# Development of Pneumatics-Based Fluid Power Laboratory Exercises

**Jeffrey L. Newcomer, Ph.D.**
**Engineering Technology Department**
**Western Washington University**
**Bellingham, WA 98225-9086**

## Abstract

This paper describes four pneumatic laboratories used in a Fluid Power class in the Engineering Technology Department at Western Washington University. These laboratories introduce students to the fundamentals of pneumatic components and control of pneumatic circuits, as well as to some commonly used circuits. The laboratory exercises are simple to create and relatively inexpensive, and they have a high return in terms of student learning.

## Introduction

Fluid Power courses need a meaningful laboratory component to guarantee that students complete the class with the practical knowledge that cannot be garnered from textbook photos or lecture overheads. Most commercially available fluid power modules are hydraulic. These are expensive and have the potential to make a tremendous mess. Other options include software simulations and fluid mechanics experiments. While these are all valuable, they do not provide real 'hands-on' experience. The Engineering Technology Department at Western Washington University (WWU) teaches a Fluid Power class for students in Manufacturing Engineering Technology and Plastics Engineering Technology in their junior year. Four pneumatic-based laboratory exercises have been developed to give students real experience using real components. The first laboratory exercise is an introduction to basic pneumatic components, pilot control of pneumatic circuits, and two-handed safety circuits. The second laboratory exercise is an introduction to solenoid valves and sequence circuits. The third laboratory exercise is an introduction to PLC control of a pneumatic circuit. The fourth laboratory exercise is an introduction to control of a fluid power circuit using a microcontroller. In these four exercises students are introduced to some of the most fundamental concepts in fluid power and control of fluid power circuits, and they gain experience working with real components on real systems. Assessment has shown that this laboratory both gives students real experience with pneumatic circuits and components and increases their comprehension of fluid power concepts. This paper describes each laboratory exercise, including the components required to create similar laboratory exercises.

## Fluid Power Course

The Fluid Power course at WWU covers both an introduction to fluid mechanics and an introduction to hydraulics and pneumatics. The course includes a team-based design project, a hydraulics research paper, and laboratory exercises, as well as traditional homework and tests that are found in most technical courses. The course meets numerous student learning objectives, which are summarized in Table 1.

Table 1: Fluid Power Course Learning Objectives

| Learning Objectives | | Learning Methods |
|---|---|---|
| **Primary** | Intro. to Fluid Mechanics | Homework, Design Project |
| | Intro. to Hydraulics | Homework, Research Paper |
| | Intro. to Pneumatics | Homework, Laboratories, Design Project |
| **Secondary** | Technology Skills | Laboratories, Design Project |
| | Written Communication | Research Paper, Design Project |
| | Oral Communication | Design Project |
| | Teamwork | Laboratories, Design Project |
| | Project Management | Design Project |
| | Creative Problem Solving | Design Project |
| **Tertiary** | Programming Skills | Laboratories |
| | Business Skills | Design Project |

Prior to the development of the laboratory exercises described herein the fluid power course did not have organized laboratory exercises, but instead relied on the design project to provide hands-on experience. The result of this was great variation in experience from student to student, as the quality of the projects were dependent upon the ambition of the students. At an earlier time in the history of the course there had been an organized laboratory, but it involved analyzing pre-existing fluid power circuits and conducting fluid mechanics experiments rather than building or controlling circuits. Since students need to be able to design, construct, analyze, and repair fluid power circuits, it was determined that in order to meet the course learning objectives the laboratories should involve building as well as analyzing pneumatic circuits

In meeting the student learning objectives for the course, the fluid power laboratory introduces students to actual pneumatics components, common pneumatic circuits, and methods of controlling fluid power circuits. Students are then able to apply their learning from the laboratories in the solution of their design projects, which generally include pneumatics as part of the solution. As such, each laboratory introduces a more complex, but more flexible method of controlling fluid power circuits, starting with pilot driven circuits and moving up to microcontroller driven circuits. Each laboratory is described in the following sections.

Laboratory One – Two-handed Safety Circuits

The first laboratory, being an introduction to pneumatic components, introduces a number of fluid power concepts: single and double acting cylinders, directional control valves, and pilot control. The laboratory uses two-handed safety, or interlock, circuits to introduce all of these concepts. These circuits operate on the principle that the user must use both hands to operate the circuit, and therefore will not be able to place his or her hands in the vicinity of the actuator.

This type of circuit is both very common and can be created a number of different ways.[1] Laboratory One provides the components and circuit diagrams to produce four different two-handed safety circuits: a Single-acting Interlock; a Double-acting, Pilot Operated Interlock; a Direct Operated, No-tie-down Interlock; and a Pilot Operated, No-tie-down Interlock with Center Stop Position. All of the necessary components for all four circuits are attached to a single backboard. A board contains two two-way, two-position push button valves, a four-way, two-position pilot valve, two four-way, two-position push button valves, a four-way, three-position pilot driven valve, and a single-acting and a double-acting cylinder, as well as the necessary connectors. Students are given the circuit diagrams and then must determine which components to use for which circuits. Figures 1 to 4 show the board with all of the components and each of the respective circuits. Although the circuits are essentially the same, they do not behave in exactly the same manner. While all four circuits theoretically require both buttons to be pressed for the cylinder to extend, in the first two the cylinder will retract if either button is released. For the fourth circuit, however, the cylinder will retract only if both buttons are released. The third circuit, despite its inherent simplicity, has the most interesting behavior. Due to the difference in cylinder area because of the rod, the cylinder will slowly open when only one valve is depressed.

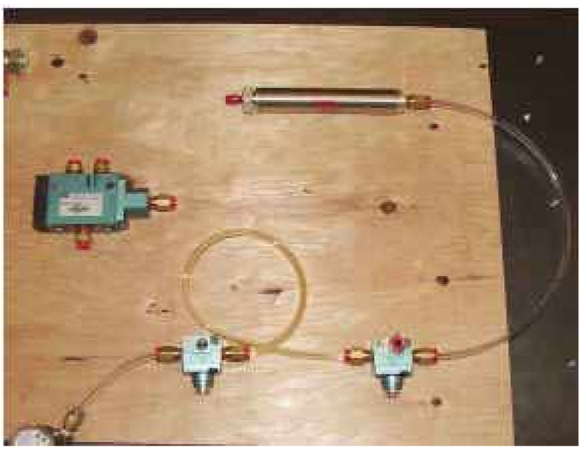

Figure1: Single-acting Interlock

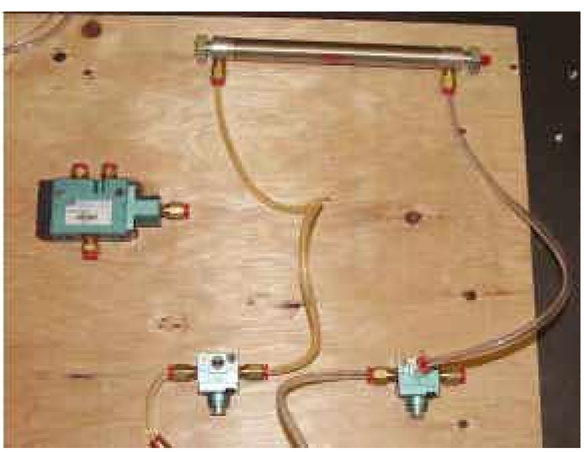

Figure 3: Direct Operated, No-tie-down Interlock

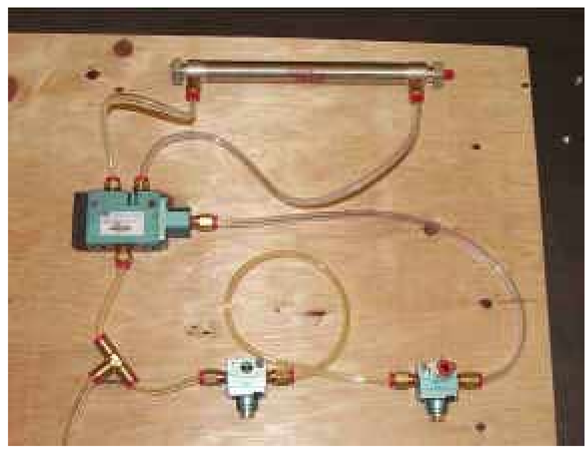

Figure 2: Double-acting, Pilot Op. Interlock

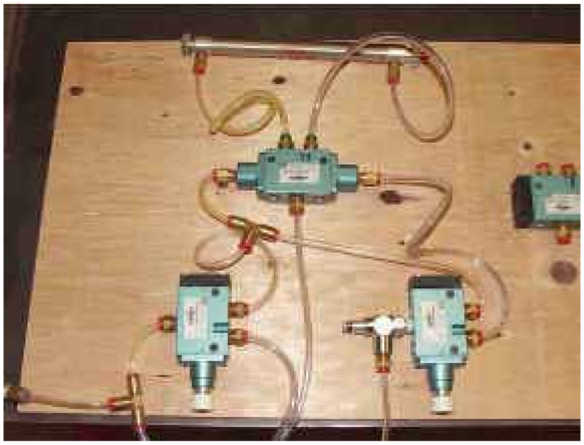

Figure 4: Pilot Operated, No-tie-down Interlock with Center Stop Position.

This laboratory allows students to see some of the behavior characteristics of basic fluid components, as well as making them familiar with pneumatic symbols and hardware. Since most students have not worked with any type of fluid power system prior to taking this class, these simple circuits provide them with an efficient introduction.

Laboratory Two – Solenoid Valves and Sequence Circuits

The second laboratory exercise builds off of the first by using similar components, however it introduces solenoid valves and sequence circuits. Students are given a circuit diagram for a sequence circuit in which pressing the start button causes the first cylinder to extend, followed by the second. The extension of the second cylinder then causes the first cylinder to retract followed by the second. Students are given a circuit diagram that is an entirely pilot-driven circuit,[1] however they are provided with three microswitches and three two position, three way solenoid valves, as well as the specified two-position, two-way push button valve and two two-position, four-way pilot driven valves, and two double-acting cylinders. Students must construct the circuit with these components. The constructed system is shown in Figure 5.

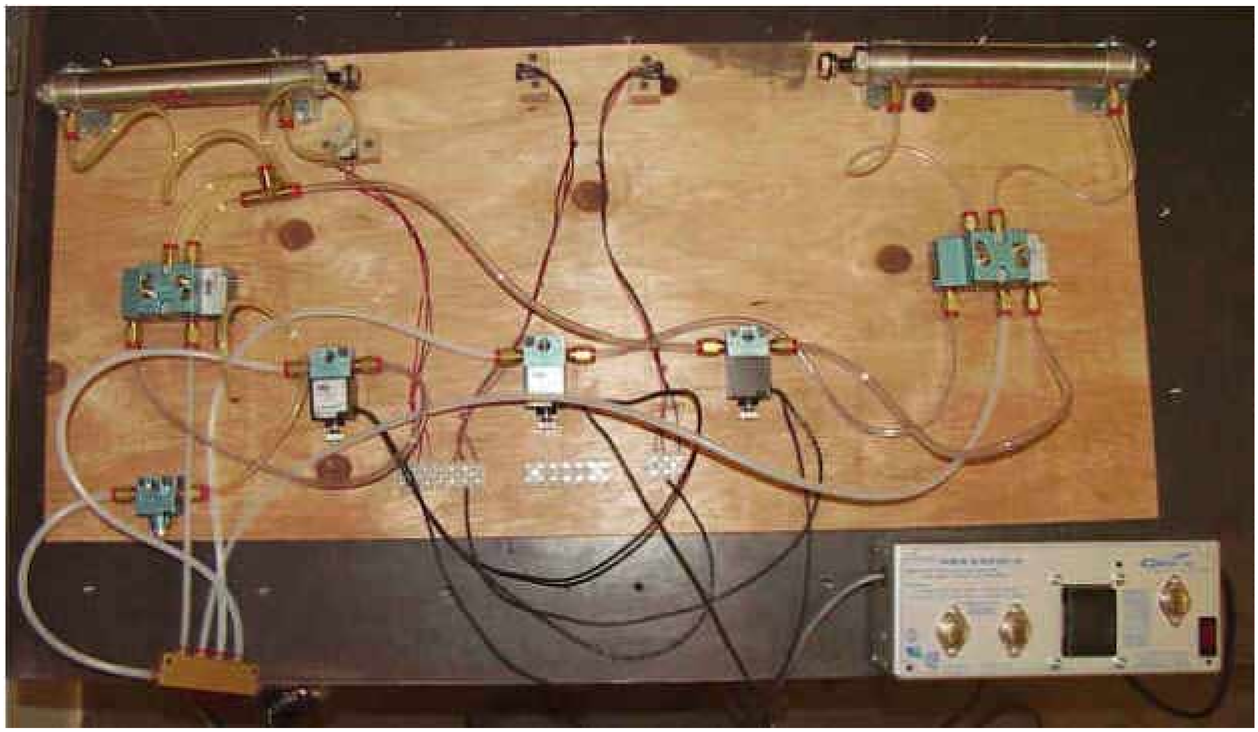
Figure 5: Sequence Circuit with Solenoid Valves

The main goal of this second laboratory exercise is to get the students working with solenoid valves. While the system is once again fairly simple, it gives students an opportunity to extend their knowledge from the first laboratory due to the incomplete instruction diagram, and to make direct comparisons between the fluid and electrical portions of the circuit. On average, students are more comfortable with the fluid portion of the circuit than the electrical portion, and almost every laboratory team completes the fluid portion first.

Laboratory Three – PLC control of Pneumatic Circuits

Laboratory three is designed to introduce Programmable Logic Controllers (PLCs) as control devices for fluid power systems. In addition, students get an opportunity to analyze an existing circuit, rather than constructing one from a diagram. Figure 6 shows the fluid power process under PLC control. Although it does not actually modify any parts, the device mimics a machine process. Parts are fed from a magazine stack (center) by a double-acting cylinder (left) and clamped in place by a second cylinder (not visible). The device is then supposed to pause for a specified period of time for the imaginary machine process. Once the delay is complete the part is unloaded with the vacuum swing arm (right) and a new piece is loaded for ‘processing’.

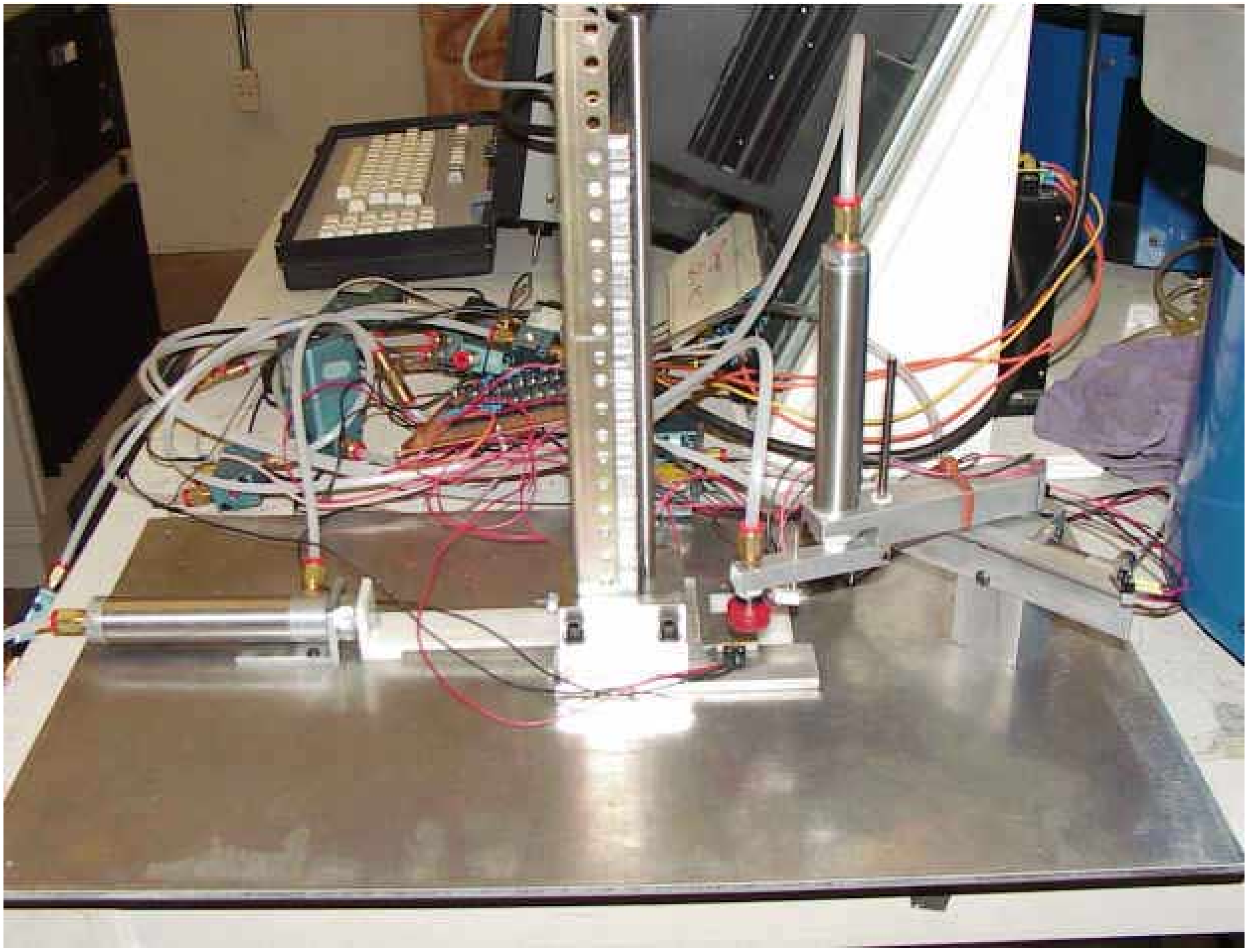

Figure 6: Fluid Power Device Under PLC Control

To begin this laboratory students must first analyze the existing circuit and create a diagram for it. This gives them an introduction to troubleshooting a circuit that has been designed and built by someone else. Once the circuit has been documented, students must write the ladder logic to control the circuit. The system has only four inputs (01 – Part loaded and clamped, 02 – Swing arm retracted, 03 – Swing arm extended, 04 – Vacuum picker contacting part) and five outputs (11 – Load and clamp part, 12 – Extend swing arm, 13 – Retract swing arm, 14 – Lower vacuum picker, 15 – Turn on vacuum), so the program is not long, but it does require students to include latching outputs, a timer, and a counter. As such, it introduces the fundamentals of PLCs.

Laboratory Four – Use of a Microcontroller with Pneumatic Circuits

Laboratory four is similar to laboratory three in that the main topic is control of a fluid power circuit, but in the case of laboratory four the control device is a microcontroller instead of a PLC. The system under control is a five-axis pneumatic robot with a gripper, which is shown in Figure 7. The robot has a sliding base, a z-axis cylinder, a 90° rotary cylinder, an extendable arm, and a second 90° rotary cylinder for the wrist with a small gripper attached. Each actuator is controlled by a two position, four way solenoid valve, each of which is in turn connected to a microcontroller through a relay circuit. Since the robot is constructed from simple pneumatic cylinders it cannot stop at intermediate positions. Even so, students can use the robot to complete machine load and unload operations. Students write programs in C which call movement subroutines (written in assembly code). Student programs are then downloaded to a microcontroller for demonstration. This laboratory allows students to compare the microcontroller to the PLC system used in the previous laboratory, as well as letting them practice their programming skills.

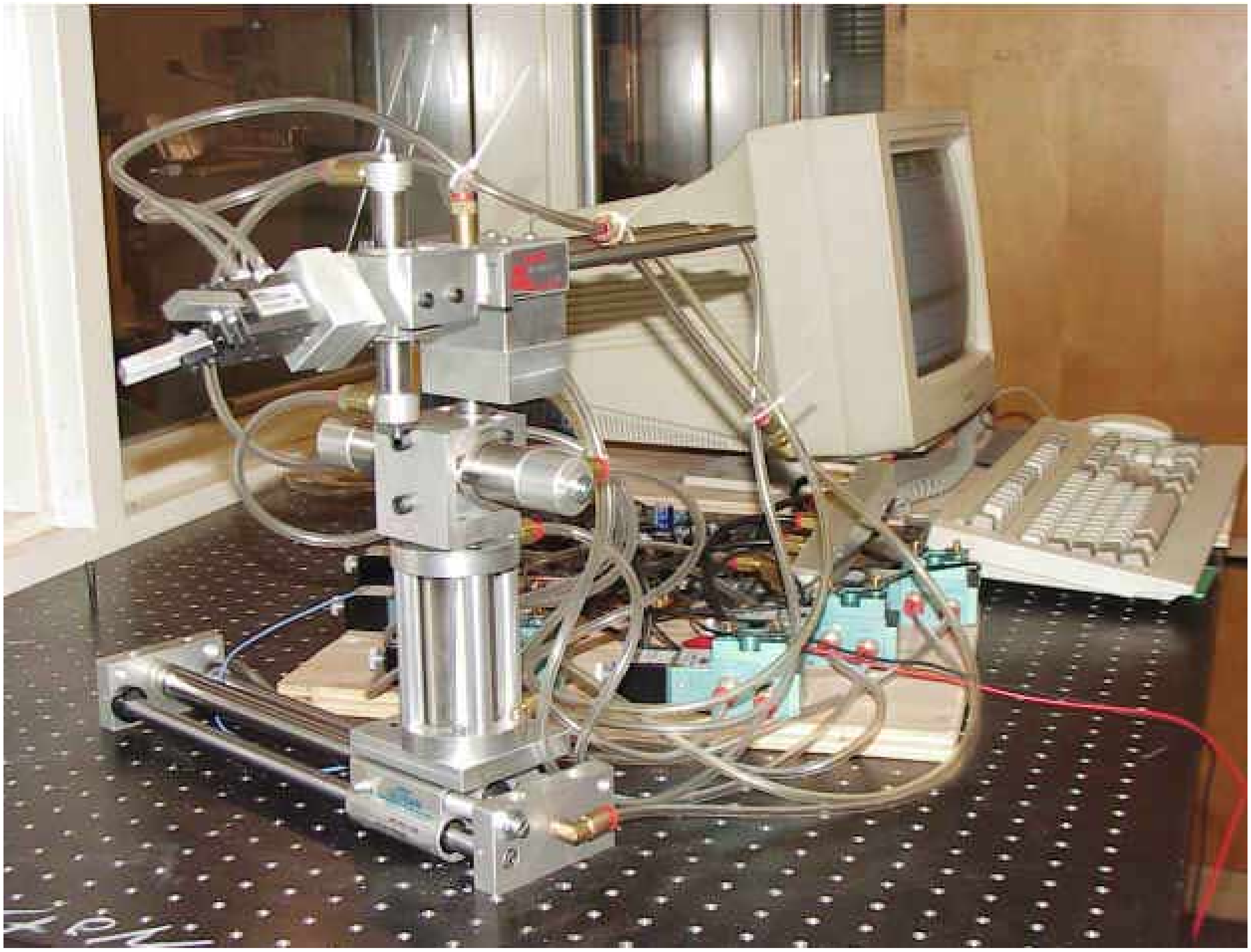

Figure 7: Five-Axis Pneumatic Robot

Conclusion

This paper has briefly described four laboratory exercises that were created to introduce students to pneumatic components, circuits, and control methods. Each of the laboratory set-ups described is simple and affordable, but allows students to gain experience with useful systems and concepts. The first laboratory introduces fluid components and pilot control. The second laboratory introduces solenoid valves. The third and fourth laboratories introduce PLC and microcontollers as control devices for pneumatic circuits. Since these laboratory exercises have been added to the class surveys of students show that they are more comfortable with pneumatics than previous groups of students were, and that students have more confidence that they can design, build, analyze, and repair fluid power circuits.

Bibliography

1. Sullivan, James, A., *Fluid Power: Theory and Applications*, Prentice Hall, New Jersey, 1998

JEFFREY L. NEWCOMER

Jeffrey L. Newcomer is an Assistant Professor of Manufacturing Engineering Technology at Western Washington University. He received a B.S. in 1988 and M.Eng. in 1989, both in Aeronautical Engineering, a M.S. in Science and Technology Studies in 1993 and a Ph.D. in Mechanical Engineering in 1994, all from Rensselaer Polytechnic Institute. Dr. Newcomer was named a NSF New Faculty Fellow at the 1999 Frontiers in Education Conference in San Juan, Puerto Rico.