Hands-On Learning Approaches in Teaching Pneumatics and Electropneumatics to Engineering Students

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***Abstract*- The integration of hands-on learning approaches into engineering education has become increasingly essential in preparing students for the practical challenges of modern industrial environments. This paper explores the application of practice-oriented teaching methods in pneumatics and electropneumatics courses within higher education. Through laboratory-based exercises, project-oriented tasks, and simulation-supported experimentation, students are provided with opportunities to bridge theoretical knowledge and real-world application. The study highlights how hands-on methodologies contribute to the development of technical competencies, problem-solving skills, and a deeper understanding of system behavior. Furthermore, the paper discusses the role of experiential learning in fostering student engagement and motivation, while addressing the pedagogical challenges of integrating practice-based approaches into curricula. The findings suggest that practice-centered education significantly enhances student preparedness for Industry 4.0 environments, where automation, control, and mechatronic systems play a key role.**

Keywords - Pneumatics, Electropneumatics, Engineering education, Hands-on learning, Practice-based teaching, Laboratory methods, Experiential learning, Project-based learning, Competence development

I. Introduction

The rapid technological advancement and the growing complexity of automated systems require future engineers to acquire not only theoretical knowledge but also the ability to apply this knowledge in practical contexts. Within the domains of pneumatics and electropneumatics – core areas of automation and control engineering - hands-on learning approaches have proven to be particularly effective in bridging the gap between classroom instruction and industrial practice [1], [2]. As Industry 4.0 continues to reshape the technological landscape, higher education institutions face the challenge of equipping students with both technical expertise and the transversal competencies needed for professional success [3], [4].

Hands-on learning methodologies, including laboratory experiments, simulation-supported training, and practice-oriented project work, allow students to directly interact with pneumatic and electropneumatic systems [5]. This experiential approach enhances technical understanding, improves problem-solving skills, and fosters a deeper comprehension of system behavior compared to purely theoretical instruction [6]. In addition, these methods provide students with the opportunity to test hypotheses, learn from errors, and engage in iterative problem-solving, thereby reinforcing critical engineering competencies [7].

Beyond the acquisition of technical knowledge, hands-on and project-based learning environments also deliver significant pedagogical benefits [8]. Group projects and collaborative laboratory tasks encourage teamwork, communication, and leadership, which are increasingly recognized as essential professional skills in engineering practice [9]. Students working in groups not only learn to manage complex technical challenges but also develop interpersonal abilities, such as negotiation, conflict resolution, and collaborative decision-making [10]. These soft skills are indispensable in multidisciplinary engineering contexts, where effective communication and cooperation across domains often determine the success of industrial projects [11].

Furthermore, practice-based learning motivates students by placing them in active roles within the educational process [12]. Rather than passively receiving information, learners become co-creators of knowledge as they design, build, and test pneumatic and electropneumatic systems [13]. This active engagement leads to higher retention of knowledge, greater enthusiasm for learning, and stronger preparation for professional challenges [14].

In light of these considerations, this paper examines the pedagogical advantages of hands-on learning approaches in the teaching of pneumatics and electropneumatics [15]. Particular attention is given to the integration of group-based projects and their contribution to both technical competence and soft skill development [16]. By highlighting the benefits of experiential methodologies, the study contributes to ongoing discussions on how engineering education can better align with the requirements of contemporary industry and prepare students for future technological environments [17].

II. Methods and Practical Implementation

A. Pneumatic Logic Control Exercises

The structured practice-oriented methodology begins with the design and testing of basic pneumatic control systems [18]. These exercises gradually introduce students to the fundamental principles of cylinder actuation, switching states, and safety considerations.

In the first exercise, students get to know the operation of single-acting cylinders that can perform work in only one direction. Using a 2/2 directional valve, they examine the role of initial positions, valve configuration, and spring return force. Factors influencing piston speed – such as cylinder dimensions, valve flow capacity, air pressure, and external load – are identified and controlled through throttle valves.

In the second exercise, students learn how to control a double-acting cylinder using a monostable valve. They also explore how a 4/2 or 5/2 valve controls cylinder motion. The task highlights the effect of valve return mechanisms and the interpretation of monostable states.

In the third exercise, students explore the control of a double-acting cylinder with a bistable valve, focusing on impulse signals and memory functions. Using electrically actuated 4/2 or 5/2 valves, learners gain experience with impulse-controlled actuation and memory functions of valves. The exercise stresses safe handling, as simultaneous inputs may create undefined or hazardous states.

In the fourth exercise, students study the use of three-position valves to stop cylinder movement mid-stroke and analyze safety implications. This task demonstrates the ability to stop piston movement mid-stroke, analyzing center positions such as closed-center or exhaust-center configurations. Safety aspects are emphasized, especially in applications involving lifting, pressing, or emergency stops.

The aim of these initial tasks is to consolidate understanding of valve states, safety requirements, and the relationship between mechanical motion and pneumatic control signals. For the sake of clarity, the pneumatic connections of the first and fourth exercises are shown in Fig. 1 and Fig. 2. The difference in the complexity of the connection is clearly visible. With the advent of new components and solutions, the functions are also expanded, and the time dedicated to their preparation also increases.

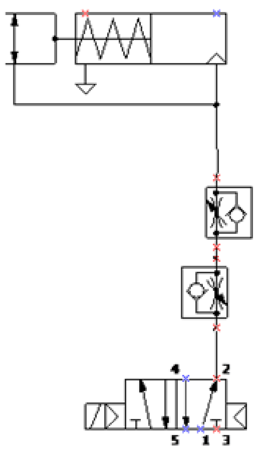

Figure 1: Control with 3/2-way valve, with placement of throttle check valves

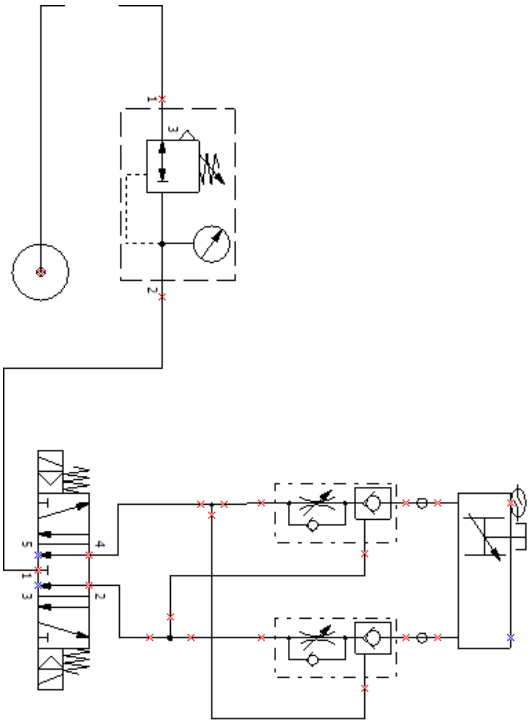

Figure 2: Pneumatic switching with 5/3 bistable valve

B. Electropneumatic Logic Control Exercises

Following the purely pneumatic tasks, students progress to electropneumatic systems where control is achieved through electrical actuation. This stage introduces the integration of switches, relays, and timers into pneumatic circuits.

In the fifth and sixth exercises, students compare direct and indirect control methods of single- and double-acting cylinders, emphasizing the role of relays. Students compare direct pushbutton control of solenoid valves with relay-assisted indirect control. The exercises highlight the advantages of indirect methods in handling higher power requirements and system reliability.

In the seventh and eighth exercises, students design latching circuits with monostable and bistable valves to maintain cylinder positions. Practical tasks focus on self-holding control solutions, where cylinder motion continues even after the pushbutton is released. Learners practice designing circuits with both electronic relays and bistable valves functioning as memory elements.

In the ninth exercise, students practice implementing time-delay control to keep cylinders in position for a defined period. Students implement delay circuits using relays and reed switches to maintain cylinder positions for a set duration. Applications include clamping, pressing, or sequential control in industrial automation.

The electropneumatic connections of the seventh and nineth exercises are shown in Fig. 3 and Fig. 4. The difference in the complexity of the connection is clearly visible. With the advent of new components and solutions, the functions are also expanded, and the dedicated time to their preparation also increases.

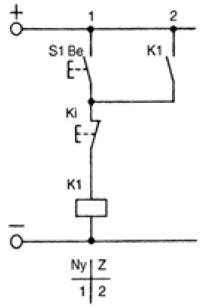

Figure 3: Self-holding circuit

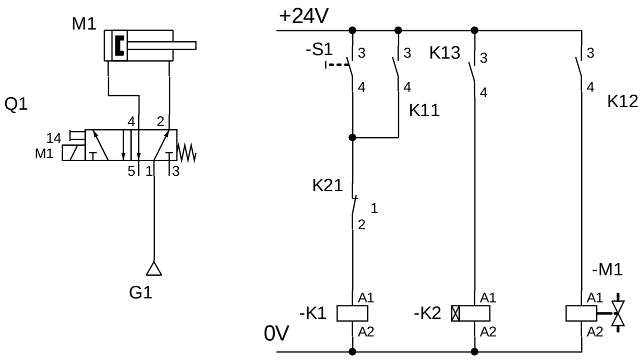

Figure 4: Monostable valve with timer

C. Sequential and Process Control

Advanced exercises emphasize process-oriented control schemes where multiple cylinders operate in defined sequences. Students design and implement sequential logic using combinations of monostable and bistable valves, reed sensors, and relays.

In the tenth to twelfth exercises, students apply sequential control in feeder units, coordinating multi-step cylinder operations with sensor feedback. These tasks simulate industrial material handling processes, such as pushing and transferring workpieces between stations, see on Fig. 5. Learners design multi-step cycles (+1, +2, –1, –2) and integrate sensor feedback to ensure safe and repeatable operations, follow on Fig. 6. Both relay-based and mixed monostable/bistable valve solutions are applied (Fig. 7).

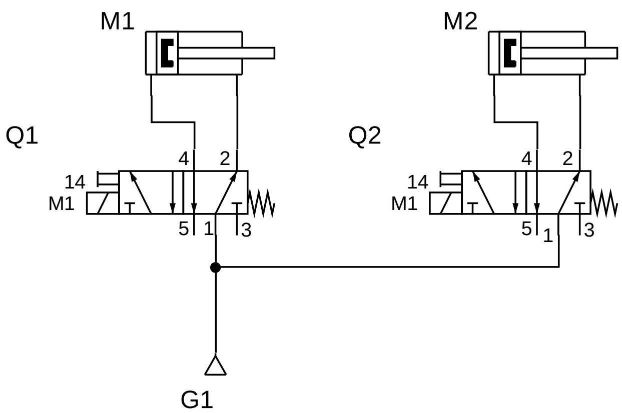

Figure 5: Pneumatic connection diagram of the dispenser

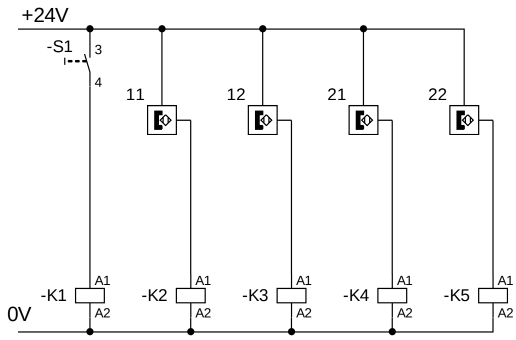

Figure 6: Sensor circuit

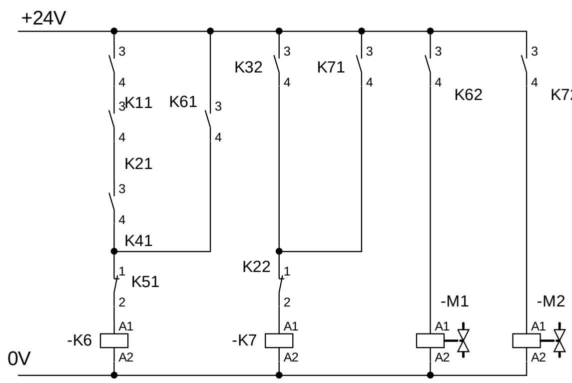

Figure 7: Complete circuit diagram of the control

III. Pedagogical Aspects

The systematic inclusion of practice-based exercises in pneumatics and electropneumatics contributes significantly to engineering pedagogy by aligning teaching methods with the demands of professional engineering practice [19]. Traditional lecture-based approaches often emphasize theoretical principles but may lack sufficient opportunities for students to develop applied skills. In contrast, hands-on and project-based learning environments foster active student engagement, deeper understanding, and transferable competences [20].

Practical laboratory exercises enable students to apply theoretical knowledge in real-world contexts, reinforcing their comprehension of physical principles such as pressure, flow, and motion control [21]. Through iterative experimentation, students strengthen critical thinking, diagnostic reasoning, and system-level understanding. Furthermore, error-based learning – when students encounter and resolve unexpected circuit behaviors - encourages resilience and adaptive problem-solving [22].

A. Teamwork, Soft Skills and Motivation

Many exercises are structured as group projects, requiring students to work together in planning, building, and testing pneumatic and electropneumatic systems. Collaborative learning not only mirrors industrial project settings but also enhances communication and interpersonal skills. Students must divide responsibilities, negotiate design decisions, and integrate their individual contributions into a functional whole. This mirrors professional engineering practice, where multidisciplinary collaboration is the norm.

In addition to technical proficiency, the exercises also foster the development of a wide range of soft skills that are essential for engineering practice. Communication skills are enhanced as students are required to explain their system designs, report experimental results, and present solutions, thereby strengthening both their technical and non-technical communication abilities. Leadership and responsibility are cultivated through group tasks, where leadership roles are often rotated, giving students the opportunity to practice project coordination, informed decision-making, and accountability. Conflict resolution skills are developed when disagreements arise over design choices, as students must engage in constructive dialogue, negotiate alternatives, and reach compromises. Moreover, time and project management abilities are strengthened through sequential exercises that demand effective scheduling, prioritization, and task allocation within the group. These competencies are highly valued by employers, as modern engineers are increasingly expected to work collaboratively across organizational, disciplinary, and cultural boundaries.

Hands-on methodologies also have strong motivational benefits. Unlike abstract lectures, laboratory and project work place students in active roles, where they can immediately observe the outcomes of their decisions and actions. The direct feedback loop between theory and practice increases intrinsic motivation and enhances knowledge retention [23, 24]. Additionally, the creative dimension of designing control solutions nurtures innovation and entrepreneurial thinking – attributes essential for modern engineering careers.

CONCLUSION

Finally, practice-based teaching in pneumatics and electropneumatics aligns directly with Industry 4.0 competence frameworks. As automation, robotics, and mechatronics advance, engineers must not only master system design but also adapt to rapidly evolving technologies. By combining technical, cognitive, and soft skill development, practice-based pedagogy ensures that graduates are better prepared for roles in advanced manufacturing, maintenance, and system integration.

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