in the design and simulation of components and systems.

Another trend observed is the increased interest in affordable and flexible solutions, such as the Arduino platform, in data collection and control of pneumatic systems.

In the light of these observations, it can be said that the current state of research in pneumatic actuation gravitates towards a common goal of optimization and performance. The goal and tools mentioned in the reviewed studies resonate strongly with the approach taken in this thesis, which underlines the relevance and timeliness of our research in the broader context of the field.

1.1 Formulation of thesis objectives

In order to assess and improve the performance of pneumatic drive systems, it is essential to first define the criteria for assessing this performance. At the heart of the assessments is the ability of the systems to maintain constant operating parameters despite variations in external factors such as pressure or load. Maintaining this consistency is essential to eliminate the inherent disadvantage of pneumatic drives: air compressibility.

The main objective of the thesis is: TO INCREASE THE PERFORMANCE OF PNEUMATIC DRIVE SYSTEMS. This objective is supported by the fundamental idea of investigating the potential and benefits of an improved one-way control valve in pneumatic systems. The new valve, based on an innovative design and equipped with an electric motor for remote control and automatic adjustment, is seen as a forerunner of future advances in the field.

An essential aspect in the performance of pneumatic systems is the ability to maintain constant operating parameters in the face of variations in external factors such as pressure and load. Traditionally, air compressibility has been a major drawback for pneumatic drives, causing undesirable fluctuations in these parameters. In the context of this research, the innovative design of the new valve aims to address and minimise the impact of air compressibility, thus providing a solution for constant and optimised performance maintenance regardless of external variations.

In order to achieve this main objective, the following **specific objectives** are set:

Objective 1: To confirm the hypothesis that the speed of a pneumatic cylinder, within a pneumatic system, is directly influenced by variations in system pressure. This will be achieved through mathematical modelling using MATLAB software, simulation of the pneumatic system using Automation Studio software and experimentation on a test rig.

Objective 2: Test the hypothesis that the speed of a pneumatic cylinder is affected by the load it is moving. The procedure will include mathematical modelling using MATLAB, simulation of the pneumatic system using Automation Studio software, and testing on a test rig.

Objective 3: Demonstrate that the improved unidirectional control valve, equipped with electric motor and remote control capability, can optimise the efficiency of pneumatic systems compared to conventional designs.

Objective 4: Justify the potential of the new unidirectional control valve to automatically adjust speed according to pressure and load variations. This capability provides increased adaptability, significantly improving the flexibility and reliability of pneumatic systems.

Therefore, this thesis aims to provide concrete and innovative solutions to improve the performance of pneumatic drive systems, thus contributing to the evolution and efficiency of the industry.

CHAPTER 2 THEORETICAL METHODS OF ANALYSIS OF PNEUMATIC DRIVE SYSTEMS

Chapter 2 looks at the theoretical methods essential for the analysis of pneumatic drive systems. In this chapter, the fundamental principles governing the operation and performance of pneumatic systems are discussed in detail.

The basic principles of pneumatic drives are covered. It begins with a discussion of the law of hydrostatics, which provides an understanding of pressure in liquids and gases. The next law presented is Pascal's Law, which outlines the principle of equal pressures in a closed fluid. The principles of force transmission are then discussed in both hydraulic and pneumatic contexts. This section continues with analysis of the law of flow and the continuity equation, focusing on how fluid moves in a system. The drosel equation and Bernoulli's relation are also discussed, providing insight into the relationship between pressure, velocity and lift. Finally, the law of energy is addressed, with an in-depth exploration of Bernoulli's equation in the context of energy in a fluid.

The principles of regulation and control in pneumatics are presented. It begins with a discussion of flow regulation, presenting the specific apparatus used in this process. It continues with pressure regulation, addressing its importance in the efficient operation of pneumatic systems. Air compressibility and gas volume variation with temperature are also key topics, providing an understanding of gas behaviour under various conditions and how these properties affect the performance of pneumatic systems.

The chapter concludes with pertinent conclusions on the importance and applicability of the theoretical principles discussed, highlighting their relevance in the analysis and efficient design of pneumatic actuation systems.

CHAPTER 3 ASSUMPTIONS AND MATHEMATICAL MODELLING OF ASSUMPTIONS

Mathematical modelling of pneumatic drive systems is essential for a thorough understanding of how they work and to predict their behaviour under varying conditions. This chapter focuses on four fundamental assumptions related to pneumatic actuation systems and the process of validating them through mathematical modelling, simulation and experimentation.

3.1 Defining assumptions

Based on the context and objectives outlined, the current study makes the following assumptions:

Assumption 1: The speed of a pneumatic cylinder in a pneumatic system is directly influenced by the pressure variation in the system.

Assumption 2: The speed of a pneumatic cylinder is directly affected by the load it has to move.

Hypothesis 3: The redesigned one-way control valve equipped with an electric motor and remote control improves the overall efficiency of pneumatic systems compared to traditional designs.

Assumption 4: Automatic speed control capability in the redesigned one-way control valve effectively controls variations induced by pressure variations and load changes.

3.2 Purpose of the work

The central aim of this PhD thesis is to highlight the potential for improving the performance of pneumatic drive systems. This potential is crystallised around an innovative unidirectional control valve. The new valve, based on a revolutionary design and equipped with an electric motor for remote control and automatic adjustment, not only represents a foretaste of future advances in the field, but also brings a novel approach to address a persistent challenge: air compressibility in pneumatic systems.

One of the main drawbacks of pneumatic actuators over time has been the compressibility of air, which has made it difficult to maintain constant operating parameters in the face of variations in external factors such as pressure and load. With the innovative design of the new valve, this research explores the possibility of maintaining stable operating parameters even when external factors vary. This can eliminate one of the biggest challenges associated with pneumatic systems.

The hope is that this research will pave the way for a new era in pneumatic systems, where efficiency, adaptability and reliability are at their highest. By identifying and addressing this central challenge, the paper aims to make a significant contribution to the evolving field of industrial engineering.

Beyond these objectives, the aim of this research also aspires to contribute to the wider field of industrial engineering by:

Improving industrial practices: by verifying the benefits of an improved flow control design, this research could inform industrial practices and encourage the adoption of such innovative designs in pneumatic systems, thereby improving their efficiency and reliability.

Encouraging further research: by shedding light on this relatively unexplored area in pneumatic system design, the study can trigger further research and innovation, leading to even more advanced and efficient pneumatic solutions in the future.

By achieving these goals, the study hopes to significantly advance both the theoretical understanding and practical application of pneumatic systems in industrial engineering.

3.3 Research limitations

The research acknowledges several limitations, including experimental constraints due to test rig configuration, scope of variables considered, model limitations, specificity of unidirectional flow control valve design, and resource limitations.

The test bench provides a controlled environment for testing, however it may not perfectly mimic industry operating conditions. Therefore, while the findings of this study should give us insights into performance, there may still be discrepancies.

In this study, the main focus is on the influence of pressure and load variation on pneumatic cylinder speed in pneumatic systems. However, there might be other factors at play in a real setting, such as temperature, humidity, component wear, which are not considered in this study.

Mathematical modelling provides a theoretical basis for our understanding, the models used may be based on certain assumptions and simplifications, which may not take into account all the complexities in a practical system.

The conclusions drawn in this research are based on a specific design of a unidirectional flow control valve. Other designs or variations may have different performance, which are not considered in this study.

Although the test bench provides a controlled environment for evaluation, it may not accurately replicate operational conditions in a practical context. Therefore, while the findings of this study should provide us with relevant information on performance in an applied scenario, there may still be some inconsistencies.

There may be limitations in terms of time, budget or available technology which may limit the scope of the research.

Identifying these limitations does not weaken the research. On the contrary, it provides an honest reflection of the scope and applicability of the findings and suggests areas that could be explored in future research.

3.4 Experimental setup

Given the purpose of this paper, the research approach was structured in the following steps:

Mathematical modelling of assumptions: This is the first step, where we used mathematical analysis to predict the behaviour of the pneumatic system under various conditions.

Pneumatic system simulation: Using Automation Studio software, we simulated the pneumatic system to validate the predictions made in the mathematical modelling stage. This step helped me to understand the behaviour of the components before physical testing and identify any possible anomalies.

Construction and set-up of the experimental bench: A customised test bench was designed and built, taking into account the specifics of the research. The experimental bench was designed in CATIA software, which allowed the creation of a detailed layout plan that included pneumatic, mechanical and electronic components. The digital model provided me with an efficient interconnection of all components.

Experimental bench testing: In this stage, experiments were carried out in a controlled environment at a constant temperature of 23 degrees Celsius and 50% humidity. This setting provided a stable environment, eliminating external influences that could affect the results.

By combining mathematical modelling, simulations and experimental testing, we have taken a rigorous and detailed approach to the problems addressed in this paper.

3.5 Implications

Integrating an electric motor with a one-way flow control valve can offer significant advantages. It allows automatic, real-time adjustments of the pneumatic system, leading to more consistent pneumatic cylinder speeds, increased system efficiency and reduced manual intervention.

However, this integration also brings its share of challenges. Designing a robust control algorithm that handles the integration of electrical and mechanical systems and ensuring the durability and reliability of the system under different operating conditions are significant tasks that require careful attention.

This research aims to further investigate these challenges and propose effective solutions to ensure the successful implementation of this integration.

3.6 Expected results

Following the enhancement of the AS2201FE-01-06SK unidirectional flow control valve with the addition of a stepper motor, we expect a number of significant results that will have a positive impact on the performance of the pneumatic systems in which it is used.

More precise adjustment: The implementation of a stepper motor will allow more precise adjustment of airflow. This will improve the efficiency of pneumatic systems, allowing finer control over piston speed.

Automatic and remote control: With the ability to adjust flow remotely, this enhancement will reduce the need for manual intervention, saving time and effort.

Increased adaptability: With the ability to automatically adjust speed according to pressure variations and load changes, we expect this improved system to be more adaptable to variations in working conditions. This should lead to increased operational flexibility and reliability of pneumatic systems.

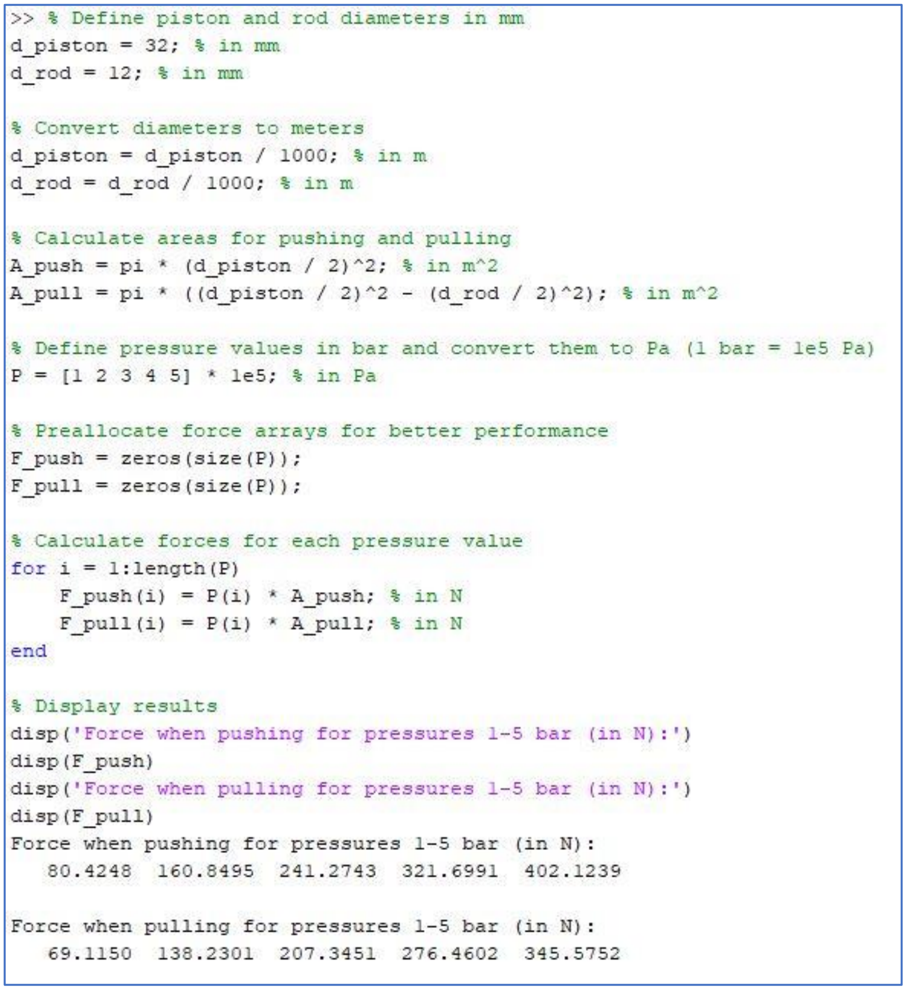
Increased efficiency: We anticipate that the redesign of the one-way control valve will lead to greater efficiency of the pneumatic system in terms of more efficient energy use and improved productivity.

In conclusion, improving this component should have a significant impact on the wider process by improving the efficiency and flexibility of the pneumatic systems in which it is used. We look forward to testing this improved unidirectional flow control valve in a real-world context to confirm these expectations.

3.7 The mathematical models used to derive assumptions

In this chapter, I focused on the simulation and mathematical modelling of the pneumatic cylinder behaviour under different conditions. Using advanced tools such as MATLAB, I addressed the following aspects:

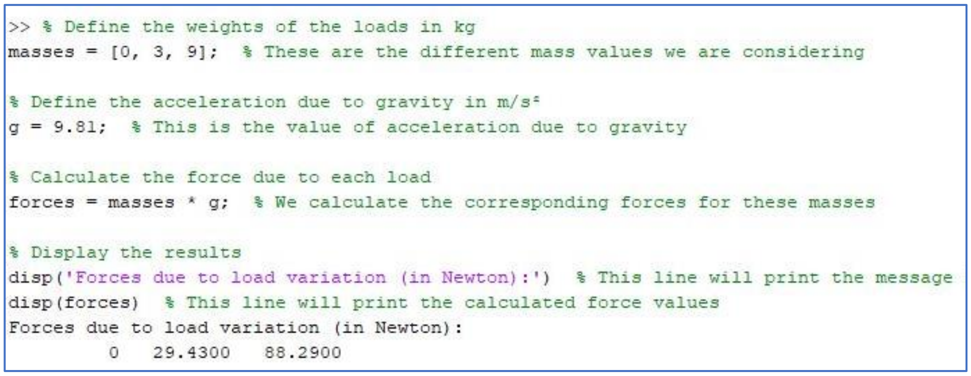
Calculation of pneumatic cylinder performance at various pressures: It provided a look at how pressure affects overall cylinder efficiency and performance.



```
>> % Define piston and rod diameters in mm
d_piston = 32; % in mm
d_rod = 12; % in mm

% Convert diameters to meters
d_piston = d_piston / 1000; % in m
d_rod = d_rod / 1000; % in m

% Calculate areas for pushing and pulling
A_push = pi * (d_piston / 2)^2; % in m^2
A_pull = pi * ((d_piston / 2)^2 - (d_rod / 2)^2); % in m^2

% Define pressure values in bar and convert them to Pa (1 bar = 1e5 Pa)
P = [1 2 3 4 5] * 1e5; % in Pa

% Preallocate force arrays for better performance
F_push = zeros(size(P));
F_pull = zeros(size(P));

% Calculate forces for each pressure value
for i = 1:length(P)
    F_push(i) = P(i) * A_push; % in N
    F_pull(i) = P(i) * A_pull; % in N
end

% Display results
disp('Force when pushing for pressures 1-5 bar (in N):')
disp(F_push)
disp('Force when pulling for pressures 1-5 bar (in N):')
disp(F_pull)
Force when pushing for pressures 1-5 bar (in N):
   80.4248  160.8495  241.2743  321.6991  402.1239

Force when pulling for pressures 1-5 bar (in N):
   69.1150  138.2301  207.3451  276.4602  345.5752
```

Fig. 3.1 MATLAB code for calculating pneumatic cylinder performance under different pressure conditions

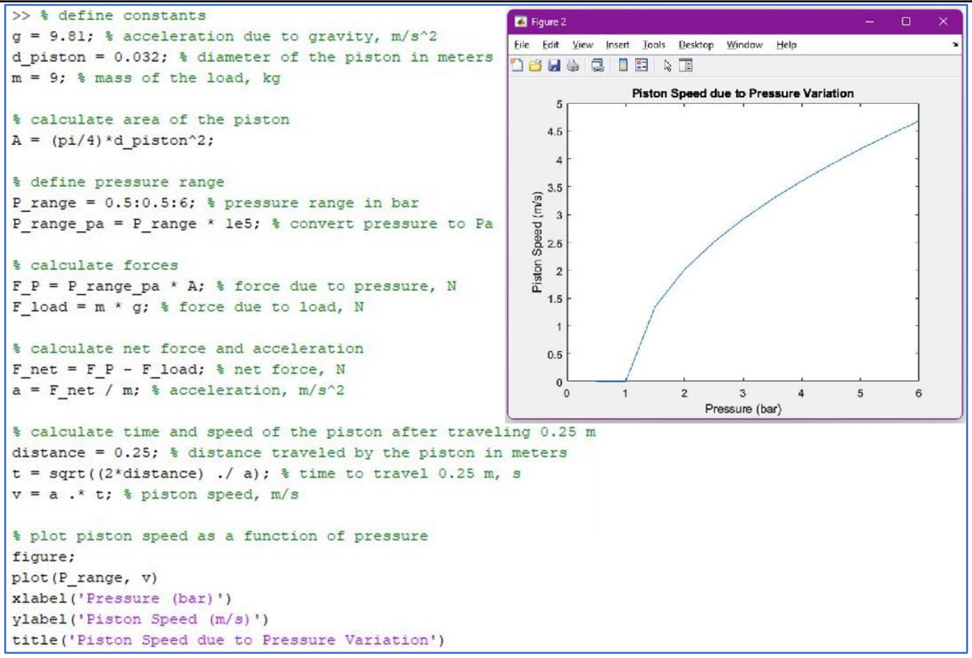
Evaluation of the variation of force on the cylinder as a function of load size: This helped me to understand the relationship between the applied load and the force exerted by the cylinder.



```
>> % Define the weights of the loads in kg
masses = [0, 3, 9];  % These are the different mass values we are considering

% Define the acceleration due to gravity in m/s²
g = 9.81;  % This is the value of acceleration due to gravity

% Calculate the force due to each load
forces = masses * g;  % We calculate the corresponding forces for these masses

% Display the results
disp('Forces due to load variation (in Newton):')  % This line will print the message
disp(forces)  % This line will print the calculated force values
Forces due to load variation (in Newton):
         0   29.4300   88.2900
```

Fig. 3.2 MATLAB code for calculating the force variation on the pneumatic cylinder as a function of load size

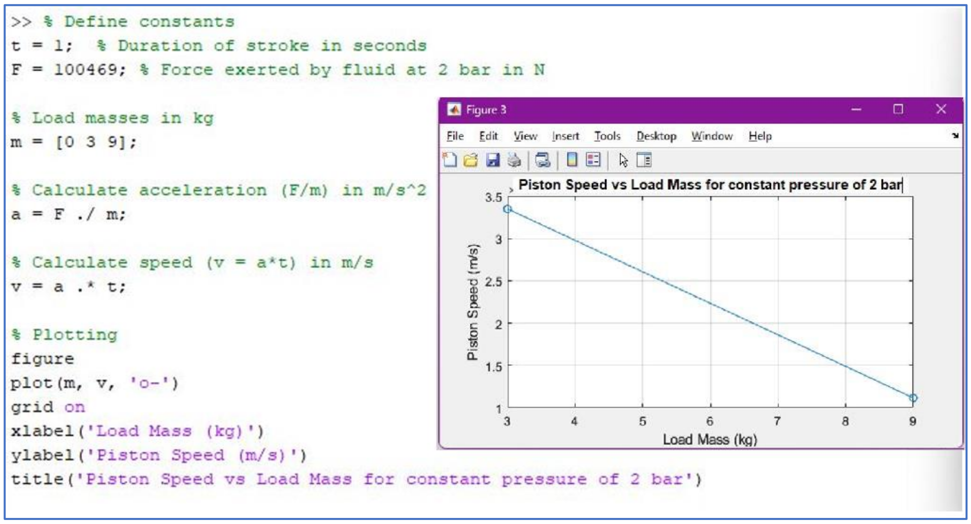
Determination of end-of-stroke cylinder velocity for each pressure level: This revealed how pressure affects the speed of piston travel at the end of its stroke.



```
>> % define constants
g = 9.81; % acceleration due to gravity, m/s^2
d_piston = 0.032; % diameter of the piston in meters
m = 9; % mass of the load, kg

% calculate area of the piston
A = (pi/4)*d_piston^2;

% define pressure range
P_range = 0.5:0.5:6; % pressure range in bar
P_range_pa = P_range * 1e5; % convert pressure to Pa

% calculate forces
F_P = P_range_pa * A; % force due to pressure, N
F_load = m * g; % force due to load, N

% calculate net force and acceleration
F_net = F_P - F_load; % net force, N
a = F_net / m; % acceleration, m/s^2

% calculate time and speed of the piston after traveling 0.25 m
distance = 0.25; % distance traveled by the piston in meters
t = sqrt((2*distance) ./ a); % time to travel 0.25 m, s
v = a .* t; % piston speed, m/s

% plot piston speed as a function of pressure
figure;
plot(P_range, v)
xlabel('Pressure (bar)')
ylabel('Piston Speed (m/s)')
title('Piston Speed due to Pressure Variation')
```

Fig. 3.3 MATLAB code for calculating the pneumatic cylinder speed at the end of the stroke for each pressure value considered

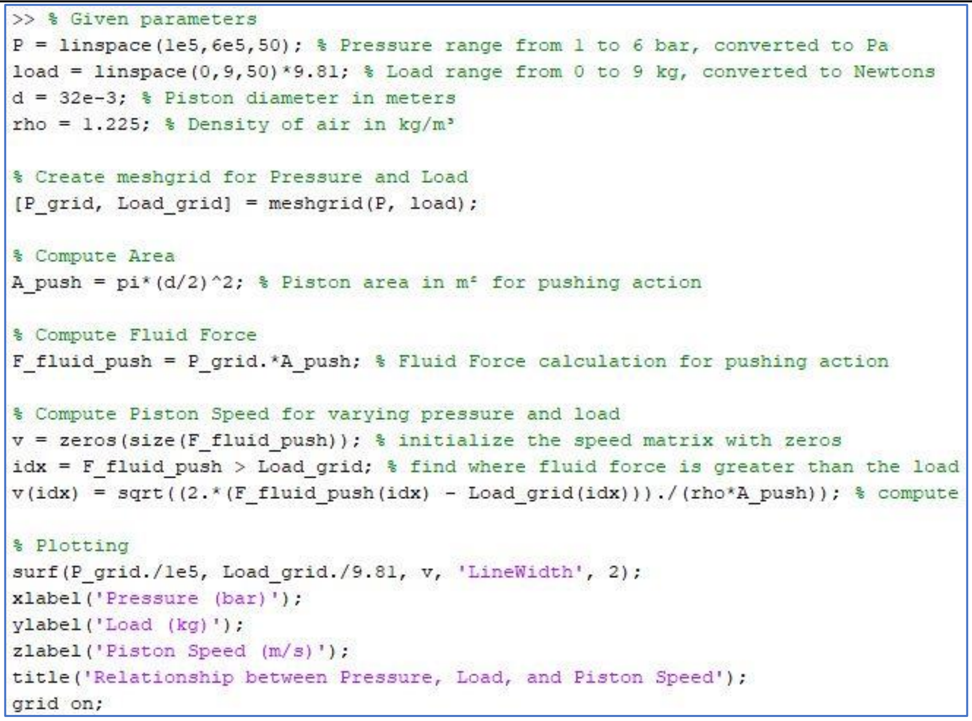
Analysis of how cylinder speed changes with variation in load mass at constant pressure: This revealed the relationship between load mass and cylinder speed, providing essential data about the ability of the cylinder to adapt to load changes.



```
>> % Define constants
t = 1;  % Duration of stroke in seconds
F = 100469; % Force exerted by fluid at 2 bar in N

% Load masses in kg
m = [0 3 9];

% Calculate acceleration (F/m) in m/s^2
a = F ./ m;

% Calculate speed (v = a*t) in m/s
v = a .* t;

% Plotting
figure
plot(m, v, 'o-')
grid on
xlabel('Load Mass (kg)')
ylabel('Piston Speed (m/s)')
title('Piston Speed vs Load Mass for constant pressure of 2 bar')
```

Fig. 3.4 MATLAB code to calculate how the pneumatic cylinder speed varies with load mass at constant pressure

Estimation of the relationship between pressure, load and pneumatic cylinder speed: This complex calculation provided a holistic view of the interdependence between the main system variables.



```
>> % Given parameters
P = linspace(1e5,6e5,50); % Pressure range from 1 to 6 bar, converted to Pa
load = linspace(0,9,50)*9.81; % Load range from 0 to 9 kg, converted to Newtons
d = 32e-3; % Piston diameter in meters
rho = 1.225; % Density of air in kg/m³

% Create meshgrid for Pressure and Load
[P_grid, Load_grid] = meshgrid(P, load);

% Compute Area
A_push = pi*(d/2)^2; % Piston area in m² for pushing action

% Compute Fluid Force
F_fluid_push = P_grid.*A_push; % Fluid Force calculation for pushing action

% Compute Piston Speed for varying pressure and load
v = zeros(size(F_fluid_push)); % initialize the speed matrix with zeros
idx = F_fluid_push > Load_grid; % find where fluid force is greater than the load
v(idx) = sqrt((2.*(F_fluid_push(idx) - Load_grid(idx)))./(rho*A_push)); % compute

% Plotting
surf(P_grid./1e5, Load_grid./9.81, v, 'LineWidth', 2);
xlabel('Pressure (bar)');
ylabel('Load (kg)');
zlabel('Piston Speed (m/s)');
title('Relationship between Pressure, Load, and Piston Speed');
grid on;
```

Fig. 3.5 MATLAB code to calculate the relationship between pressure, load and speed of the pneumatic cylinder

The 3D graph from the MATLAB simulation demonstrates the complex relationship between pressure, load and speed of the pneumatic cylinder. It shows the relationship between pressure, load and pneumatic cylinder speed. It shows that an increase in pressure leads to an increase in pneumatic cylinder speed, while an increase in load leads to a decrease in pneumatic cylinder speed.

However, it is important to note that this model is a simplification and does not take into account other effects, such as air resistance or friction, which could also affect the speed of the pneumatic cylinder.

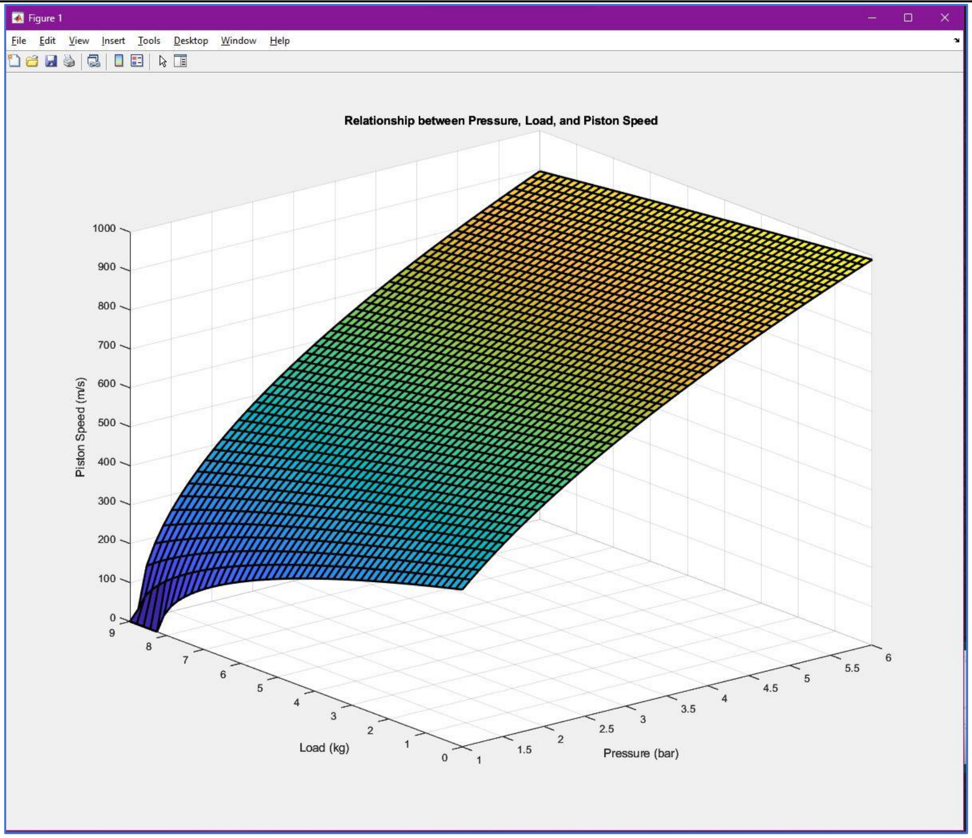


Fig. 3.6 Reality graph between pressure, load and pneumatic cylinder speed

3.8 Conclusions

We have analysed different hypotheses related to pneumatic systems, focusing on the impact of pressure and load variations on pneumatic cylinder speed. We also evaluated the effectiveness of the flow control valve and the integration of an electric motor for flow control.

Using mathematical models in Matlab, we validated most of the hypotheses. Our results indicate that pressure and load significantly influence cylinder velocity. Also, optimizing the flow control valve and adding an electric motor to it can increase the performance of pneumatic systems.

These findings are valuable for the field of pneumatic systems, providing insights for improving performance and opening new avenues for industrial applications.

CHAP. 4 EXPERIMENTAL CONTRIBUTIONS ON THE DESIGN AND REALIZATION OF A UNIDIRECTIONAL CONTROL ELECTRODE

In this chapter, the contributions of the experimental development of a unidirectional control valve, the key innovation of this research, are presented. This device, intended for the control and operation of pneumatic systems, has been subjected to a detailed design, simulation and testing process.

The design steps are described, outlining key principles and technical decisions. Using CATIA software, we have created an efficient and robust model, adapted to current requirements.

The construction of the valve, its vital components and the electronics that allow its regulation and supervision are presented. Equipment such as the Arduino Mega 2560 and AVENTICS™ PE5 R412010760 pressure sensors are central to this phase.

We conclude by integrating the valve into the test bench and evaluating its performance. This chapter presents the value and impact of this innovation in pneumatic systems.

4.1 Current status of one-way flow control valve AS2201FE-01-06SK

The AS2201FE-01-06SK valve from SMC Corporation is essential to our experimental system. Functioning as a directional valve speed controller, this pneumatic tool is used in many industries, from automation to machining.

In pneumatic systems, this valve regulates the flow of compressed air, thus controlling the speed of the pneumatic cylinders. By adjusting it, the speed and force of the cylinders can be precisely adjusted.

In a system, the valve connects to a source of compressed air and controls actuators, such as pneumatic cylinders. The effectiveness, safety and adaptability of the system are ensured by its use.

Although the AS2201FE-01-06SK valve is efficient and complex, there are some limitations. These have guided me in formulating the hypotheses we wish to evaluate.

4.2 Limitations, need for improvement one-way flow control valve

Although the valve has fulfilled its basic functionality, there are areas where it can be optimised to improve efficiency and performance in various scenarios:

Cylinder speed stability: Pressure fluctuations can affect the constant speed of the pneumatic cylinder, which can compromise system accuracy and efficiency. Better management of these variations will lead to more consistent control.

Influence of load on speed: Load changes can influence the speed of the pneumatic cylinder. Adapting to these changes will increase system reliability.

Automatic flow rate adjustment: The current component does not support automatic or remote adjustment, limiting efficiency. Introducing this functionality can save time and provide better control.

Remote control and automation: Manual adjustment can be impractical in complex environments. The ability to adjust cylinder speed automatically and remotely will improve operability.

By improving these aspects, the performance and efficiency of systems using the valve will be significantly increased, making them easier to operate and maintain.

4.3 Methods of improving the one-way flow control valve

Following analysis and understanding of the need for component improvement, we developed an improvement strategy aimed at increasing efficiency, performance and usability. The main element of improvement is the addition of a stepper motor to the existing component. This modification allows the opening and closing of the control valve to be adjusted from a control panel without the need for manual intervention.

The benefits of this improvement are directly related to the four assumptions:

Electronic valve opening and closing adjustment will allow more precise control over the speed of the pneumatic cylinder, even under conditions of varying system pressure.

With the stepper motor, the speed of the pneumatic cylinder can be fine-tuned to the load, ensuring superior control of the cylinder's movement regardless of load changes.

With the introduction of electronic control, the one-way control valve becomes much more efficient and flexible than traditional designs, offering the possibility of precise remote adjustment.

With the ability to automatically and remotely adjust speed through flow, we can effectively control speed variations induced by pressure variations and load changes, thus increasing the operational flexibility and reliability of pneumatic systems.

4.4 Experimental bench setup

The experimental bench is designed with an emphasis on modularity and interchangeability. Such features bring several significant benefits:

Flexibility in testing: Modularity allows you to quickly change components, making it easy to test different scenarios without reconfiguring the entire system.

Testing different cylinders: We have the ability to evaluate pneumatic cylinders of different sizes under comparable conditions, ensuring accurate and relevant data.

Electro-drosel testing: At the heart of this modularity is the ability to test the main component, the electro-drosel, in various conditions and combinations. This provides an in-depth understanding of its performance and efficiency in different scenarios and in conjunction with various other components.

Adaptability for the future: Not only can the system be adapted or improved as research progresses, but it also offers the opportunity to incorporate and test new versions or improvements of the electro-drone.

Essentially, the modular design of the bench facilitates rigorous testing of components, including the electro-drosel, ensuring that we have all the tools we need for cutting-edge research.

4.5 Experimental bench design in CATIA

The experimental bench, developed in Catia, is a modular system designed to test different pneumatic pistons under various pressure and load conditions, with the main purpose of testing the new electro-drosel component. It comprises:

Pneumatic system: Includes all components that work with compressed air, including the pneumatic cylinder, the electro-drum and the air compressor.

Control system: Responsible for regulating and monitoring cylinder pressure and speed.

Using this bench, we can see how pressure and load variation affect the speed of the pneumatic cylinder. Also, thanks to its modular design, different types and sizes of pneumatic cylinders can be easily tested.

The key element of the bench is the unidirectional electro-control valve, which remotely adjusts the speed of the pneumatic cylinder, playing a key role in our experiments on this new electro-drive component.

Figure 4.1 shows the bench with a 250 mm pneumatic cylinder, used to study the effects of the electro-drum in systems with large air volumes. The aim is to analyse the influence of this airscrew on cylinder speed in such systems.

In contrast, Figure 4.2 shows the bench with a smaller 40 mm cylinder, which helps us to analyse the performance of the electro-drosel in fast response systems.

The bench is distinguished by its adaptability, with easily replaceable components. Its precise design ensures correct installation, promoting accuracy and consistency of results.

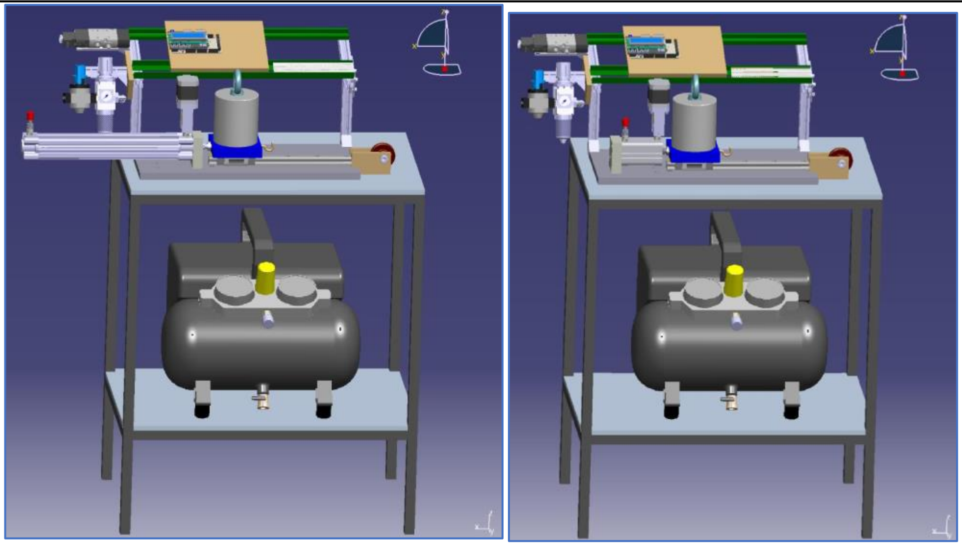
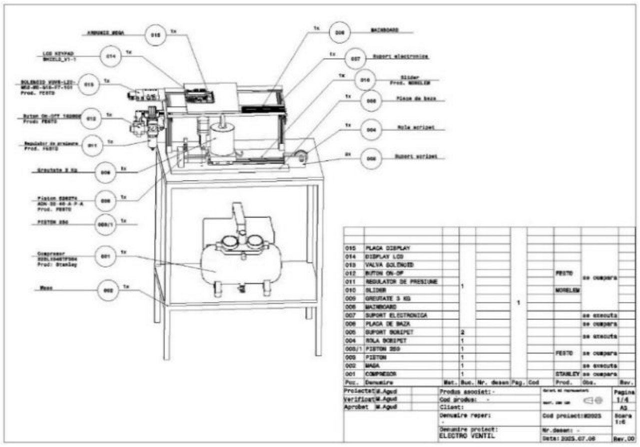


Fig. 4.1 Experimental bench equipped with a pneumatic cylinder Ø32 250 mm/40mm stroke designed in CATIA PLM Express V5-6R2023

4.5.1 Drawing of the experimental bench assembly

Figure 4.3 shows a 2D diagram of the experimental rig, illustrating the arrangement and interconnection of its mechanical, pneumatic and electronic components.



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012	BUTON ON-OF								
011	REGULATOR DE PRESIUNE								
010	SLIDER						MORELEW		
009	GREUTATE 3 KG								
008	MAINBOARD								
007	SUPORT ELECTRONICA							se executa	
006	PLACA DE BAZA							se cumpara	
005	SUPORT SCRIPET		2					se executa	
004	ROLA SCRIPET		1						
003/1	PISTON 250		1				FESTO	se cumpara	
003	PISTON		1						
002	MASA		1					se executa	
001	COMPRESOR		1				STANLEY	se cumpara	

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Aprobat M.Agud
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Fig. 4.2 Experimental bench assembly executed in CATIA PLM Express V5-6R2023

The index table associates each component with an identification number and specifies whether the part was purchased or produced in the project.

4.5.2 Electro-directional control design

The unidirectional flow control valve used in this study is a specialized variant that includes the unidirectional flow control valve integrated with a residual pressure relief valve. This unique configuration uses a one-touch mounting mechanism, increasing ease of operation and effectiveness.

To pursue the overall objective of this research : INCREASE THE PERFORMANCE OF PNEUMATIC DRIVE SYSTEMS by remote or automatic adjustment of pneumatic cylinder speed, a significant modification was made to this valve i.e. the addition of a stepper motor. The stepper motor has been assimilated to favour a symbiotic kinematic relationship between itself and the valve.

One aspect to note is the unique dual motion feature of the unidirectional flow control valve, which includes both rotational and translational motions. In contrast, the stepper motor shaft performs only one rotational movement. This functional difference required the design of a special coupling, designed using CATIA software, to ensure operational compatibility and to prevent system jamming.

This major modification of the unidirectional flow control valve marks a pioneering contribution to this field of research, combining mechanical and electronic elements for optimised control of pneumatic systems.

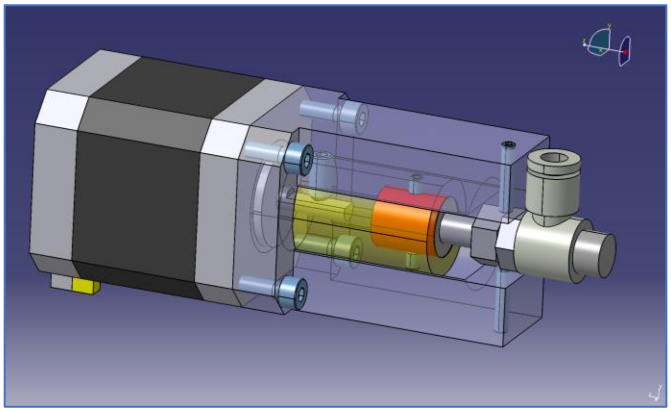


Fig. 4.3 3D stepper motor assembly with control valve rendered in Catia

Figure 4.3 shows the 3D assembly of the stepper motor with control valve. The assembly is simple and reliable, consisting of two main components: the motor mount and the coupling.

The coupling plays a crucial role in this assembly, ensuring the efficient transmission of rotary motion from the engine to the valve. At one end, the coupling is secured to the valve rosette with two screws. It constrains the rotational movement of the motor, while allowing the valve to perform the linear movement required for flow regulation. At the opposite end, the coupling is clamped to the motor with one screw, allowing only rotational movement.

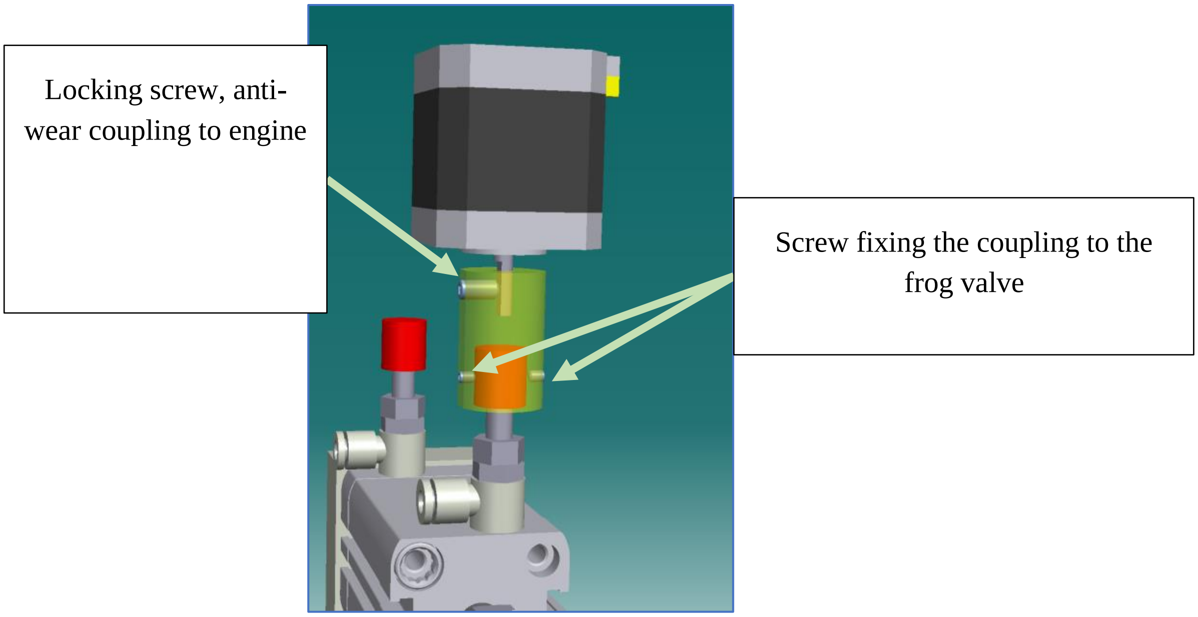


Fig. 4.4 Drosel - coupling - motor assembly realised in Catia

Figure 4.4 illustrates how the coupling is attached. It is obvious that it has been designed so that it is firmly fixed to the spindle valve, allowing the rotational movement to be transmitted. In addition, it can be seen that the design of the coupling ensures that the rotation of the motor shaft in the coupling is locked. This is an essential feature that ensures efficient and correct operation of the assembly.

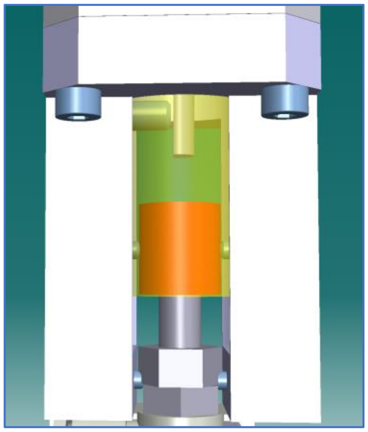


Fig. 4.5 Drosel - coupling - motor assembly realised in Catia

Figure 4.5 clearly illustrates how the coupling is constrained on the spindle valve. It is easy to see the screw gap that limits the rotation of the motor shaft relative to the coupling, ensuring a firm fit between the motor housing and the spindle housing. This design detail is essential to ensure optimum operation of the assembly, as well as improving its efficiency and reliability.

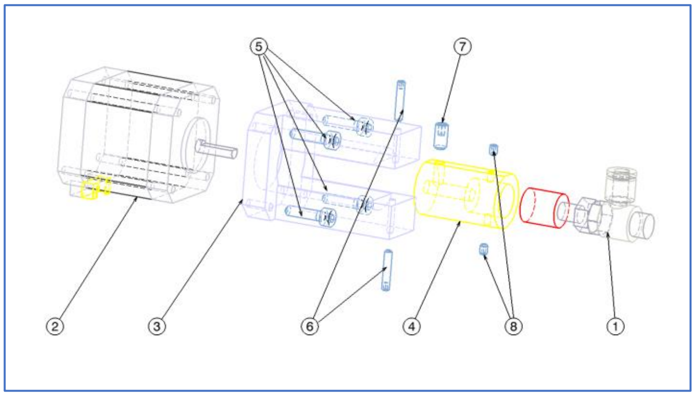


Fig. 4.6 View from the exploded drawing made in CATIA

Figure 4.7 is an image generated by the CAD design software, CATIA, showing the improved speed controller assembly in an exploded view. It highlights how the various components of the assembly fit together and interact with each other.

What follows is an overview of the components that make up this assembly, each of which plays a key role in optimising the speed controller's performance:

1.The SMC pneumatic component is the centerpiece of this assembly, controlling the exhaust air velocity to regulate the speed of a piston in a pneumatic system.

2.The stepper motor is the new addition to our assembly, offering the possibility to adjust the airflow in a more precise and remote way.

3.The motor bracket connects the stepper motor to the pneumatic component, ensuring a solid fit and correct alignment of these two main components.

4.The coupling is an essential component that allows the transmission of motion from the engine to the pneumatic component, while allowing linear motion of the pneumatic component.

5-8. The fixing screws are essential for the solid assembly of the components, ensuring the stability of the assembly and preventing any unwanted movement of the components during operation.

Design drawings are an essential part of any design and engineering process. They provide the details needed for the actual production of parts and components. The working drawings for the motor mount and coupling, created in CATIA, are shown below.

The implementation of these design drawings in the manufacturing process plays a crucial role in making components to the required standards. By providing precise guidance and minute detail, the drawings facilitate the manufacture of components with the level of accuracy required to ensure the correct operation of the improved speed controller assembly.

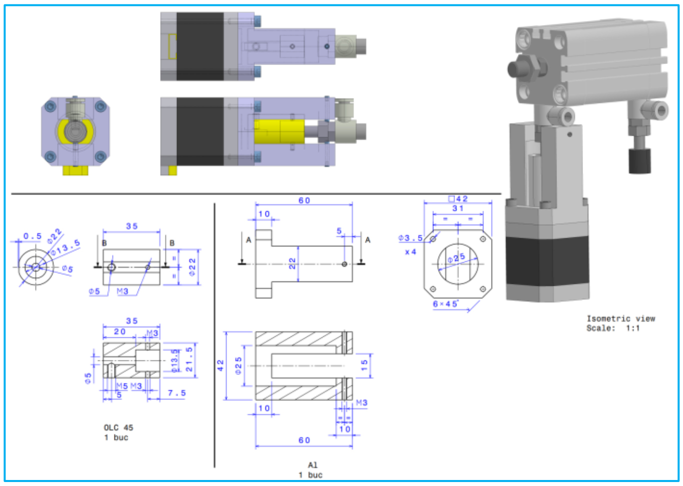


Fig. 4.7 Execution drawing for coupling made in CATIA

To illustrate the manufacturing process of the assembly created, we have included images from different stages of the manufacturing process. These images illustrate the execution of both the coupling and the motor mount and show how the components fit together to form the final assembly.

Fig. 4.8 Execution and finished product made in CATIA

In conclusion, by implementing this enhancement, I expect to significantly improve the performance and efficiency of the pneumatic system, while reducing the need for manual intervention and providing a higher level of control and flexibility.

4.6 Detailed description of the components of the experimental bench

The experimental bench is essential as it is used to test research hypotheses. It combines mechanical, pneumatic and electronic components into a complex system, where each part has a precise role. In this chapter, each component is described, explaining its importance and functionality. The presentation will cover the mechanical, pneumatic and electronic components in order. The aim is to highlight the complexity and engineering of the experimental bench, ensuring correct understanding of its operation and the results obtained. It is also essential to mention that we have paid great attention to detail in the construction of the bench to guarantee the accuracy and repeatability of the tests

4.6.1 Mechanical part of the experimental bench

The mechanical part of the experimental bench combines complexity with reliability to ensure experiments. It contains essential elements, all meticulously designed. The sturdy stand serves as the base, housing the compressor for efficient organisation. The bench itself consists of a corrosion-resistant aluminium plate, with a piston mount for the pneumatic cylinder. A skid rail ensures smooth movement of the cylinder, reducing friction. There is also an aluminium profile support that houses the electronic and pneumatic components, providing flexibility and strength.

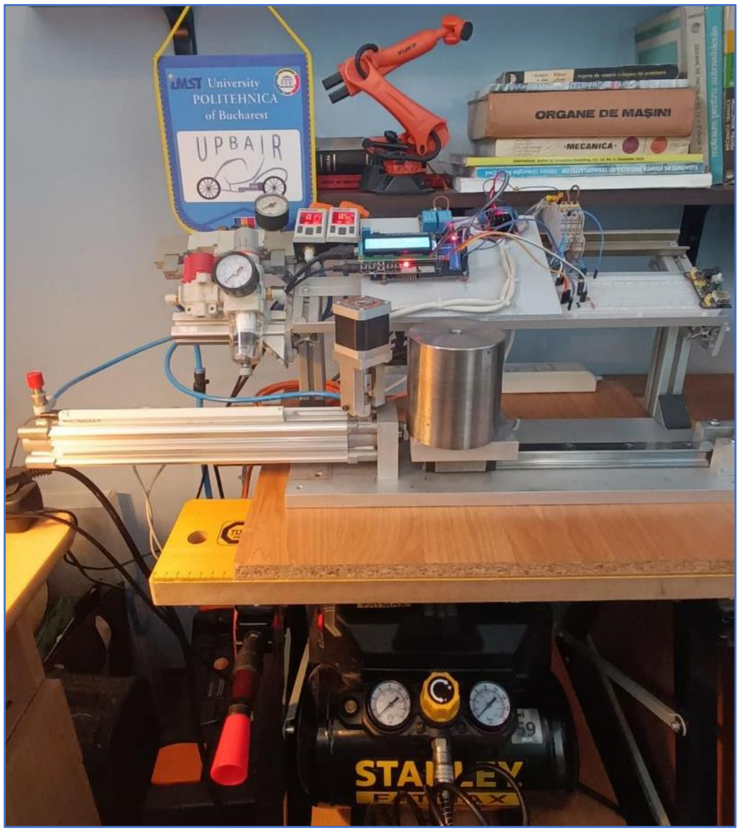


Fig. 4.9 Experimental bench

The components were modelled in CATIA, software that allows detailed representation. Figures 4.12 show the execution drawings of the bench, highlighting the design.

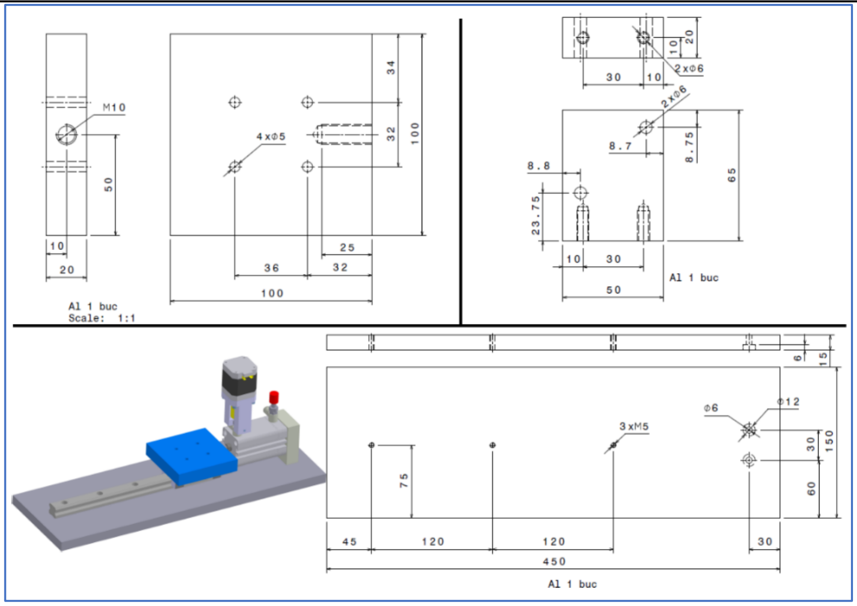


Fig. 4.10 Execution drawings for mounting plates made in CATIA

In conclusion, the mechanical component of the bench combines robustness with adaptability, optimizing it for the proposed experiments.

4.6.2 Pneumatic part of the experimental bench

The pneumatic part of the experimental bench is a complex assembly of components, all essential for the performance and operation of our experiments. This system is a replica of the one simulated in the Automation Studio software, thus ensuring the consistency and validity of the results obtained.

4.6.3 Electronic part of the experimental bench

The electronic part of the experimental bench acts as a bridge between the physical and digital environments, transforming sensor signals into concrete actions and controlling the whole system to ensure controlled and repeatable experiments.

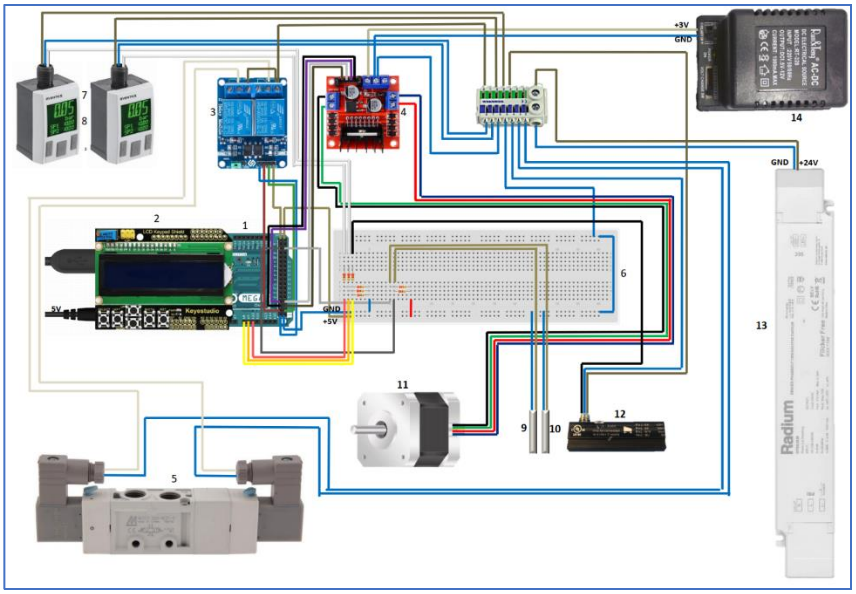


Fig. 4.11 Wiring diagram of the experimental bench

There are two main types of electronic components: those that control, such as the Arduino Mega 2560 and stepper motor, and those that collect information, such as pressure and magnetic sensors. These elements work together to ensure that the experimental bench works properly.

Fig. 4.11 gives a look at the wiring diagram, which details the connections between the electronic components. The Arduino Mega 2560 microcontroller is the heart of this schematic, processing sensor signals and controlling other components.

4.7 How the experimental bench works

The main stages of operation and the interdependencies between its different components are:

Power-up and initialization: The experimental bench is started using the main control panel of the arduino. At this stage, all components are initialized and ready to start testing. Sensors are calibrated and set to positions, and the electro-switch is set to a start position.

Setarea parametrilor de testare: Se poate seta diferiți parametri, cum ar fi presiunea aerului, sarcia sau viteza dorită a cilindrului pneumatic prin satarea timpului parcurs de catre pistonului, folosind software-ul de control și monitorizare sau panoul de comandă.

Test procedure: Once the parameters are set, testing can begin. The piston is actuated and speed and pressure are monitored in real time via pressure and magnetic sensors. The solenoid valve adjusts the air flow according to the commands and feedback received from the sensors.

Test scenarios: Depending on the research objectives, different test scenarios can be set up: for example, changing the pressure to test the electro-cup reaction or simulating specific conditions by changing loads from 0;3;6;9 kg to evaluate performance in real operating situations.

Data monitoring and recording: During testing, all data is monitored and recorded in the control software for further analysis. This allows to evaluate the performance of the electro-soup and to confirm or refute proposed hypotheses.

Stopping and reporting: After the test is completed, the bench is stopped and the data is saved and processed to generate reports and charts. These reports can be used for detailed analysis and comparison with other test results.

4.7.1 Purpose of the experimental bench

The main purpose of the experimental rig is to test and demonstrate the efficiency of using the unidirectional control electro-cup in pneumatic systems. This is done by testing four hypotheses, which relate to how the speed of a piston in a pneumatic system is influenced by variations in pressure and load, and the ability to control and regulate the speed of the pneumatic cylinder using the electro-drive.

Assumption 1: The speed of a piston in a pneumatic system is influenced by the pressure variation in the system.

Assumption 2: The speed of a piston in a pneumatic system is affected by the load it has to move.

Assumption 3: Redesigned one-way control valve incorporating an electric motor (electro-drosel) allows remote control.

Assumption 4: The ability to automatically adjust the speed of the pneumatic cylinder with the one-way flow control solenoid valve will allow effective control over speed variations induced by pressure variations and load changes, thus improving the operational flexibility and reliability of pneumatic systems.

4.7.2 Block diagram of the experimental bench operation

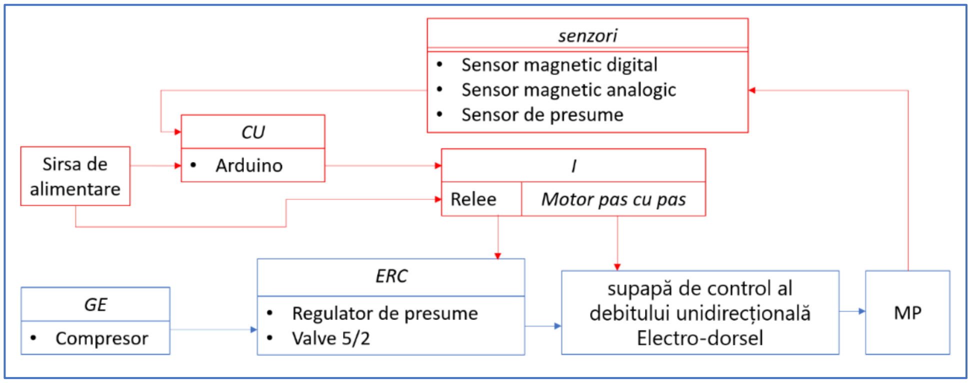


Fig. 4.12 Block diagram of the experimental bench

Figure 4.12 shows the system operation diagram, which serves as a conceptual framework for understanding how the different components of the system interact and work together. The system consists of two main components: the pneumatic system (marked in blue) and the electrical system (marked in red). These two systems work together to control the speed of the pneumatic air cylinder as a function of changing pressure and load.

CHAP. 5 PNEUMATIC SYSTEM DESIGN AND SIMULATION IN AUTOMATION STUDIO

This chapter presents the use of Automation Studio software in the proposed research for pneumatic system design and simulation.

It starts with a presentation of the Automation Studio software and the main components of the pneumatic system. Then, the model is built and simulated. This approach allowed me to analyze the pneumatic cylinder speed and understand the contribution of each component to the performance of the system. Conclusions are based on the results of these simulations.

5.1 Pneumatic system simulation

In this chapter, we used Automation Studio software to simulate the pneumatic system. This simulation allows an understanding of the behaviour and interactions between system components without the need for physical implementation.

5.2 Simulation and Analysis

The section focuses on detailed analysis of the pneumatic system using Automation Studio software. Through simulation, it tests and validates the operation of the system before implementation, identifying possible optimizations or problems. The simulation process involves building a digital model of the system, selecting and configuring the appropriate components.

5.2.1 Creating the System Model

We built a digital model of the pneumatic system in Automation Studio software, based on the actual setup on the experimental bench. All the components in the system, with all their parameters, were reproduced in this digital model. Central to this model is the pneumatic schematic, a detailed representation of all connections and components of the system.

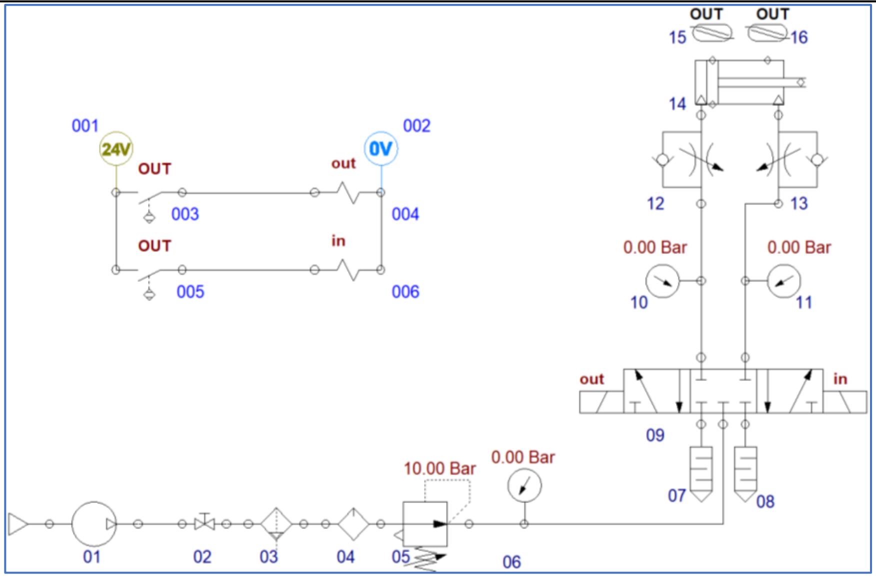


Fig. 5.1 Pneumatic and electrical diagram made in Automation Sudio

The meticulous detail ensures that the simulation is as close to reality as possible. Once the model is ready, you can run the simulation and use various analysis tools provided by the software to study the behaviour of the system.

5.2.2 Hypothesis testing through simulation

After modeling and parameterizing the pneumatic system in Automation Studio software, we moved on to testing our hypotheses through simulation.

Simulation Assumption 1: Varying the pressure in the system influences the speed of the pneumatic cylinder

The pressure in the pneumatic system plays a crucial role in determining the speed of travel of the pneumatic cylinder. To test this hypothesis, we varied the pressure in the system during simulations and monitored the effects on the pneumatic cylinder speed. The simulation results showed that the speed of the pneumatic cylinder is indeed sensitive to pressure variations in the system. Specifically, we observed that an increase in pressure leads to an acceleration of the speed of the pneumatic cylinder, while a reduction in pressure leads to a deceleration of the speed of the pneumatic cylinder.

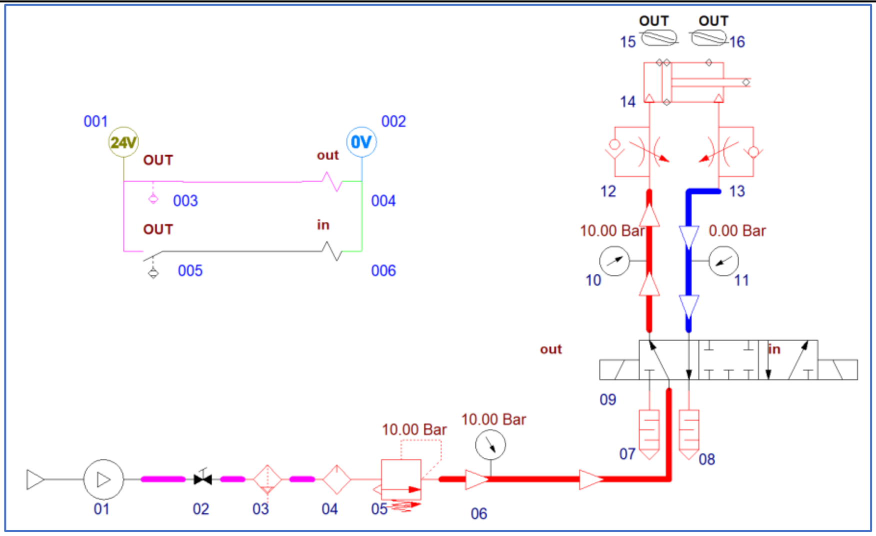
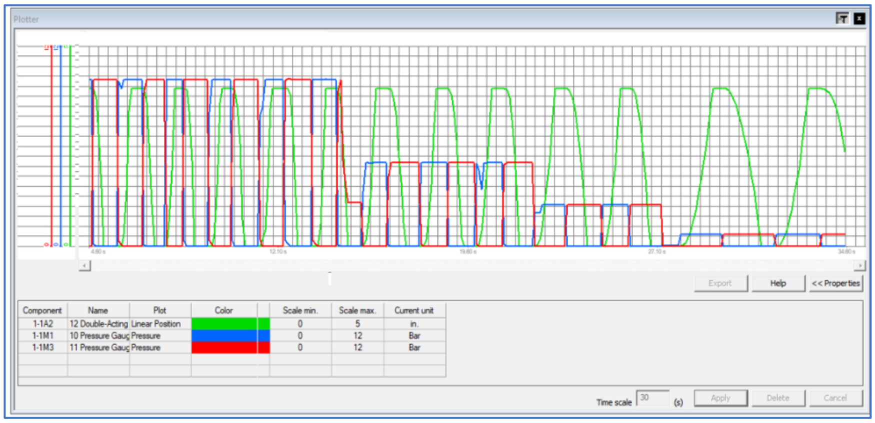


Fig. 5.2 Simulation of the pneumatic scheme made in Automation Sudio

Figure 5.3 shows the simulated pneumatic scheme, showing the air flow indicated by arrows and the pressure level in the system represented by different colours. In this picture, warmer colours e.g. red indicate higher pressure, while cooler colours e.g. blue indicate lower pressure.



Component	Name	Plot	Color	Scale min.	Scale max.	Current unit
1-1A2	12 Double-Acting	Linear Position	🟩	0	5	in.
1-1M1	10 Pressure Gaug	Pressure	🟦	0	12	Bar
1-1M3	11 Pressure Gaug	Pressure	🟥	0	12	Bar

Time scale 30 (s)

Fig. 5.3 Diagram of the relationship between system pressure and pneumatic cylinder speed

Figure 5.3 is a graphical representation of the behaviour of our pneumatic system during operation. This diagram gives a clear picture of the relationship between system pressure and pneumatic cylinder speed.

On the graph, the blue line represents the pressure in the system during extension of the pneumatic cylinder rod, while the red line indicates the pressure in the system during retraction of the pneumatic cylinder rod. Meanwhile, the green line illustrates the position of the pneumatic cylinder during these two stages.

Although the green line indicates the position of the pneumatic cylinder, its speed can be derived by observing the length of time the piston travels a certain distance. Thus, we can see that at times when the pressure in the system decreases (indicated by the decreasing blue and red lines), the time it takes for the pneumatic cylinder to travel a certain distance increases, indicating a decrease in the speed of the pneumatic cylinder.

This confirms the original hypothesis that pressure variation in the system influences the speed of the pneumatic cylinder. Thus, the results of this simulation provide an empirical validation of this hypothesis and highlight the importance of maintaining adequate pressure in the system to ensure optimal pneumatic cylinder speed.

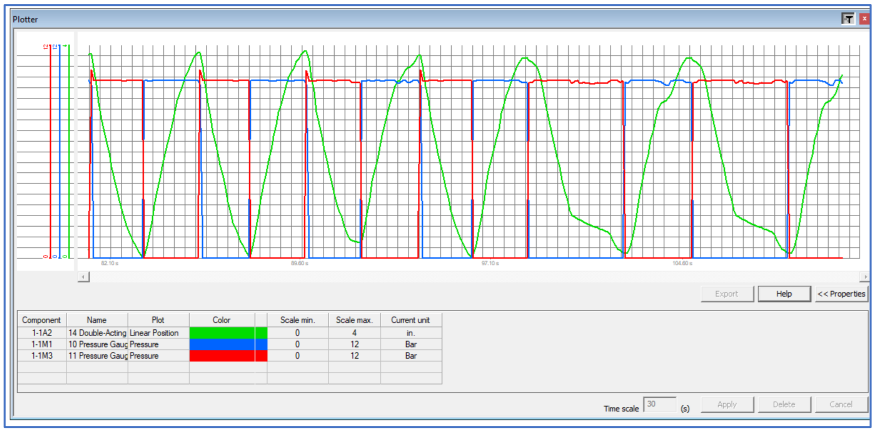
Simulation Hypothesis 2: Increasing load influences pneumatic cylinder speed

To validate the second hypothesis, we simulated the system with increasing loads applied on the piston. In a real pneumatic system, the load could be the force required to perform a particular task, such as lifting an object or moving a mechanical component. In the simulation, we varied this load and observed how the speed of the pneumatic cylinder is affected.

In Figure 5.4, we can see the results of this simulation. On the graph, the blue line represents the pressure in the system during the extension of the pneumatic cylinder rod, while the red line shows the pressure in the system during the retraction of the pneumatic cylinder rod. As in the previous analysis, the green line illustrates the position of the pneumatic cylinder during these two stages.

It can be seen that as the load increases, the time taken for the piston to travel the same distance increases. This indicates a decrease in the speed of the pneumatic cylinder, which confirms our hypothesis that increasing the load influences the speed of the pneumatic cylinder.

This underlines the importance of balancing the load in a pneumatic system with the available pressure to ensure efficient operation. This is also an important consideration for the design of pneumatic systems, as larger loads may require higher pressures or larger piston diameters to maintain desired operating speeds.



Component	Name	Plot	Color		Scale min.	Scale max.	Current unit
1-1A2	14 Double-Acting	Linear Position	🟩	🟩	0	4	in.
1-1M1	10 Pressure Gaug	Pressure	🟦	🟦	0	12	Bar
1-1M3	11 Pressure Gaug	Pressure	🟥	🟥	0	12	Bar

Time scale 30 (s)

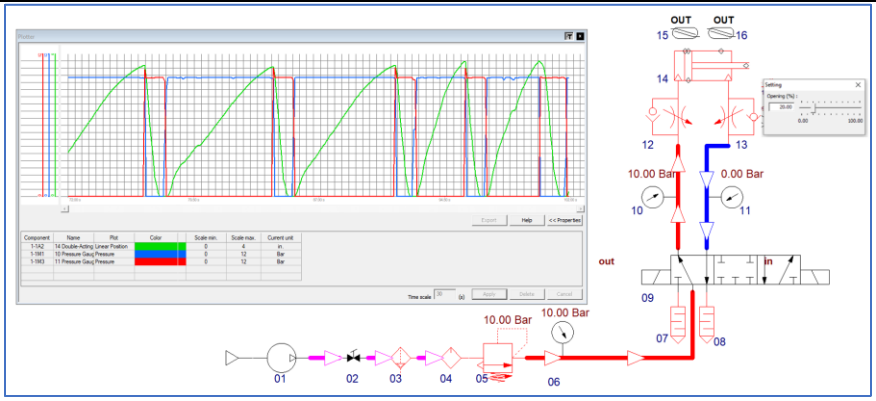
Fig. 5.4 Simulation results

Pneumatic cylinder speed control by droselization

Pneumatic cylinder speed control is essential in many pneumatic system applications. One common method of controlling pneumatic cylinder speed involves the use of a drosel, a device that allows the flow of air through the cylinder to be adjusted[28].

In most cases, the air drosel is mounted on the air exhaust line of the pneumatic cylinder. This method of 'exhaustive' drosolization provides more predictable and effective control over the speed of the pneumatic cylinder than controlling the air flow into the cylinder. Controlling the flow of air out of the cylinder ensures a smooth and constant movement of the pneumatic cylinder, avoiding sudden or unexpected movements.

In the simulation carried out in Automation Studio, we used the drosel configured on the air exhaust line of the pneumatic cylinder. By adjusting the aperture of the air screwdriver, we were able to control the flow of air discharged from the cylinder, and therefore the speed of travel of the pneumatic cylinder. The simulation results confirm the effectiveness of the air exhaust line drosolization in regulating the speed of the pneumatic cylinder in a pneumatic system.



Component	Name	Plot	Color	Scale min.	Scale max.	Current unit
1-1A2	14 Double-Acting	Linear Position	🟩	0	4	in.
1-1M1	10 Pressure Gaug	Pressure	🟦	0	12	Bar
1-1M3	11 Pressure Gaug	Pressure	🟥	0	12	Bar

Fig. 5.5 Simulation with pneumatic cylinder speed adjustment by droser performed in A.S.

The simulations carried out in Automation Studio looked at the impact of adjusting the spindle on the air exhaust line on the travel speed of the pneumatic cylinder. According to the results, the displacement speed of the pneumatic cylinder showed an inversely proportional relationship with the size of the spindle opening. The larger the aperture of the spindle, the higher the displacement speed of the pneumatic cylinder.

These results confirm the effectiveness of air exhaust line drosolization in regulating pneumatic cylinder speed in a pneumatic system, as discussed in the literature [25].

5.2.3 Results and discussions following simulations in Automation Studio

Based on simulations performed in Automation Studio software, we obtained the following results, which are directly relevant to our initial assumptions.

Assumption 1: Varying the pressure in the system influences the speed of the pneumatic cylinder

From the simulation results, we observed that there is an inversely proportional relationship between system pressure and pneumatic cylinder speed. In other words, when the pressure in the system decreases, the speed of the pneumatic cylinder also decreases. This phenomenon can be explained by the basic physical principles governing fluid mechanics. The pressure in a pneumatic system is the driving force that pushes the piston through the cylinder. Therefore, when the pressure decreases, the force acting on the pneumatic cylinder is lower, resulting in a lower travel speed.

Hypothesis 2: Increasing load influences pneumatic cylinder speed

As with the first hypothesis, our simulations confirm that there is a direct relationship between the load on the piston and its speed. Indeed, when the load increases, the speed of the pneumatic cylinder decreases. This result is consistent with the basic principles of mechanics. When the load acting on a body increases, it needs more force to move at the same speed. In the absence of a corresponding increase in pressure in the system, the piston will move more slowly.

Interpretation of drosolization simulation results

In addition, we have analysed the effect of drosolisation on pneumatic cylinder speed. Drosolization, which is a technique to control the flow of air to and from the piston, was found to have a significant impact on pneumatic cylinder speed. We have found that by controlling the airflow through drosolization, we can effectively adjust the speed of the pneumatic cylinder. This is consistent with existing literature, which suggests that drosolization can be an effective method of controlling the speed of a pneumatic piston.

5.2.4 Conclusions the simulations made in Automation Studio

By examining the results obtained from the simulations carried out in Automation Studio software, certain conclusions can be drawn about the behaviour and control of a pneumatic system.

Varying the pressure in the system influences the speed of the pneumatic cylinder. Pressure and pneumatic cylinder speed are inversely proportional; a decrease in system pressure will result in a lower pneumatic cylinder speed. This shows the importance of precise pressure control in any pneumatic system to ensure optimum operation.

Increasing the load influences the speed of the pneumatic cylinder. Load and speed of the pneumatic cylinder are also inversely proportional; an increase in the load on the piston will result in a lower travel speed. This is an important consideration in the design and operation of pneumatic systems, especially in situations where the load can vary significantly.

Drosolisation allows the speed of the pneumatic cylinder to be controlled. Our results confirm that drosolization can be an effective method to control the speed of a piston in a pneumatic system.

Therefore, to ensure efficient and reliable operation of a pneumatic system, it is essential to consider and carefully control these three factors: pressure in the system, load on the piston and air flow controlled by drosolization.

In conclusion, these findings represent an important step in understanding the behaviour and control of pneumatic systems. However, more studies and simulations would be beneficial to further develop and improve these systems.

CHAP. 6 ANALYSIS AND VALIDATION OF EXPERIMENTAL RESULTS OBTAINED ON THE TEST BENCH

This chapter is a pivotal point of the study. Here, the results we obtained from testing the proposed hypotheses using the experimental rig are presented and analysed. The information gathered and interpreted in this chapter allows insight into how pneumatic cylinder velocity in a pneumatic system is influenced by variations in pressure, load and the efficiency of the integration of the solenoid in the system.

The chapter presents the raw data obtained. This will be followed by a detailed analysis and interpretation of the results, linking the data to the hypotheses and exploring their significance in the context of the research.

This chapter is important for understanding the effectiveness of the electro-drosel in controlling pneumatic cylinder speed and will give a clear picture of the potential of this technology. Therefore, I will need to be rigorous in analyzing and interpreting the data to ensure that the results are robust and relevant.

6.1 Presentation of Results for Hypothesis 1

Hypothesis 1 was tested using the experimental rig described in the previous chapter. For each pneumatic cylinder the testing started at a pressure of 3 bar, with the time set for travel of the pneumatic cylinder rod stabilised at 2 seconds. Subsequently, the pressure was gradually decreased to 2 bar and finally to 1 bar. The main objective of this test was to observe whether the pneumatic system is able to effectively adjust its cylinder speed while maintaining a constant 2-second travel time of the pneumatic cylinder rod despite the simulated pressure fluctuations. These tests and their results are illustrated in the following images.

6.1.1 Test procedure for pneumatic cylinder 1 Assumption 1

The procedure is a visual representation of pneumatic cylinder 1, which has a diameter of 32 mm and a stroke of 250 mm. It was tested under initial experimental conditions to validate Hypothesis 1.

After initiating the test, data were acquired using the data system. This data was stored and processed in real time by the Arduino control unit, which generated a data file with all relevant measurements. The data file included the travel time of the pneumatic cylinder, the status of the electro-drosel (open or closed), the set time and other relevant information for the experiment.

The data file generated by the Arduino was downloaded to a laptop for further analysis. This process of data acquisition and file generation allowed me to accurately monitor and record the behaviour of pneumatic cylinder 1 in the experiment.

The data obtained was then analysed to understand how the speed of the pneumatic cylinder varied with the pressure in the system. I was also able to observe how the electro-drosel adjusted the airflow to compensate for variations in speed. By doing this, we were able to validate Hypothesis 1 for pneumatic cylinder 1.

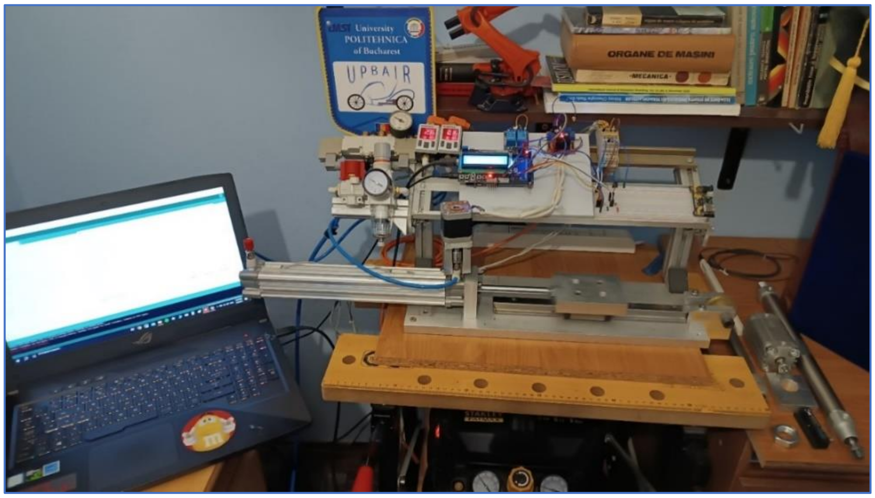


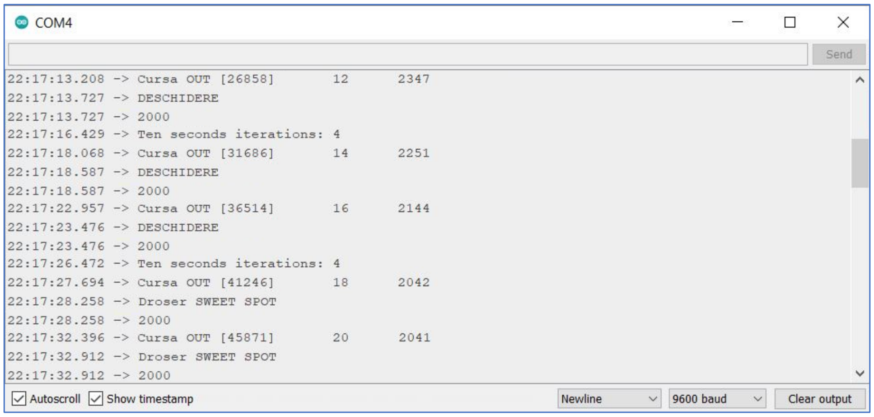
Fig. 6.1 Pneumatic cylinder 1 set at 3 bar to prove Hypothesis 1

6.1.2 Analysis of results for pneumatic cylinder 1 Assumption 1

Pneumatic cylinder 1, was the subject of the initial test to validate Hypothesis 1. To begin, the piston was set to a pressure of 3 bar and the travel time for the pneumatic cylinder rod was set to 2 seconds.

After the system was switched on, the piston began to make outward and rod-in movements while the Arduino control unit read signals from magnetic sensors on the cylinder. This allowed me to measure the time the pneumatic cylinder stroke took and compare it to the set time of 2 seconds.

Data acquisition at 3 bar for pneumatic cylinder 1:



```
22:17:13.208 -> Cursa OUT [26858]       12      2347
22:17:13.727 -> DESCHIDERE
22:17:13.727 -> 2000
22:17:16.429 -> Ten seconds iterations: 4
22:17:18.068 -> Cursa OUT [31686]       14      2251
22:17:18.587 -> DESCHIDERE
22:17:18.587 -> 2000
22:17:22.957 -> Cursa OUT [36514]       16      2144
22:17:23.476 -> DESCHIDERE
22:17:23.476 -> 2000
22:17:26.472 -> Ten seconds iterations: 4
22:17:27.694 -> Cursa OUT [41246]       18      2042
22:17:28.258 -> Droser SWEET SPOT
22:17:28.258 -> 2000
22:17:32.396 -> Cursa OUT [45871]       20      2041
22:17:32.912 -> Droser SWEET SPOT
22:17:32.912 -> 2000
```

5

Fig. 6.2 Data acquisition at 3 bar for pneumatic cylinder 1

If the stroke time was too short, the Arduino commanded the stepper motor to turn clockwise, opening the solenoid valve and increasing the airflow to increase the speed of the pneumatic cylinder. Conversely, if the time was too long, the Arduino commanded the motor to spin counterclockwise, closing the valve and reducing the airflow to slow the piston. This adjustment process was repeated until the piston travel time was within +/- 0.1 seconds of the set 2-second time.

After the piston reached the set time, the pressure was reduced to 2 bar, then to 1 bar, and we watched to see if the stroke travel time of the pneumatic cylinder changed. The change in pneumatic cylinder stroke travel time at these new pressure settings validated hypothesis number 1 for pneumatic cylinder 1.

6.1.2.1 Data acquisition for pneumatic cylinder 1 to 2 bar Assumption 1

After pneumatic cylinder 1 reached the set time for the race at a pressure of 3 bar, the pressure was reduced to 2 bar. At this pressure, I continued to monitor and record the stroke time of the pneumatic cylinder. Adjustments to the system continued to be made automatically, via the Arduino system, until the stroke travel time was back within +/- 0.1 seconds of the 2 second set time. Observing this adjustment of the pneumatic cylinder speed to the change in pressure is a crucial point in validating hypothesis number 1.

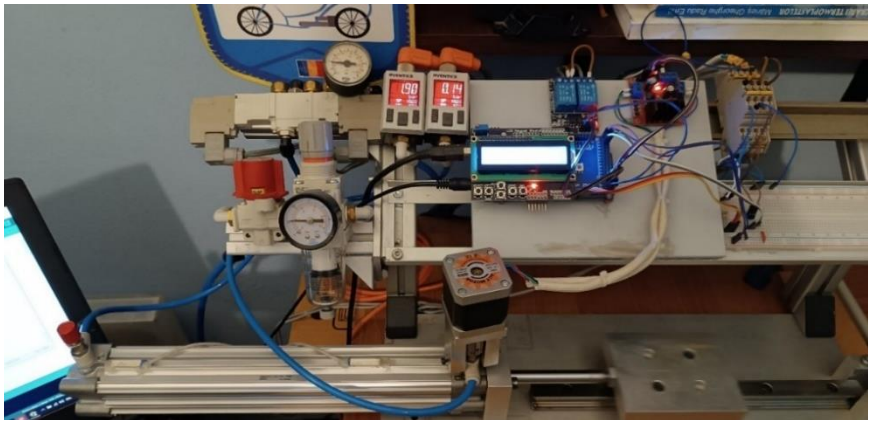
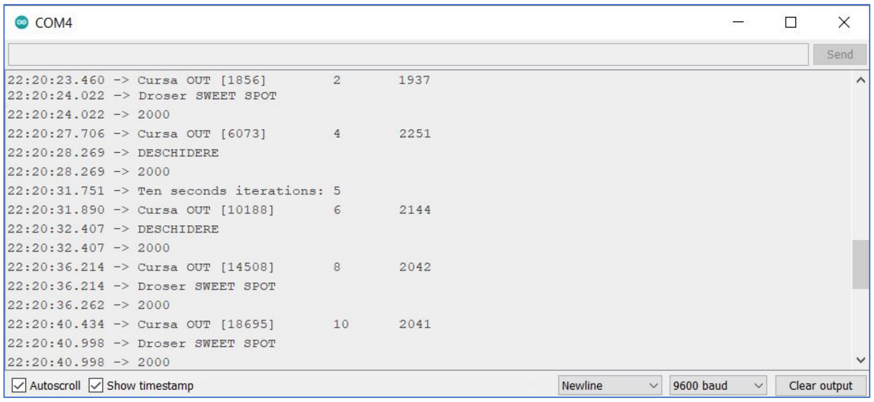


Fig. 6.3 Pneumatic cylinder 1 set at 2 bar to prove Hypothesis 1

Acquisition of 3 bar to 2 bar switching data for pneumatic cylinder 1:



```
22:20:23.460 -> Cursa OUT [1856]        2       1937
22:20:24.022 -> Droser SWEET SPOT
22:20:24.022 -> 2000
22:20:27.706 -> Cursa OUT [6073]        4       2251
22:20:28.269 -> DESCHIDERE
22:20:28.269 -> 2000
22:20:31.751 -> Ten seconds iterations: 5
22:20:31.890 -> Cursa OUT [10188]       6       2144
22:20:32.407 -> DESCHIDERE
22:20:32.407 -> 2000
22:20:36.214 -> Cursa OUT [14508]       8       2042
22:20:36.214 -> Droser SWEET SPOT
22:20:36.262 -> 2000
22:20:40.434 -> Cursa OUT [18695]       10      2041
22:20:40.998 -> Droser SWEET SPOT
22:20:40.998 -> 2000
```

Fig. 6.4 Data acquisition at switching from 3 bar to 2 bar for pneumatic cylinder 1

6.1.2.2 Data acquisition for pneumatic cylinder 1 at 1 bar Assumption 1

After testing at 2 bar, the pressure was subsequently reduced to 1 bar. The procedure of monitoring and recording the travel time of the pneumatic cylinder continued, as in the previous cases. Compressed air flow adjustments, made via the Arduino system and stepper motor, were made until the stroke travel time was within +/- 0.1 seconds of the set time of 2 seconds. This process of adapting to pressure variations by changing the speed of the pneumatic cylinder completed the validation of hypothesis number 1 for pneumatic cylinder 1.

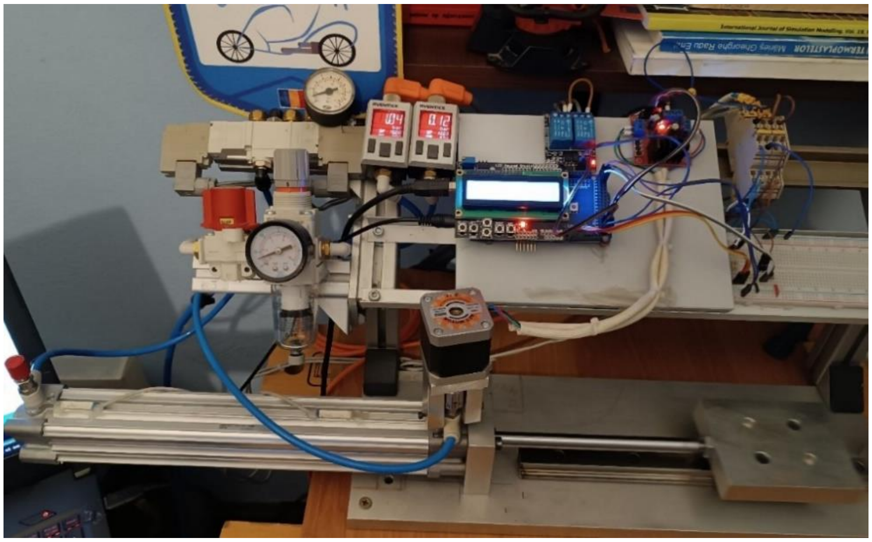
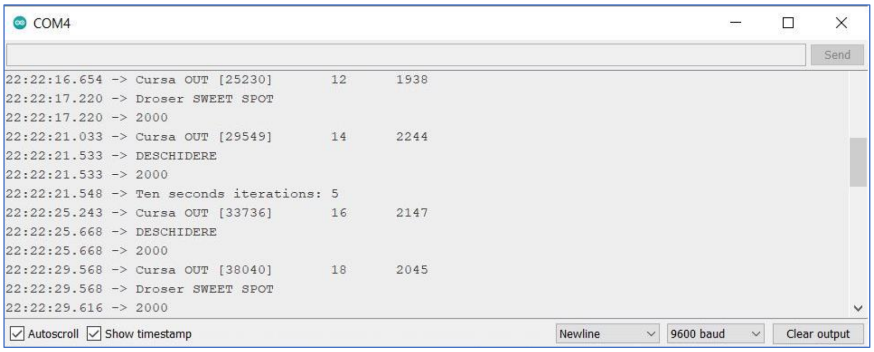


Fig. 6.5 Pneumatic cylinder 1 set at 1 bar to prove Hypothesis 1

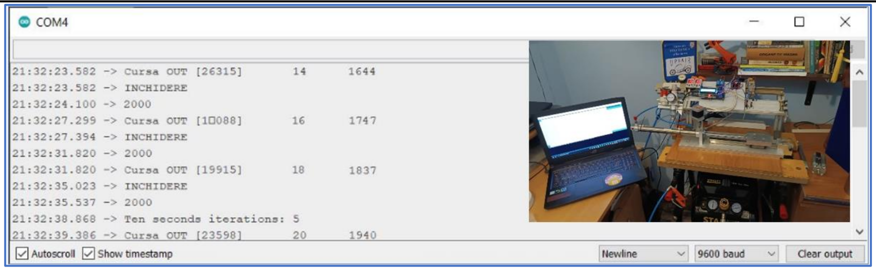
Acquisition of 2 bar to 1 bar switching data for pneumatic cylinder 1:



```
22:22:16.654 -> Cursa OUT [25230]       12      1938
22:22:17.220 -> Droser SWEET SPOT
22:22:17.220 -> 2000
22:22:21.033 -> Cursa OUT [29549]       14      2244
22:22:21.533 -> DESCHIDERE
22:22:21.533 -> 2000
22:22:21.548 -> Ten seconds iterations: 5
22:22:25.243 -> Cursa OUT [33736]       16      2147
22:22:25.668 -> DESCHIDERE
22:22:25.668 -> 2000
22:22:29.568 -> Cursa OUT [38040]       18      2045
22:22:29.568 -> Droser SWEET SPOT
22:22:29.616 -> 2000
```

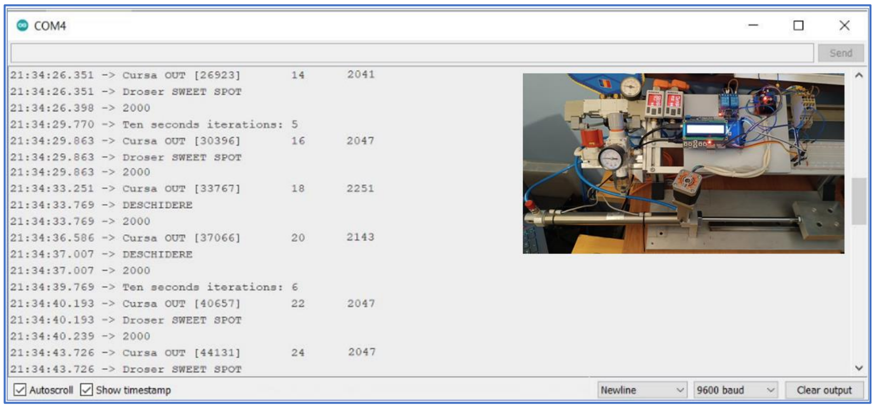
Fig. 6.6 Data acquisition at 2 bar to 1 bar switching for pneumatic cylinder 1

Hypothesis 1 was subjected to the same test procedure for pneumatic cylinders 2 and 3. Thus, cylinder 2, with a diameter of 25mm and a stroke of 250mm, and cylinder 3, with a diameter of 32mm and a stroke of 40mm, were both tested using the experimental bench described above. For each of these cylinders, testing began at a pressure of 3 bar, with the time set for travel of the pneumatic cylinder rod stabilised at 2 seconds. Subsequently, the pressure was gradually decreased to 2 bar and finally to 1 bar. The main objective of this test was to observe whether the pneumatic system is able to effectively adjust its cylinder speed while maintaining a constant 2-second travel time of the pneumatic cylinder rod despite the simulated pressure fluctuations. These tests and their results are illustrated in the following images.



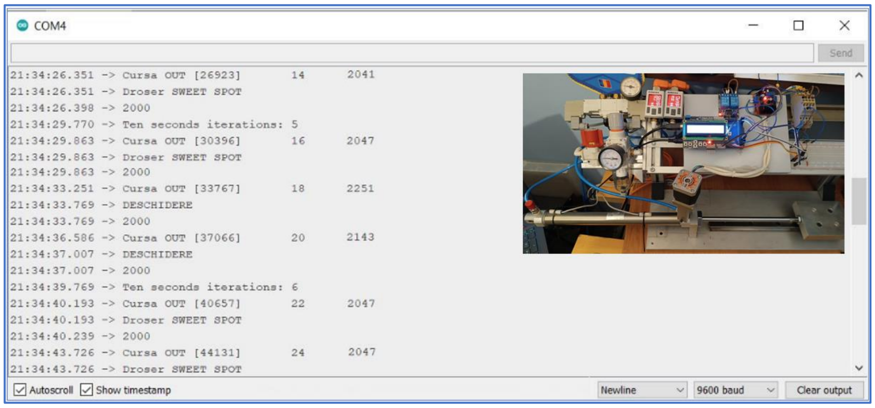
```
21:32:23.582 -> Cursa OUT [26315]       14      1644
21:32:23.582 -> INCHIDERE
21:32:24.100 -> 2000
21:32:27.299 -> Cursa OUT [1□088]       16      1747
21:32:27.394 -> INCHIDERE
21:32:31.820 -> 2000
21:32:31.820 -> Cursa OUT [19915]       18      1837
21:32:35.023 -> INCHIDERE
21:32:35.537 -> 2000
21:32:38.868 -> Ten seconds iterations: 5
21:32:39.386 -> Cursa OUT [23598]       20      1940
```

Fig. 6.7 Data acquisition at 3 bar for cylinder 2



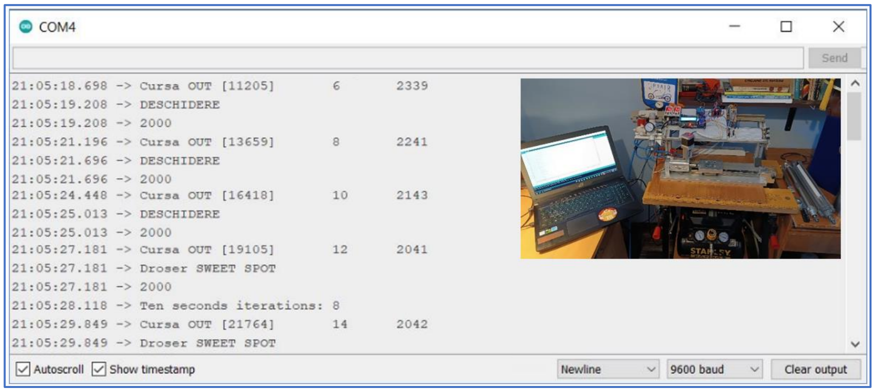
```
21:34:26.351 -> Cursa OUT [26923]       14      2041
21:34:26.351 -> Droser SWEET SPOT
21:34:26.398 -> 2000
21:34:29.770 -> Ten seconds iterations: 5
21:34:29.863 -> Cursa OUT [30396]       16      2047
21:34:29.863 -> Droser SWEET SPOT
21:34:29.863 -> 2000
21:34:33.251 -> Cursa OUT [33767]       18      2251
21:34:33.769 -> DESCHIDERE
21:34:33.769 -> 2000
21:34:36.586 -> Cursa OUT [37066]       20      2143
21:34:37.007 -> DESCHIDERE
21:34:37.007 -> 2000
21:34:39.769 -> Ten seconds iterations: 6
21:34:40.193 -> Cursa OUT [40657]       22      2047
21:34:40.193 -> Droser SWEET SPOT
21:34:40.239 -> 2000
21:34:43.726 -> Cursa OUT [44131]       24      2047
21:34:43.726 -> Droser SWEET SPOT
```

Fig. 6.8 Data acquisition at 3 bar to 2 bar switching for cylinder 2



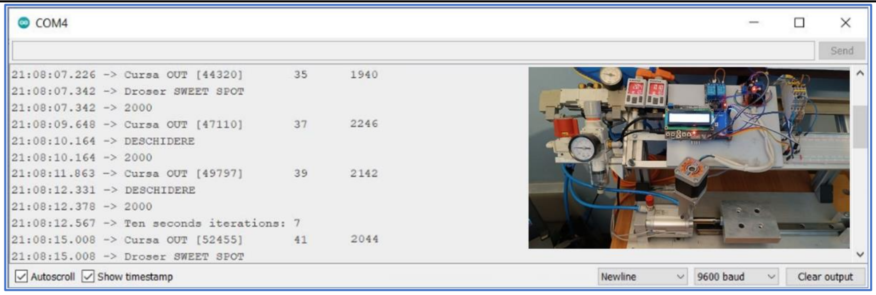
```
21:34:26.351 -> Cursa OUT [26923]       14      2041
21:34:26.351 -> Droser SWEET SPOT
21:34:26.398 -> 2000
21:34:29.770 -> Ten seconds iterations: 5
21:34:29.863 -> Cursa OUT [30396]       16      2047
21:34:29.863 -> Droser SWEET SPOT
21:34:29.863 -> 2000
21:34:33.251 -> Cursa OUT [33767]       18      2251
21:34:33.769 -> DESCHIDERE
21:34:33.769 -> 2000
21:34:36.586 -> Cursa OUT [37066]       20      2143
21:34:37.007 -> DESCHIDERE
21:34:37.007 -> 2000
21:34:39.769 -> Ten seconds iterations: 6
21:34:40.193 -> Cursa OUT [40657]       22      2047
21:34:40.193 -> Droser SWEET SPOT
21:34:40.239 -> 2000
21:34:43.726 -> Cursa OUT [44131]       24      2047
21:34:43.726 -> Droser SWEET SPOT
```

Fig. 6.9 Data acquisition at 2 bar to 1 bar switching for cylinder 2



```
21:05:18.698 -> Cursa OUT [11205]       6       2339
21:05:19.208 -> DESCHIDERE
21:05:19.208 -> 2000
21:05:21.196 -> Cursa OUT [13659]       8       2241
21:05:21.696 -> DESCHIDERE
21:05:21.696 -> 2000
21:05:24.448 -> Cursa OUT [16418]       10      2143
21:05:25.013 -> DESCHIDERE
21:05:25.013 -> 2000
21:05:27.181 -> Cursa OUT [19105]       12      2041
21:05:27.181 -> Droser SWEET SPOT
21:05:27.181 -> 2000
21:05:28.118 -> Ten seconds iterations: 8
21:05:29.849 -> Cursa OUT [21764]       14      2042
21:05:29.849 -> Droser SWEET SPOT
```

Fig. 6.10 Data acquisition at 3 bar for cylinder 3



```
21:08:07.226 -> Cursa OUT [44320]       35      1940
21:08:07.342 -> Droser SWEET SPOT
21:08:07.342 -> 2000
21:08:09.648 -> Cursa OUT [47110]       37      2246
21:08:10.164 -> DESCHIDERE
21:08:10.164 -> 2000
21:08:11.863 -> Cursa OUT [49797]       39      2142
21:08:12.331 -> DESCHIDERE
21:08:12.378 -> 2000
21:08:12.567 -> Ten seconds iterations: 7
21:08:15.008 -> Cursa OUT [52455]       41      2044
21:08:15.008 -> Droser SWEET SPOT
```

☑ Autoscroll ☑ Show timestamp

Fig. 6.11 Data acquisition at switching from 3 bar to 2 bar for cylinder 3

```
21:08:49.232 -> Cursa OUT [1957]        2       1938
21:08:49.232 -> Droser SWEET SPOT
21:08:49.279 -> 2000
21:08:51.902 -> Cursa OUT [4616]        4       1939
21:08:51.902 -> Droser SWEET SPOT
21:08:51.948 -> 2000
21:08:54.480 -> Cursa OUT [7171]        6       1940
21:08:54.480 -> Droser SWEET SPOT
21:08:54.527 -> 2000
21:08:57.008 -> Cursa OUT [9828]        8       2144
21:08:57.348 -> DESCHIDERE
21:08:57.348 -> 2000
21:08:57.397 -> Ten seconds iterations: 8
21:08:59.754 -> Cursa OUT [12390]       10      2042
21:08:59.754 -> Droser SWEET SPOT
```

☑ Autoscroll ☑ Show timestamp

Fig. 6.12 Data acquisition at 2 bar to 1 bar switching for cylinder 3

6.2 Conclusions for Hypothesis 1

Following the testing process for Hypothesis 1, it can be concluded that the experimental process was successfully executed for all three pistons under different pressure conditions. It was possible to acquire the necessary data despite some small interruptions that did not significantly affect the results obtained.

The operation of the electro-drosel was mostly optimal, with minor deviations that did not impact the test process or the results. The magnetic sensors had some difficulty reading signals, possibly due to vibration, which may be an area for future improvement. However, these small deviations did not affect the validation of the hypothesis.

These results demonstrate that the test procedure was successfully executed, which allows me to move on to the analysis and interpretation of the results in the next chapter.

6.3 Presentation of results for Hypothesis 2

Three different types of pneumatic cylinders, each with distinct sizes and specifications, were used to test Hypothesis 2. In each of these tests, we started with a base load of 0 kg, which we successively increased to 3 kg, 6 kg and then 9 kg. Throughout the process, attention was focused on how this load variation influences the speed of the pneumatic cylinder and the time it takes to travel its stroke.

The main objective of this test was to observe whether the pneumatic system is able to effectively regulate its cylinder speed, aiming to maintain a constant 2 seconds for cylinder rod displacement, even in the face of simulated load fluctuations. All these tests and their consequences are graphically represented in the following images.

6.3.1 Test procedure for cylinders 1, 2 and 3 - Assumption 2

In this experimental phase, pneumatic cylinders 1, 2 and 3 were tested. At first, they were subjected to a pressure of 2 bar with a preset time of 2 seconds to travel the rod. Once the system was activated, the cylinders started a cycle of extension and retraction movements, this rhythm being monitored by the Arduino device which detected the signals emitted by magnetic sensors positioned on the cylinder.

Based on the comparison between the actual pneumatic cylinder travel time and the predefined time, the system optimised the speed of the pneumatic cylinder by adjusting the airflow. This adjustment process was achieved by controlling a stepper motor that operated the air screw, thus influencing the air flow rate.

After stabilizing the pneumatic cylinder at the desired 2-second travel time, with an error margin of +/-0.1 seconds, the load was incrementally increased: first to 3 kg, then to 6 kg and finally to 9 kg. During these adaptations, it was observed whether the time required for the pneumatic cylinder to complete the stroke changed. If the time altered, but the system, via the electro-spring, was able to adjust and maintain the speed of the pneumatic cylinder at 2 seconds, then hypothesis 2 was validated for piston 1, and hypotheses 3 and 4 were also confirmed.

Data collection at this stage is essential to determine the ability of the control system to adjust the speed of the pneumatic cylinder to align with the initial setting of 2 seconds per displacement. The data collected provides a clear view of the system's adaptability to load changes and how they affect the speed of the pneumatic cylinder.

Therefore, this information is crucial to assess the efficiency of the system in maintaining the speed of the pneumatic cylinder according to the initial settings, even in the presence of load variations. The data collection underlines the criticality of verifying the assumption that, by adjusting the airflow through the electro-drosel, the system can counterbalance variations in pneumatic cylinder speed with respect to the applied load.

6.3.1.1 Data acquisition for - Hypothesis 2

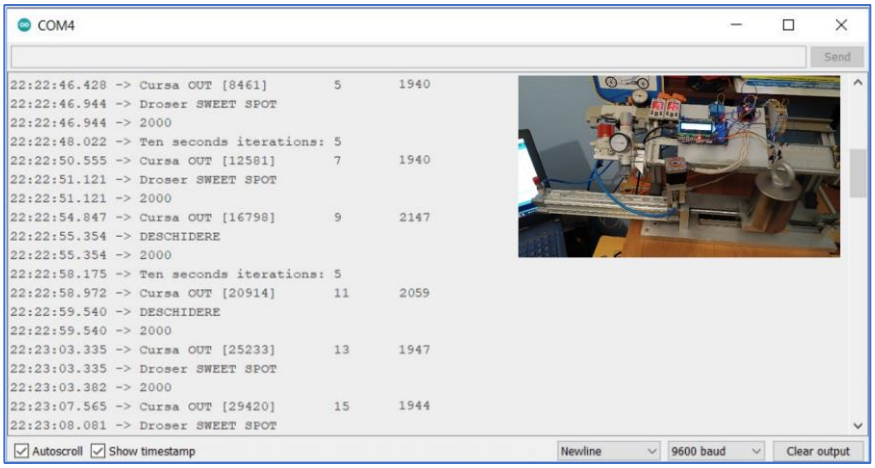
In the process of testing Hypothesis 2, data acquisition played a key role. The data collection process was meticulously structured to accurately capture how the speed of the pneumatic cylinder adapts to load variations. Using precision monitoring equipment, every movement of the pneumatic cylinder was recorded, from small adjustments to major speed changes.

Data acquisition was performed in real time, allowing instant evaluation of system performance. This facilitated direct observations of the behaviour of the pneumatic cylinder at different loads, and allowed any deviations from the set parameters to be quickly identified. Using associated software, the collected data was then analysed to highlight trends and patterns in the behaviour of the pneumatic cylinder.

In addition to speed and travel time, other parameters such as pressure were monitored, giving a complete picture of the dynamics of the pneumatic system under different load conditions. This detailed data collection was vital not only to validate Hypothesis 2, but also to provide valuable information about the overall efficiency of the system and its potential for optimisation. These tests and their results are illustrated in the following images.

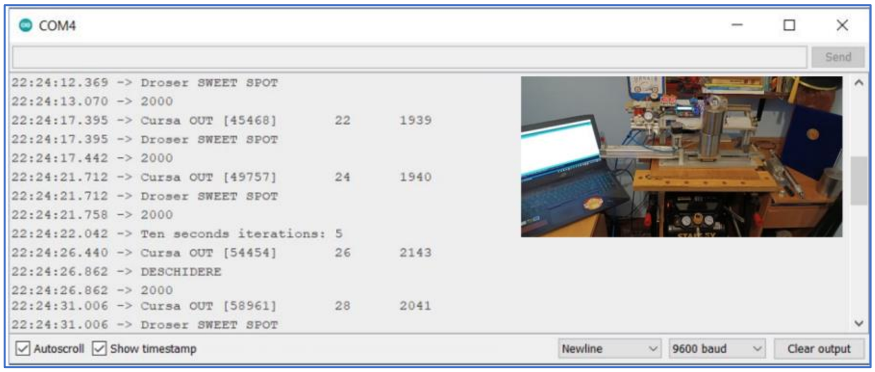
```
22:20:23.460 -> Cursa OUT [1856]        2       1937
22:20:24.022 -> Droser SWEET SPOT
22:20:24.022 -> 2000
22:20:27.706 -> Cursa OUT [6073]        4       2251
22:20:28.269 -> DESCHIDERE
22:20:28.269 -> 2000
22:20:31.751 -> Ten seconds iterations: 5
22:20:31.890 -> Cursa OUT [10188]       6       2144
22:20:32.407 -> DESCHIDERE
22:20:32.407 -> 2000
22:20:36.214 -> Cursa OUT [14508]       8       2042
22:20:36.214 -> Droser SWEET SPOT
22:20:36.262 -> 2000
22:20:40.434 -> Cursa OUT [18695]       10      2041
22:20:40.998 -> Droser SWEET SPOT
22:20:40.998 -> 2000
```

Fig. 6.13 Data acquisition at 2 bar without load for pneumatic cylinder 1



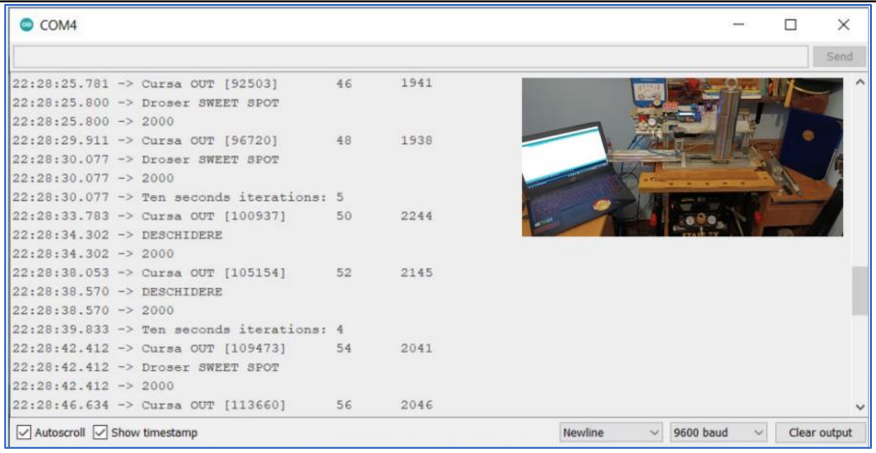
```
22:22:46.428 -> Cursa OUT [8461]        5       1940
22:22:46.944 -> Droser SWEET SPOT
22:22:46.944 -> 2000
22:22:48.022 -> Ten seconds iterations: 5
22:22:50.555 -> Cursa OUT [12581]       7       1940
22:22:51.121 -> Droser SWEET SPOT
22:22:51.121 -> 2000
22:22:54.847 -> Cursa OUT [16798]       9       2147
22:22:55.354 -> DESCHIDERE
22:22:55.354 -> 2000
22:22:58.175 -> Ten seconds iterations: 5
22:22:58.972 -> Cursa OUT [20914]       11      2059
22:22:59.540 -> DESCHIDERE
22:22:59.540 -> 2000
22:23:03.335 -> Cursa OUT [25233]       13      1947
22:23:03.335 -> Droser SWEET SPOT
22:23:03.382 -> 2000
22:23:07.565 -> Cursa OUT [29420]       15      1944
22:23:08.081 -> Droser SWEET SPOT
```

Fig. 6.14 Data acquisition at 2 bar with 3kg load for pneumatic cylinder 1



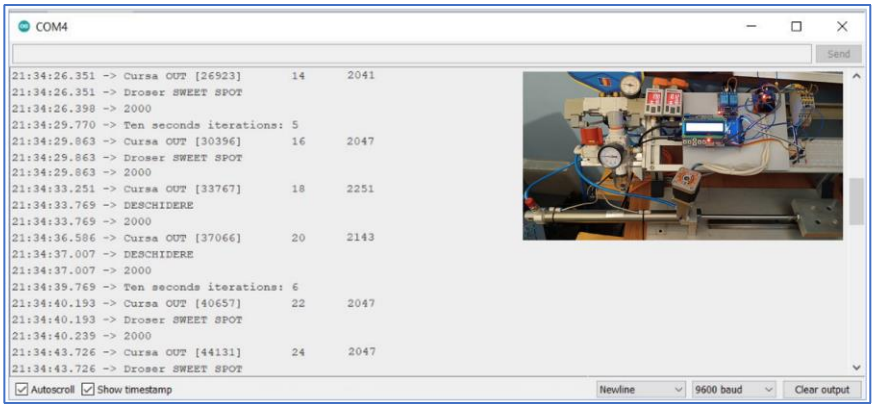
```
22:24:12.369 -> Droser SWEET SPOT
22:24:13.070 -> 2000
22:24:17.395 -> Cursa OUT [45468]       22      1939
22:24:17.395 -> Droser SWEET SPOT
22:24:17.442 -> 2000
22:24:21.712 -> Cursa OUT [49757]       24      1940
22:24:21.712 -> Droser SWEET SPOT
22:24:21.758 -> 2000
22:24:22.042 -> Ten seconds iterations: 5
22:24:26.440 -> Cursa OUT [54454]       26      2143
22:24:26.862 -> DESCHIDERE
22:24:26.862 -> 2000
22:24:31.006 -> Cursa OUT [58961]       28      2041
22:24:31.006 -> Droser SWEET SPOT
```

Fig. 6.15 Data acquisition at 2 bar with 6kg load for pneumatic cylinder 1



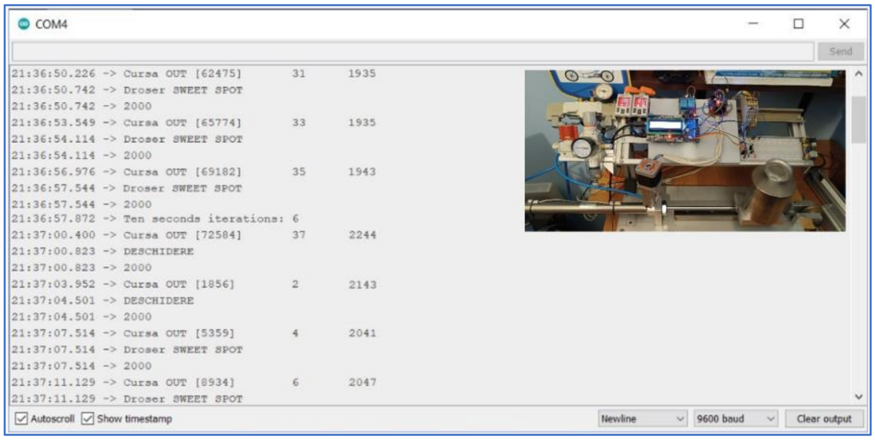
```
22:28:25.781 -> Cursa OUT [92503]       46      1941
22:28:25.800 -> Droser SWEET SPOT
22:28:25.800 -> 2000
22:28:29.911 -> Cursa OUT [96720]       48      1938
22:28:30.077 -> Droser SWEET SPOT
22:28:30.077 -> 2000
22:28:30.077 -> Ten seconds iterations: 5
22:28:33.783 -> Cursa OUT [100937]      50      2244
22:28:34.302 -> DESCHIDERE
22:28:34.302 -> 2000
22:28:38.053 -> Cursa OUT [105154]      52      2145
22:28:38.570 -> DESCHIDERE
22:28:38.570 -> 2000
22:28:39.833 -> Ten seconds iterations: 4
22:28:42.412 -> Cursa OUT [109473]      54      2041
22:28:42.412 -> Droser SWEET SPOT
22:28:42.412 -> 2000
22:28:46.634 -> Cursa OUT [113660]      56      2046
```

Fig. 6.16 Data acquisition at 2 bar with 9kg load for pneumatic cylinder 1



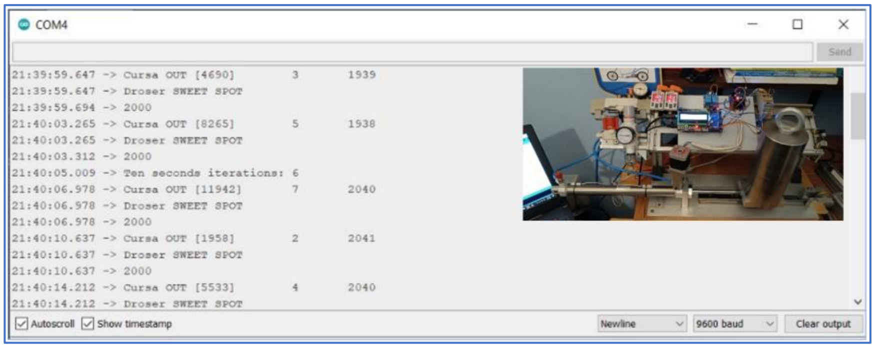
```
21:34:26.351 -> Cursa OUT [26923]       14      2041
21:34:26.351 -> Droser SWEET SPOT
21:34:26.398 -> 2000
21:34:29.770 -> Ten seconds iterations: 5
21:34:29.863 -> Cursa OUT [30396]       16      2047
21:34:29.863 -> Droser SWEET SPOT
21:34:29.863 -> 2000
21:34:33.251 -> Cursa OUT [33767]       18      2251
21:34:33.769 -> DESCHIDERE
21:34:33.769 -> 2000
21:34:36.586 -> Cursa OUT [37066]       20      2143
21:34:37.007 -> DESCHIDERE
21:34:37.007 -> 2000
21:34:39.769 -> Ten seconds iterations: 6
21:34:40.193 -> Cursa OUT [40657]       22      2047
21:34:40.193 -> Droser SWEET SPOT
21:34:40.239 -> 2000
21:34:43.726 -> Cursa OUT [44131]       24      2047
21:34:43.726 -> Droser SWEET SPOT
```

Fig. 6.17 Data acquisition at 2 bar with 0kg load for pneumatic cylinder 2



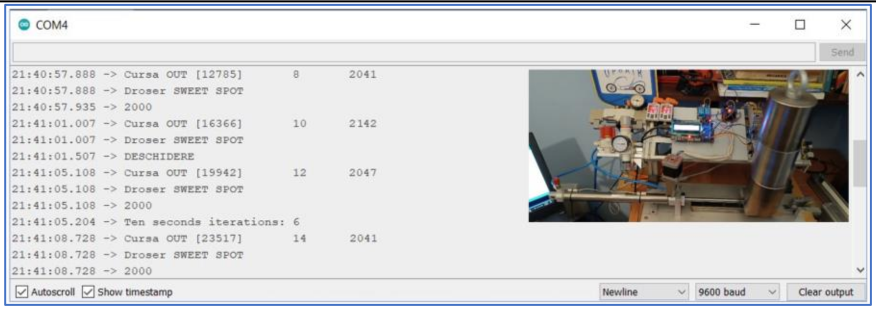
```
21:36:50.226 -> Cursa OUT [62475]       31      1935
21:36:50.742 -> Droser SWEET SPOT
21:36:50.742 -> 2000
21:36:53.549 -> Cursa OUT [65774]       33      1935
21:36:54.114 -> Droser SWEET SPOT
21:36:54.114 -> 2000
21:36:56.976 -> Cursa OUT [69182]       35      1943
21:36:57.544 -> Droser SWEET SPOT
21:36:57.544 -> 2000
21:36:57.872 -> Ten seconds iterations: 6
21:37:00.400 -> Cursa OUT [72584]       37      2244
21:37:00.823 -> DESCHIDERE
21:37:00.823 -> 2000
21:37:03.952 -> Cursa OUT [1856]        2       2143
21:37:04.501 -> DESCHIDERE
21:37:04.501 -> 2000
21:37:07.514 -> Cursa OUT [5359]        4       2041
21:37:07.514 -> Droser SWEET SPOT
21:37:07.514 -> 2000
21:37:11.129 -> Cursa OUT [8934]        6       2047
21:37:11.129 -> Droser SWEET SPOT
```

Fig. 6.18 Data acquisition at 2 bar with 3kg load for pneumatic cylinder 2



```
21:39:59.647 -> Cursa OUT [4690]        3       1939
21:39:59.647 -> Droser SWEET SPOT
21:39:59.694 -> 2000
21:40:03.265 -> Cursa OUT [8265]        5       1938
21:40:03.265 -> Droser SWEET SPOT
21:40:03.312 -> 2000
21:40:05.009 -> Ten seconds iterations: 6
21:40:06.978 -> Cursa OUT [11942]       7       2040
21:40:06.978 -> Droser SWEET SPOT
21:40:06.978 -> 2000
21:40:10.637 -> Cursa OUT [1958]        2       2041
21:40:10.637 -> Droser SWEET SPOT
21:40:10.637 -> 2000
21:40:14.212 -> Cursa OUT [5533]        4       2040
21:40:14.212 -> Droser SWEET SPOT
```

Fig. 6.19 Data acquisition at 2 bar with 6kg load for pneumatic cylinder 2



```
21:40:57.888 -> Cursa OUT [12785]       8       2041
21:40:57.888 -> Droser SWEET SPOT
21:40:57.935 -> 2000
21:41:01.007 -> Cursa OUT [16366]       10      2142
21:41:01.007 -> Droser SWEET SPOT
21:41:01.507 -> DESCHIDERE
21:41:05.108 -> Cursa OUT [19942]       12      2047
21:41:05.108 -> Droser SWEET SPOT
21:41:05.108 -> 2000
21:41:05.204 -> Ten seconds iterations: 6
21:41:08.728 -> Cursa OUT [23517]       14      2041
21:41:08.728 -> Droser SWEET SPOT
21:41:08.728 -> 2000
```

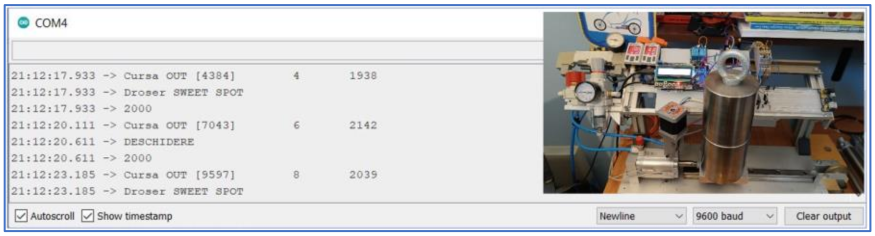
Fig. 6.20 Data acquisition at 2 bar with 9kg load for pneumatic cylinder 2

```
21:08:07.226 -> Cursa OUT [44320]       35      1940
21:08:07.342 -> Droser SWEET SPOT
21:08:07.342 -> 2000
21:08:09.648 -> Cursa OUT [47110]       37      2246
21:08:10.164 -> DESCHIDERE
21:08:10.164 -> 2000
21:08:11.863 -> Cursa OUT [49797]       39      2142
21:08:12.331 -> DESCHIDERE
21:08:12.378 -> 2000
21:08:12.567 -> Ten seconds iterations: 7
21:08:15.008 -> Cursa OUT [52455]       41      2044
21:08:15.008 -> Droser SWEET SPOT
```

Fig. 6.21 Data acquisition at 2 bar with 0kg load for pneumatic cylinder 3

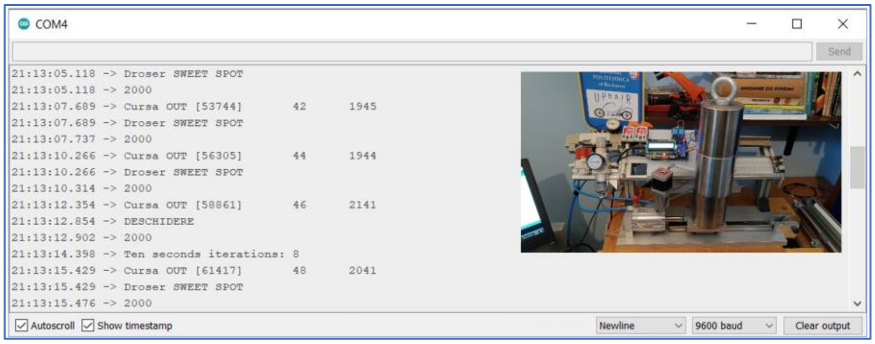
```
21:11:27.740 -> Droser SWEET SPOT
21:11:34.174 -> Cursa OUT [2059]        2       1940
21:11:34.174 -> Droser SWEET SPOT
21:11:34.174 -> 2000
21:11:36.750 -> Cursa OUT [4620]        4       1946
21:11:36.750 -> Droser SWEET SPOT
21:11:36.750 -> 2000
21:11:39.397 -> Cursa OUT [7175]        6       2144
21:11:39.754 -> DESCHIDERE
21:11:39.754 -> 2000
21:11:41.903 -> Cursa OUT [9737]        8       2046
21:11:41.903 -> Droser SWEET SPOT
```

Fig. 6.22 Data acquisition at 2 bar with 3kg load for pneumatic cylinder 3



```
21:12:17.933 -> Cursa OUT [4384]        4       1938
21:12:17.933 -> Droser SWEET SPOT
21:12:17.933 -> 2000
21:12:20.111 -> Cursa OUT [7043]        6       2142
21:12:20.611 -> DESCHIDERE
21:12:20.611 -> 2000
21:12:23.185 -> Cursa OUT [9597]        8       2039
21:12:23.185 -> Droser SWEET SPOT
```

Fig. 6.23 Data acquisition at 2 bar with 6kg load for pneumatic cylinder 3



```
21:13:05.118 -> Droser SWEET SPOT
21:13:05.118 -> 2000
21:13:07.689 -> Cursa OUT [53744]       42      1945
21:13:07.689 -> Droser SWEET SPOT
21:13:07.737 -> 2000
21:13:10.266 -> Cursa OUT [56305]       44      1944
21:13:10.266 -> Droser SWEET SPOT
21:13:10.314 -> 2000
21:13:12.354 -> Cursa OUT [58861]       46      2141
21:13:12.854 -> DESCHIDERE
21:13:12.902 -> 2000
21:13:14.398 -> Ten seconds iterations: 8
21:13:15.429 -> Cursa OUT [61417]       48      2041
21:13:15.429 -> Droser SWEET SPOT
21:13:15.476 -> 2000
```

Fig. 6.24 Data acquisition at 2 bar with 9kg load for pneumatic cylinder 3

6.4 Conclusions for Hypothesis 2

Following the testing process for Hypothesis 2, it can be concluded that the experimental testing was successfully performed for all three pistons under different load conditions. The data acquisition was performed successfully, although there were some minor interruptions that did not influence the results significantly.

The performance of the electro-drosel was largely consistent, with a few minor variations that did not have a major impact on the results or the testing process. Reading signals from the magnetic sensors had some difficulties, possibly due to vibration, which is a possible area of improvement for future experiments. However, these minor inconveniences did not impact the validation of the hypothesis.

These results show that the test procedure has been properly implemented, which allows us to advance the analysis and interpretation of the results in the next chapter.

6.5 Presentation of results for Hypothesis 3

Hypothesis 3 postulates that the redesigned unidirectional control valve, incorporating an electric motor (electro-drosel), allows remote control of pneumatic cylinder speed in a pneumatic system.

6.5.1 Description of Hypothesis 3

Hypothesis 3 is closely related to the first two hypotheses tested. In Hypothesis 1, we showed that the electric motor (electro-spring) can control the speed of the pneumatic cylinder in a pneumatic system, adjusting to pressure variations. In Hypothesis 2, we have shown that this control mechanism can regulate the speed of the pneumatic cylinder in a pneumatic system, even when the applied load changes.

This hypothesis focuses on the possibility of remote control of the speed of the pneumatic cylinder. This involves an interface between the electric motor and an automatic control system, which could be programmed and monitored remotely.

Using the data acquired from Assumptions 1 and 2, they can examine how the system responded to pressure changes and load changes, and determine if the system can be effectively controlled remotely.

To validate this hypothesis, I can check that the system responded to commands and that the speed of the pneumatic cylinder adjusted properly, without the necessary manual intervention.

6.6 Presentation of results for Hypothesis 4

Hypothesis 4 explores the idea that the ability to automatically adjust the speed of the pneumatic cylinder with the electro-spring allows effective control over speed variations induced by pressure variations and load changes. Consequently, this could improve the operational flexibility and reliability of pneumatic systems.

6.6.1 Description of Hypothesis 4

Hypothesis 4 builds on the success of the previous hypotheses, which established that the electro-drosel can control and regulate the speed of the pneumatic cylinder in a pneumatic system according to pressure variations and load changes.

Automatic speed control and regulation would allow operators to manage the system without being in close proximity to it, thus improving operational flexibility. In addition, this could increase the reliability of the system as it would reduce the need for manual intervention.

To validate this hypothesis, I will analyze the performance of the system under varying pressure and load conditions, while evaluating its ability to autonomously adjust to these changes. This will involve detailed examination of the data acquired during the testing of Hypotheses 1 and 2, with a focus on aspects that demonstrate system adaptability and autonomy in speed control.

CHAPTER 7 DATA ANALYSIS AND CONFIRMATION OF HYPOTHESES AND OBJECTIVES

After collecting and presenting the data obtained in the testing process, it is essential to return to the original research questions and analyze these data in the context of the hypotheses formulated. Analysing and interpreting the results is a crucial step in the scientific endeavour, as it is the time to assess the validity of the hypotheses and draw the appropriate conclusions.

In this chapter, I analyse the results of the experiment for each hypothesis in turn, seeking to better understand the dynamics of the pneumatic system and to verify the hypotheses formulated. Each section will examine specific test data obtained for the respective hypotheses, giving a clear picture of the impact that integrating the electric motor into the one-way control valve system has on the pneumatic cylinder speed.

Interpreting the results will allow me to understand not only whether the hypotheses are supported or rejected, but also why these results were obtained. By exploring this dimension of the research, I aim to make valuable contributions to our understanding of pneumatic systems and how to optimise them.

7.1 Analysis of results for Hypothesis 1

Assumption 1 anticipates fluctuations in pneumatic piston speed caused by pressure variations. To counteract this effect, we introduced the electro-drosel as a solution to compensate for these variations.

At a decrease in pressure from 3 to 2 bar, a corresponding reduction in pneumatic cylinder displacement speed was observed. However, due to the regulating capabilities of the electro-drum, it was possible to compensate for this speed change in only three iterations. This behaviour underlines the efficiency of the electro-drosel in regulating the air flow and therefore the speed of the pneumatic cylinder, even under conditions of pressure variation.

A bigger challenge came when the pressure was reduced to 1 bar. In this situation, the speed of the pneumatic cylinder dropped considerably, requiring a greater number of iterations for the electro-drosel to return the cylinder speed to the original setting. This behaviour can be attributed both to the significant pressure drop and to the software algorithm controlling the stepper motor of the electro-drosel.

The software is configured to rotate the motor at a constant pitch of 10% of a full stroke, regardless of the size of the gap between the actual air cylinder speed and the set speed. In the event of a significant drop in cylinder speed, this approach can result in a longer adjustment period.

If the software could perform a calculation to adjust the number of motor steps according to the size of the speed gap, the tuning process could be more efficient. This is a possible system improvement that could be considered in future developments.

In conclusion, the tests performed for Hypothesis 1 validate the fluctuations of the cylinder speed. The introduction of an electro-drosel into the pneumatic system ensures an effective adjustment of the pneumatic cylinder speed, even in the face of pressure variations. However, the stepper motor control algorithm may affect the quality of the adjustment, signalling a potential area for optimisation of the system.

7.2 Analysis of results for Hypothesis 2

Assumption 2 anticipates fluctuations in pneumatic piston speed caused by load variations. To counteract this effect, we introduced the electro-drosel as a solution to compensate for these variations.

For pneumatic cylinder No. 1, where air consumption was significantly higher, variations in pneumatic cylinder speed in response to load changes were observed. This phenomenon is to be expected as load changes are a disturbance to the pneumatic system and the pneumatic cylinder speed is likely to be influenced by them. However, the electro-drosel has proven to be effective in compensating for speed variations and maintaining speed within the set range, even in the presence of these disturbances.

For pistons 2 and 3, which had lower air consumption, small variations in speed were also recorded when different loads were introduced. This suggests that even in pistons with lower air consumption, load changes can generate speed variations. However, these variations were small and were quickly compensated for by the electro-spring.

One point to note is that the observed speed variations might have been more pronounced if the load had been increased to the load limit of the pneumatic cylinder. This indicates that the electro-drum tuning may perform differently depending on the magnitude of the applied load, which should be explored in further studies.

In conclusion, the tests performed for Hypothesis 2 validate the fluctuations of the cylinder speed. The introduction of an electro-drosel into the pneumatic system ensures an effective adjustment of the pneumatic cylinder speed, even in the face of load variations. These results indicate the robustness and reliability of the system, even in the face of disturbances such as load changes. However, it is evident that there is some dependence between load magnitude and tuning performance, which deserves further investigation.

7.3 Analysis of results for Hypothesis 3

Hypothesis 3 proposes the idea of the electro-drosel, allowing remote control of pneumatic cylinder speed in a pneumatic system.

This represents a significant advancement in pneumatic technology, offering the ability to adjust the operation of pneumatic systems to the specific needs of the application in real time, without the need for an operator to be physically present. In addition, remote control offers the potential to improve the efficiency and performance of pneumatic systems, optimising their operation to match current working conditions.

Experimental results indicate that this hypothesis is supported. By using a stepper motor controlled drosel, we were able to achieve effective control over the speed of the pneumatic cylinder, even when operating conditions varied. Remote control allowed the settings to be changed in real time as needed, providing great flexibility in managing pneumatic systems.

Therefore, the experimental results support Hypothesis 3 and confirm that improvements to the one-way control valve allow efficient and flexible remote control of pneumatic cylinder speed in a pneumatic system, as well as the ability to do so remotely. These findings pave the way for further development of pneumatic technology and suggest the potential of these approaches to improve the performance and efficiency of pneumatic systems in a variety of applications.

7.4 Analysis of results for Hypothesis 4

Hypothesis 4 argues that the possibility of automatic speed regulation by means of an electro-drosel can considerably improve the efficiency and flexibility of pneumatic systems. With this hypothesis, it is assumed that fine adjustments made automatically by the system will allow more efficient management of speed variations and load changes, which will contribute to improving the overall performance of the system.

The results acquired from the tests support this hypothesis. We observed that the electro-drosel allowed fine adjustment of the pneumatic cylinder speed according to pressure variations and load changes. Furthermore, due to its ability to make fine and fast adjustments, it allowed a constant speed to be maintained even under pressure or load fluctuations. This is a major advantage in terms of energy efficiency and operational flexibility.

Such a system can also operate efficiently without continuous supervision, thus reducing the need for human intervention and possible associated errors.

In conclusion, the experimental results obtained in this research support Hypothesis 4, confirming that automatic pneumatic cylinder speed regulation with the electro-drosel improves the efficiency and flexibility of pneumatic systems. These findings have important implications for the future development of pneumatic technology and its potential use in a wide range of industrial applications.

7.5 General interpretation of the results

The overall interpretation of the experimental results obtained from the testing of the proposed hypotheses indicates that the use of an electro-drosel brings significant improvements in the operation of pneumatic systems.

First, in the context of Hypothesis 1, it was observed that the electro-drosel was able to adjust the speed of the pneumatic cylinder in pressure variations. This was achieved despite the fact that some iterations were required to achieve the set speed, suggesting that the software could be optimised to improve this process.

Second, for Hypothesis 2, fluctuations in pneumatic cylinder speed were found as a function of load. However, the electro-drosel was able to bring the cylinder speed back to the set speed even with these variations. This shows the potential of the electro-drosel to maintain constant operation even under load fluctuations.

As for Hypothesis 3, experiments have shown that the electro-drone can facilitate remote control of the speed of the pneumatic cylinder. This demonstrates the advantages of using an electro-drosel in terms of accessibility and adaptability.

Finally, Hypothesis 4 through the experiments performed supports automatic pneumatic cylinder speed regulation by means of an electro-drosel with the ability to handle speed variations arising from pressure and load fluctuations, which has been shown to be an important contribution to improving the flexibility and reliability of pneumatic systems.

In conclusion, the results of this study confirm all four hypotheses, suggesting that the implementation of an electro-drosel can bring substantial benefits to the efficiency, flexibility and adaptability of pneumatic systems. These findings offer promising prospects for the future development of pneumatic technologies.

CHAPTER 8 FINAL C[illegible]LUSIONS AND PERSONAL CONTRIBUTIONS

8.1 General conclusions

As I delved deeper into the areas of research that are the subject of this PhD thesis, I realized the profound significance of the interactions between pneumatic and electrical components and the impending need for innovation in this space. The rapid evolution in valve and control component technology offers us unique opportunities for optimization and performance. To meet the current needs of the industry, it is imperative to combine theoretical understanding with practical application.

Since this PhD thesis aligns closely with my field of specialization, I have structured and realized the major objectives related to unidirectional electrocouplers and their behavior in pneumatic systems in particular:

- Studying and demonstrating how modernized valve design can provide increased efficiency and reliability in practical applications.

- Investigate the dynamic behaviour of valves under variable conditions and identify ways to improve.

In terms of specific objectives, we addressed:

- Detailed mathematical modelling of cylinder velocity.

- Development and validation of simulations in Automation Studio software.
- Construction of a test rig for experimental validation of hypotheses.
- Detailed analysis of experimental and theoretical results and their correlation to draw relevant conclusions.

Theoretical and experimental investigations have been pursued in two main directions: optimising valve design for maximum efficiency and validating the performance of these valves under real conditions.

The thesis shed light on future design and application possibilities, taking into account the rapid technological evolution and the need for robust solutions in pneumatic systems. With a growing interest in the industrial sector for efficiency and reliability, our research aligns perfectly with current trends and modern industry requirements.

As a result of our research, we have identified promising directions for further development of valve technology and pneumatic systems. This provides us with a solid basis for future research and the practical applicability of our findings.

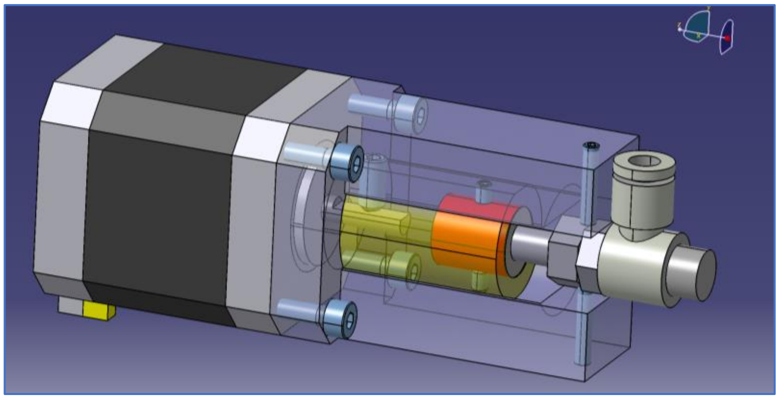


Fig. 8.1 Schematic of the upgraded valve design.

This final paper highlights the relevance, applicability and significant contributions of our research in the field of pneumatic systems and provides a solid basis for future innovations.

8.2 Recommendations and future research directions

As discussed and concluded in the previous section, rapid technological change and increasingly stringent industry requirements offer us a lot of opportunities, but also challenges. Based on the conclusions drawn and the experience gained during this thesis, I propose the following recommendations and directions for future research:

Adapting valve design to new materials: As technology advances, new and more efficient materials become available. Thus, I recommend periodic evaluation of materials and their potential integration into valve design to provide greater performance and durability.

Integrating IoT technology: With the advancement of the Internet of Things (IoT), there is an opportunity to integrate sensors and other smart components into valves for real-time monitoring and dynamic performance adjustment.

Advanced simulation software development: Although we have used Automation Studio for simulations, there is an ongoing need for software development that allows for more detailed simulations tailored to specific industry needs.

Study on the integration of renewable energy sources: In the context of a global trend towards sustainability, research should also focus on the possibility of using renewable energy sources in pneumatic systems.

Training and education: In addition to innovation and research, I recommend the development of training programmes for engineers and technicians in the field so that they can understand and exploit new technologies and discoveries to the full.

In conclusion, I would point out that pneumatic systems, although widely studied and used over the years, remain an evolving field. This thesis has made significant contributions, but the research does not stop there. It is essential that industry and academia work closely together to address future challenges and move forward in this promising direction.

8.3 Exploitation of research results

In the framework of this scientific approach on IMPROVING THE PERFORMANCE OF PNEUMATIC DRIVE SYSTEMS, the results of the research have been exploited as follows:

During the development of this thesis, a total of 5 scientific reports were presented and discussed in the Doctoral School of Engineering and Management of Technological Systems. These are:

Report 1: Recent developments in valve design for pneumatic systems.

Report 2: Methodologies and theoretical approaches in pneumatic valve performance assessment.

Report 3: Advanced mathematical modelling of valve behaviour under dynamic conditions.

Report 4: Construction and optimization of test rig for experimental evaluation of valves.

Report 5: Simulation, data acquisition and practical validation of valve performance under real conditions.

The experimental part of the research was carried out in the laboratories of Plastor and the National University of Science and Technology POLITEHNICA Bucharest.

Articles that have emanated during the course of this research and have been published in peer-reviewed journals will be listed later in this section.

1. Mihalache Ghinea, **Mihai Agud**, Mircea Bodog, Mark Antonio Agud. - *Pneumatic Cylinders Controlled by Two Different Controllers, Arduino and MyRIO: an Educational Approach.* International Journal of Education and Information Technologies, E-ISSN: 2074-1316, Volume 16, 14 Mar. 2022, Art. 12 DOI: 10.46300/9109.2022.16.12
2. Mihalache Ghinea, **Mihai Agud**, Mircea Bodog - *Simulation of pneumatic systems using Automation Studio software platform.* International Journal of Simulation Modelling ISSN: 1726-4529 Volume 19(4):655-666 DOI:10.2507/IJSIMM19-4-541
3. Prada A., Blaga F., Mihaila S., **Mihai Agud** - *Experimental Research Regarding the Defects Occurring at the Injection-molding of Long Technical Parts.* Made of Thermoplastic Material, Using CAE Systems. Case Study, Mater. Plast, Year 2023, Volume 60, Issue 2, 121-133 DOI:10.37358/MP.23.2.5668
4. **Mihai Agud**, Ștefan Velicu, Florin Enache, Mihai-Stelian Hagiescu, Cristian Paunescu - *Functional optimization of an air car by modeling and simulation* SLS&OPTIROB 2023, International Journal of Modeling and Optimization (*IJMO*)

5. Florin Enache, **Mihai Agud**, Stefan Velicu, Anisoara Corabieru - *Enhancing speed regulation in pneumatic systems with electric flow control valves.* TECHNICAL UNIVERSITY OF CLUJ-NAPOCA, ACTA TECHNICA NAPOCENSIS, Series: Applied Mathematics, Mechanics, and Engineering, Vol. XX, Issue xx, Month, 20xx- in publication

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