Design and Development of Pneumatic Lab Activities for a Course on Fluid Power

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Mohit Raj Verma received his Mechanical Engineering degree from Purdue University in 2014 and after two years of engineering practice and teaching, continued his education at Purdue University Northwest in College of Technology where he is pursuing his M.S. in both Mechanical and Industrial Engineering Technology. He is very fond of learning new things and technology. As an undergraduate he balanced a rigorous course load and a number of extracurricular activities that have allowed him to enhance his skills. Specific to engineering, through his academic project work he have developed abilities in 3-D design and modeling, an understanding of materials and mechanics, and have practiced in different manufacturing technologies. In his Machine Design and Fluid Mechanics course, he along with his teammates created a hydro-controlled arm. He also developed a strong interpersonal and communication skills. Throughout all of his experiences, he has used his dedication to efficient and creative problem solving and his ability to prioritize and manage competing demands to positive ends. He is very eager to apply his engineering knowledge and skills to respective organization or company.

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Introduction

The transmission and control of power by means of fluid under pressure is becoming increasingly used in all branches of industry specially packaging industry. The extensive use of hydraulics and pneumatics systems to transmit power is because properly constructed fluid power systems possess a number of favorable characteristics. For instance, they eliminate the need for complicated systems of gears, cams, and levers. In addition, they transmit motion without the slack or delay inherent in the use of solid machine parts. In particular, pneumatic systems are very common, and have much in common with hydraulic systems with a few key differences. The reservoir is eliminated, as there is no need to collect and store the air between uses in the system. Also because air is a gas it is compressible and regulators are not needed to recirculate flow, but the compressibility also means that the systems are not as stiff or strong.

Pneumatic systems respond very quickly, and are commonly used for low force applications in many locations on the factory floor. From pedagogical standpoint, knowledge and understanding of hydraulic and pneumatic systems and their components make engineers better qualified to performance their job in industrial. The significant feedback received from employers in industry stated that the department's graduates need to be better trained in hydraulics and pneumatics. By doing this lab activities themselves, students not only learn how to operate the system, but they will also be challenged (via lab activities) to do the tasks, provided with a real-life scenario. And their performance will be measured based on their critical thinking for completing the circuit.

Despite the immense capabilities of hydraulics presented in terms of moving higher loads and in other industrial utilization, pneumatics are still in wide use. Pneumatics is used mainly in mining and general construction works. Pneumatic devices are used frequently in the dentistry industry across the world. On the other hand, hydraulics means use of pressurized fluids to execute a mechanical task. Hydraulics is frequently used in the concepts of turbines, dams, and rivers. Air brakes in buses, air compressors, compressed air engines, jackhammers, and vacuum pumps are some of the most commonly used types of mechanical equipment that are based on pneumatics technology. Commonly seen hydraulics based equipment types are hydraulic presses, hydraulic hoppers, hydraulic cylinders, and hydraulic rams (Abolghasemi M., 2017).

The undergraduate Mechanical Engineering Technology curriculum at University includes a course on fluid power, called Fluid Power (MET 230), which is a sophomore-level course. About 60% of the course is lecture while the rest is devoted to lab activities. Table 1 shows various topics and their corresponding laboratory activities. The hydraulic laboratory activities are already completed and available; however, the pneumatic laboratory activities are in the process of development. Table below shows the outline of a typical Fluid Power Course.

Table 1. The contents of fluid power.

<table>
<tr><th colspan="2">Lecture</th><th>Lab</th></tr>
<tr><td rowspan="6">Hydraulics</td><td>Principles and Laws</td><td>No lab</td></tr>
<tr><td>Pumps</td><td rowspan="3">Labs 1 - 4
Labs 6, 7, 9, and 10</td></tr>
<tr><td>Cylinders</td></tr>
<tr><td>Valves</td></tr>
<tr><td>Motors</td><td>Labs 5 and 8</td></tr>
<tr><td>Circuit design and analysis</td><td>No lab</td></tr>
<tr><td rowspan="3">Pneumatics</td><td>Principles and Laws</td><td>No lab</td></tr>
<tr><td>Cylinders and Valves</td><td>Labs 1 – 4</td></tr>
<tr><td>Circuit design and analysis</td><td>No lab</td></tr>
</table>

Goal and Objectives

The goal of the project is to design pneumatic laboratory activities for Mechanical Engineering Technology in Pneumatic, Fluid Power (MET 23000) course, and to build the trainers using pneumatic components provided by an industrial partner Bimba (Bimba Manufacturing Inc, 2017).

Following are the objectives of the project:-

1. To develop laboratory activities to be performed by students on Automation Studio.
2. To build a prototype design and layout using Bimba Products to test and verify the laboratory activities.
3. Prepare a laboratory manual for students and a solution manual for the imstructor.
4. To design a board layout for six other trainers with all the components on it.
5. Identify the drawer layouts including spare equipment.
6. Develop lab activities with conceptual problems and logical thinking to be answered by students.

Methodology

The design and development of the laboratory activities were completed in collaboration with the industrial partner (Bimba Manufacturing Inc., 2017). The author worked on one of the trainers, as the prototype, to build and test the designed laboratory activities (Figure 1). After several rounds of discussion, design modification, and testing, a set of four pneumatic laboratory activities were finalized, as will be discussed in this section. Figure 1 shows the completed prototype design of the pneumatic circuit bench.

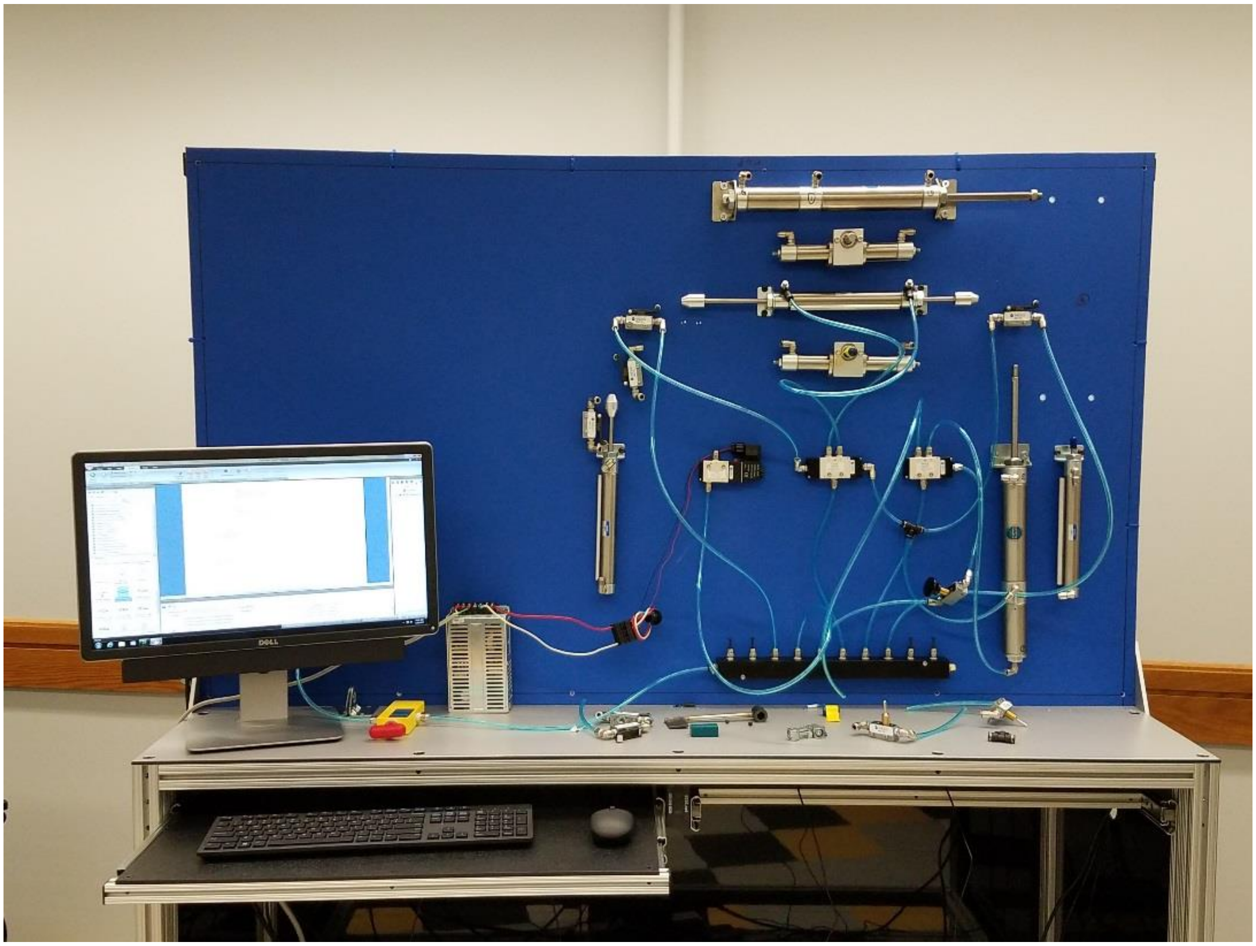

Figure 1. The prototype of the pneumatic trainers.

Various software packages are available for design, control and simulation of hydraulic, pneumatic, and motion control (Hydraulic circuit design and simulation, 2016). For this project, Automation Studio Software (2017) was used, which is an innovative system design, simulation and project documentation software solution for the design and support of automation of fluid power systems. The laboratory activities were verified using this simulation software. Figure 2 shows the example of a circuit design form Laboratory activity 2 in Appendix D.

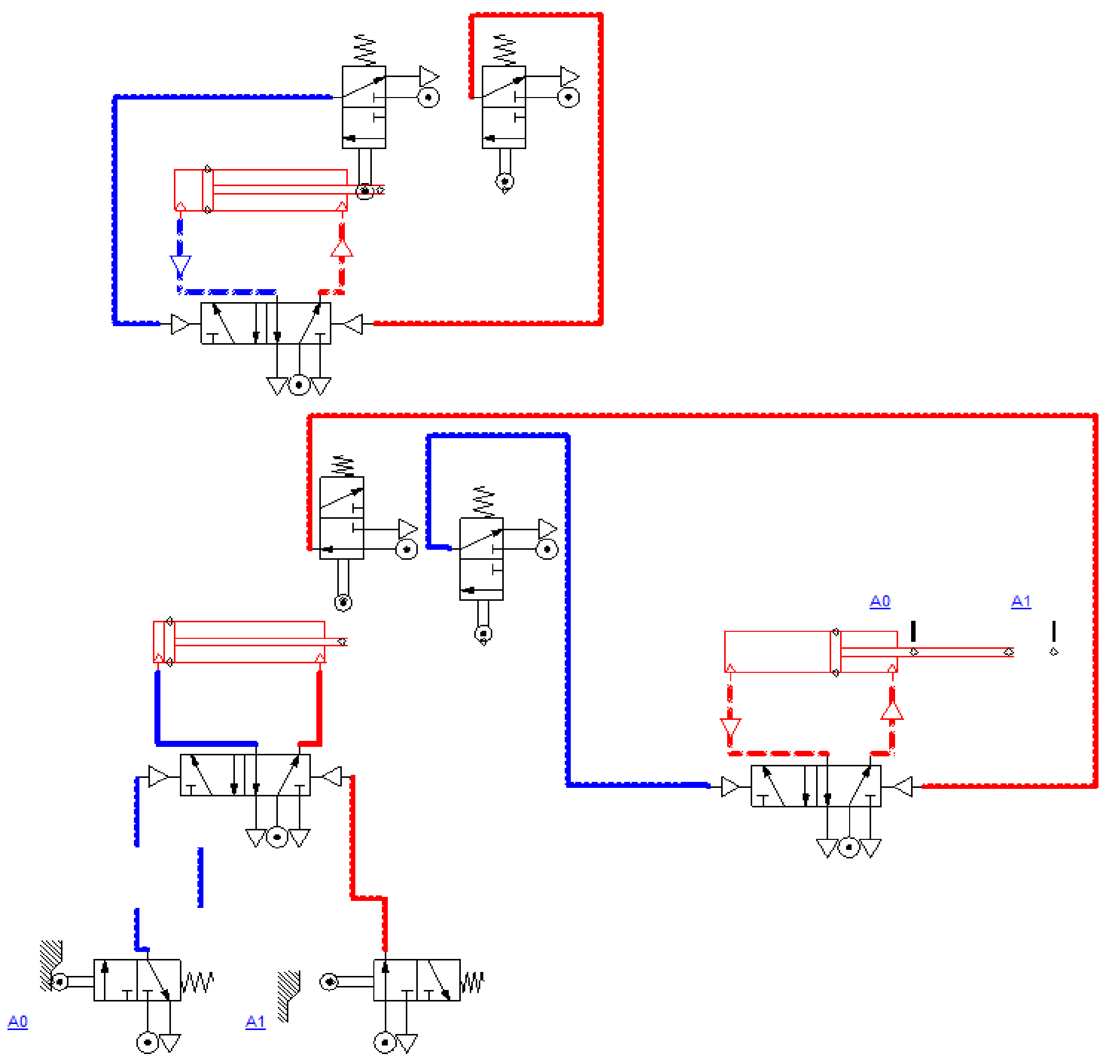

Figure 2. Sample of an Automated Cam Cycling Circuit in Automation Studio.

A detailed drawing of the pneumatic circuit bench along with the components was designed in Solidworks (Dassault Systems SolidWorks Corporation, 2017). This drawing not only helped in just understanding the layout but also helped in enhancing the component's location and spacing. Figure 3 shows the detailed Solidworks drawing with components on the board.

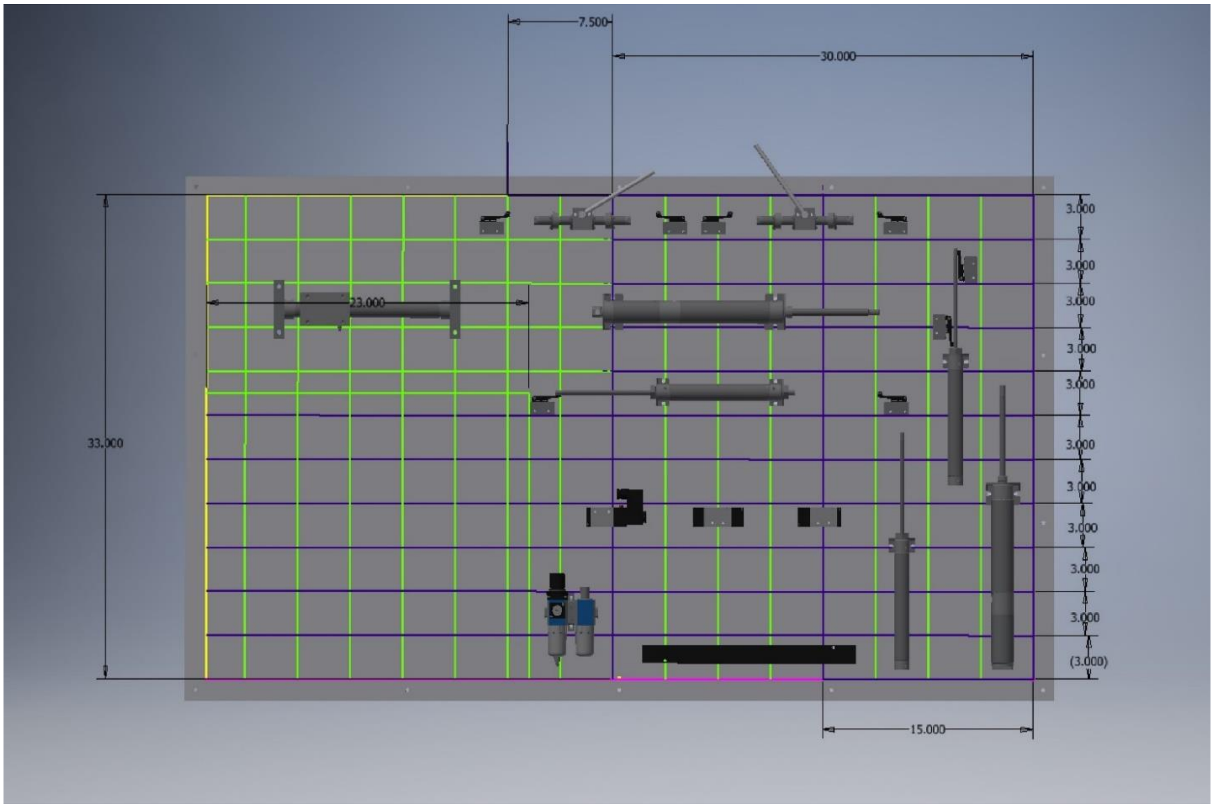

Figure 9. Solid works model of the bench.

The trainer accommodates various pneumatic components in pneumatic circuit bench for education and training purposes. The frame of the bench was fabricated from 59in × 35in High-density polyethylene (HDPE) with ¼" thickness. The bench also includes two large drawer of size 29in × 24in × 5.5in to accommodate tubes and four small drawer of size 29in × 24in × 3.8in to accommodate fitting, valves, actuators, etc. Furthermore, the laboratory activities to be performed on the trainer are shown in Appendix D, with activities for students and Solution Manual in Appendix F. Also, Table 2 below shows a list of all the components used in all the laboratory activities, detailed list of components is provided in Appendix G.

Table 2. The components provided by Bimba that are used.

Serial No.	Components	Quantity	Laboratory(s)
1	Single Acting Cylinder	1	1
2	Double Acting Cylinder	1	1,2
3	Rotating Three Position Cylinder	1	4
4	Non-Rotating Three Position Cylinder	1	4
5	Double Rod Double Acting Cylinder	1	3
6	Bidirectional Motor	2	3
7	Push button valve	3	1,2,3,4
8	5/2 way externally piloted directional valve	1	1,2
9	5/2 way externally piloted spring return valve	1	3
10	3/2 way mechanically triggered valve	4	2,2
11	3/2 way Solenoid valve	1	3
12	Flow Control Valve	2	3
13	24V Power Supply	1	3
14	Electric push button	1	3
15	Inline Manifold	1	1,2,3,4
16	Safety Valve	1	1,2,3,4
17	Air regulator and Filter	1	1,2,3,4

Discussion

After the implementation of the prototype laboratory activities were performed by students during fall, 2016. A verbal feedback from students was performed by the instructor to get a better understanding of the laboratories. It was collected by the instructor to make laboratory easier to understand to the future students. Students seems excited about the pneumatic part of the class. However, after the feedback of that survey and a brief discussion with faculty members it was recommended that the laboratory should include logical reasoning and questions.

To overcome that concern laboratory related problems were added to the laboratory activities and are shown in Appendix E. Students also need to make sketches and answer laboratory related questions, guidelines for that are shown in Appendix C.

Also Safety was also considered as one of the prominent factors while designing the pneumatic circuit bench. From that point of view it is recommended that not more than four students should work on one trainer at a time. Rules and guidelines related to safety for both student and instructor are shown in Appendices A and B.

Conclusion

The following conclusions could be drawn from the obtained results:

1. The workbench for this project had been designed and developed successfully as the platform for laboratory activities to be performed for Fluid Power Class. The system included various basic pneumatic system components such as filters, lubricators, regulators, pressure gages, valves, actuators, switches, sensors, fittings and tubes.
2. The bench had four laboratory activity exercises namely control of a single and double acting cylinder, Cam Cycling, Memory Circuit, and Sequencing Three position Cylinder. Various exercises had been successfully designed and developed to operate pneumatically and electrically.
3. The developed workbench had overall dimensions of 59in length, and 35in height, the bench also includes two large drawer of size 29in × 24in × 5.5in to accommodate tubes and four small drawer of size 29in × 24in × 3.8in to accommodate fitting, valves, actuators, etc.
4. The developed laboratories also have logical reasoning problems for students to answer.

Recommendations and Further Research:

Design, control and simulation of pneumatic and motion control software should be incorporated in the new laboratories to process and run information in the multimedia circuit and allow to display the results in meaning full manner. 3D printed cut-away sections of various pneumatic components for the pneumatic circuit bench should also be developed for demonstration and understanding. For future, it is recommended to design and upgrade the trainer with more advanced laboratory modules using PLC controls.

Appendix A: General safety rules and student responsibilities (student copy)

Electricity is used on portions of this laboratory equipment's; the risk of serious electrical shock may be present. Exercise due care and caution when operating this equipment. Do not use the laboratory equipment unless you are properly supervised by a laboratory instructor.

- Make sure outlets and electrical cords are in good order. Do not attempt any repairs. If there are any discrepancies inform the laboratory instructor immediately.
- To reduce the risk of electrical shock, do not open the display panel or control panel cover.
- Do not use faulty equipment. If the equipment does not operate as described in this manual, switch OFF the equipment, disconnect the power cord from the wall outlet and inform the laboratory instructor immediately.
- Water is an excellent electrical conductor. Do not touch the electrical components, cords or plugs with wet hands or while standing on a wet surface.
- If an electrical fire occurs, switch OFF the apparatus, disconnect the power cord from the wall outlet and inform the laboratory instructor immediately. Use an ABC type extinguisher.
- DO NOT TOUCH THE HEAT SENSORS OR WALLS! The walls might get extremely heated and cause severe burns.
- Turn OFF the laboratory apparatus when not in use. This will reduce the risk of an accident occurring.
- Do not leave the main air pressure valve open after experiment is done.

Appendix B: General safety rules and student responsibilities (Instructor copy)

Electricity is used on portions of this laboratory equipment; the risk of serious electrical shock may be present. Exercise due care and caution when operating this equipment. Do not use the laboratory equipment unless you are properly supervised by a laboratory instructor.

- Make sure outlets and electrical cords are in good order. Do not attempt any repairs. If there are any discrepancies inform the laboratory instructor immediately.
- To reduce the risk of electrical shock, do not open the display panel or control panel cover.
- Do not use faulty equipment. If the equipment does not operate as described in this manual, switch OFF the equipment, disconnect the power cord from the wall outlet and inform the laboratory instructor immediately.
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- Turn OFF the laboratory apparatus when not in use. This will reduce the risk of an accident occurring.
- Do not leave the main air pressure valve open after experiment is done.

Appendix C: Laboratory Report Requirements

Sketch:

- A sketch to summarize the laboratory apparatus is required for the experiment. This drawing is not necessarily to scale and does not have to be in 3-dimensions. The goal is to communicate the overall layout an instrumentation used.
- A sketch will be provided with the laboratory to have an overview of the components.
- The sketch/circuit will have bolded marks on it, that's where to connect the lines.
- Connect the circuit properly with straight lines only (use pencil if necessary).
- There should be no lines intersecting each other, make a semicircle over the line in case of overlapping.

Answers to Questions:

- Answers to questions can be produced electronically (typed) or hand written (clearly).
- If instructor couldn't read or understand your answer it will be considered WRONG!
- Answer all conceptual questions in handout, unless otherwise specified.
- Answer questions completely and in a way that the reader knows what was being asked.
- It is not necessary to start an answer with "Yes, …" or "No, …". Simply start with the detailed answer and the supporting reasoning.
- Discuss means provide details and support for the answer, do not just list.
- It is acceptable to include a table/graph/image as clarification or support for the answer.
- "Human Error" is not an acceptable source of error without a full justified explanation of an error that could not have been fixed during the experiment.

Appendix D: Laboratory Activities

Laboratory 1

Objective

To be able to design and assemble a circuit that extends and retracts a single acting (spring return) and double acting cylinder.

Equipment

1. Single Acting Cylinder (C1)
2. Double Acting Cylinder (C2)
3. 2 X Push button valve (V1)
4. 5/2 way externally piloted directional valve (DV1)

Application

Finished parts are accumulating on the end of a conveyor. The parts need to be transferred on to a connecting conveyor that carries them to the final inspection and packaging stations. The technician needs to be able to activate and then release a transfer device powered by a pneumatic cylinder (Circuit 1).

Circuit Problem

Using the given components and layout, design a schematic circuit to perform the above given application.

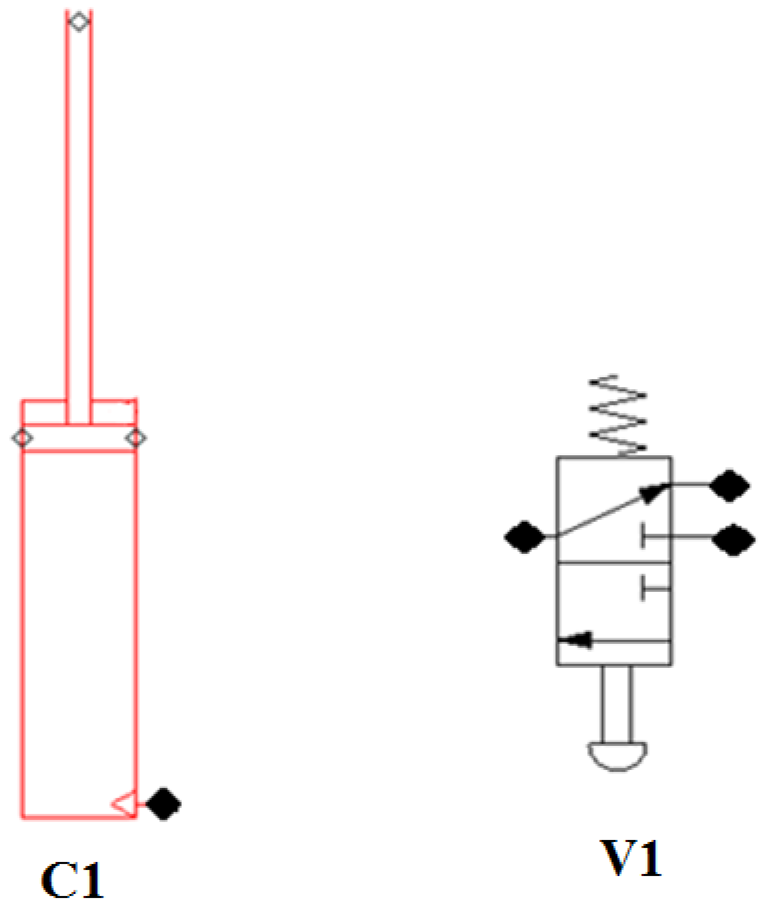


Figure 1: Circuit 1 for Laboratory 1 Spring Return Cylinder

Objective for Laboratory Activity 1

Parts need to be clamped for a drilling operation. It should activate and deactivate a pneumatic clamp that holds the part in a fixture on the drilling machine. The clamp must be activated before the drilling cycle begins and deactivated at the end of the drilling cycle (Circuit 2).

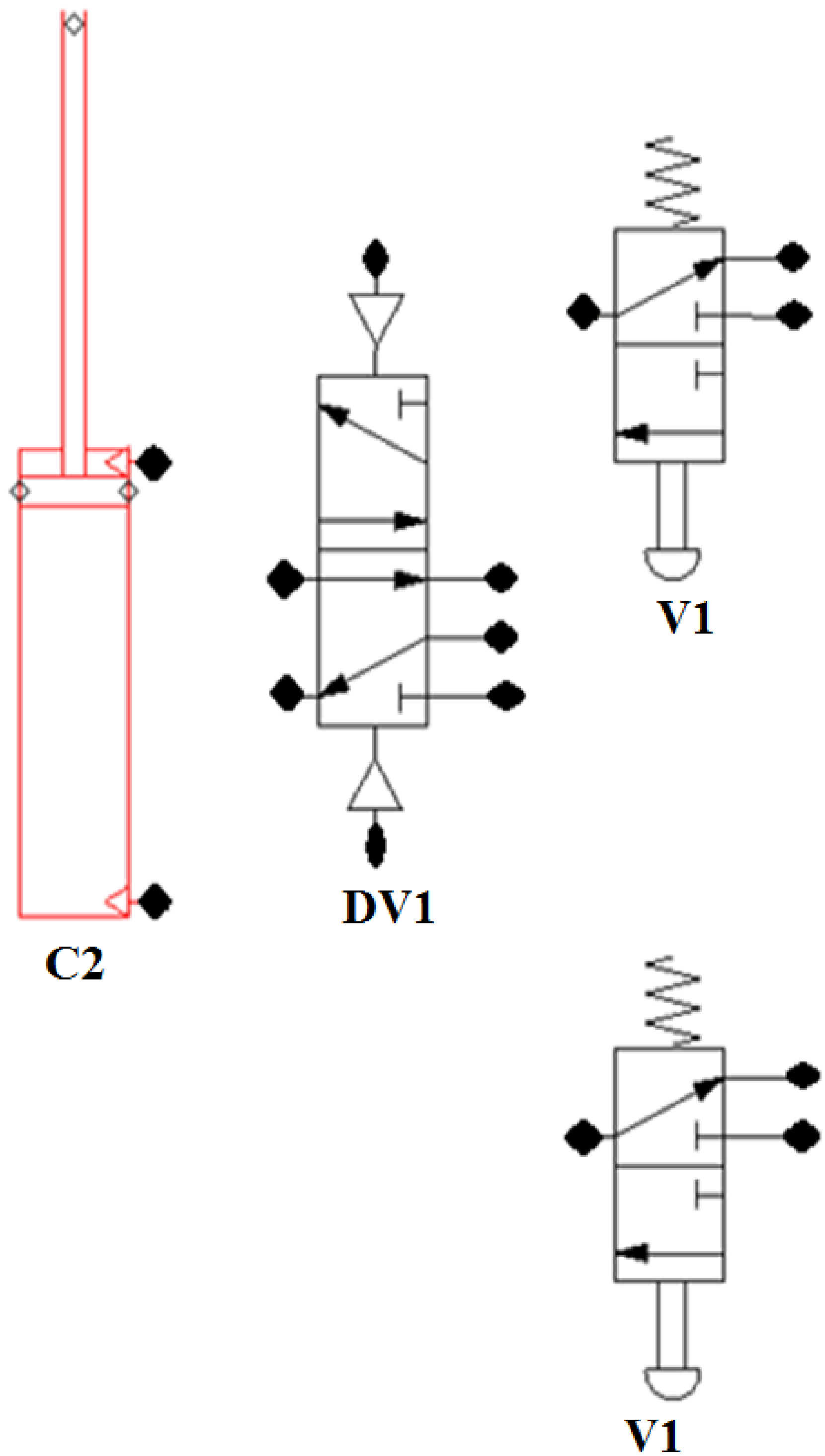


Figure 2: Circuit 2 for Laboratory 1 Double Acting Cylinder.

Laboratory 2

Objective

To be able to design and assemble a "ONE SHOT CYCLE" circuit.

Equipment

5. Double Acting Cylinder (C2)
6. 2 X 3/2way valve mechanically triggered (MV1)
7. 5/2 way externally piloted directional valve (DV1)
8. Push button valve (V1)

Application

Boxes are being filled with packing material that is dispensed in a time-released quantity. The exact amount of packing material needed is dispensed in one cycle. The operator must not be able to double pack the boxes, which would create an overflow situation. The operator will push a button to activate the dispensing gate. Once the button is pushed the cycle will continue until completed. A new cycle cannot be started until the first cycle is completed and the push button released. Even if the push button is held down continuously, a new cycle cannot be started.

Circuit Problem

Using the given components, design a schematic circuit which will only operate the cylinder for one timed cycle. No matter how long the valve is held shifted, only one cycle of the cylinder will result. The main pressure valve controls the time delay before the retraction of the cylinder. The one shot cycle is a limited memory time function. (Circuit 1)

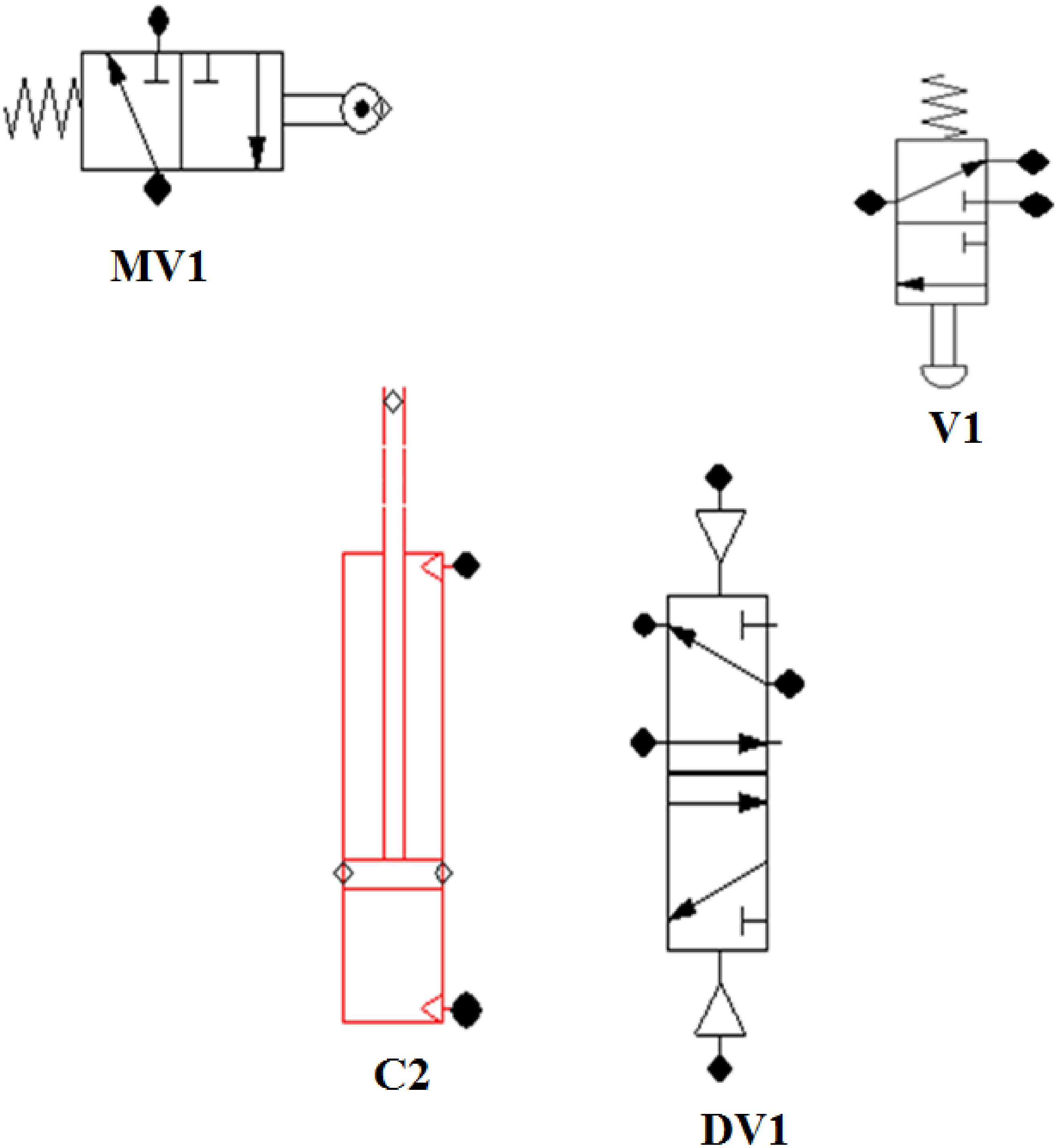


Figure 1: Circuit 1for Laboratory 2 One Shot Cycle

Objective for Laboratory Activity 2

To be able to design and assemble an "AUTOMATIC CAM CYCLING" circuit.

Application

The machine head of a precision grinder needs to continuously reciprocate over a cylinder head surface being finished. The speed of the stroke must be controlled in both directions. (Circuit 2).

Circuit Problem:

Using the given components and layout, design a schematic circuit that automatically cycles the continuous reciprocation of a cylinder. Limit valves located at the full extension and retraction of the cylinder are mechanically (cam) operated. Flow control valves that control the flow of the exhaust air leaving the cylinder (bleeding out) govern the speed of the operation. The cycle is started and stopped by the shifting of toggle valve.

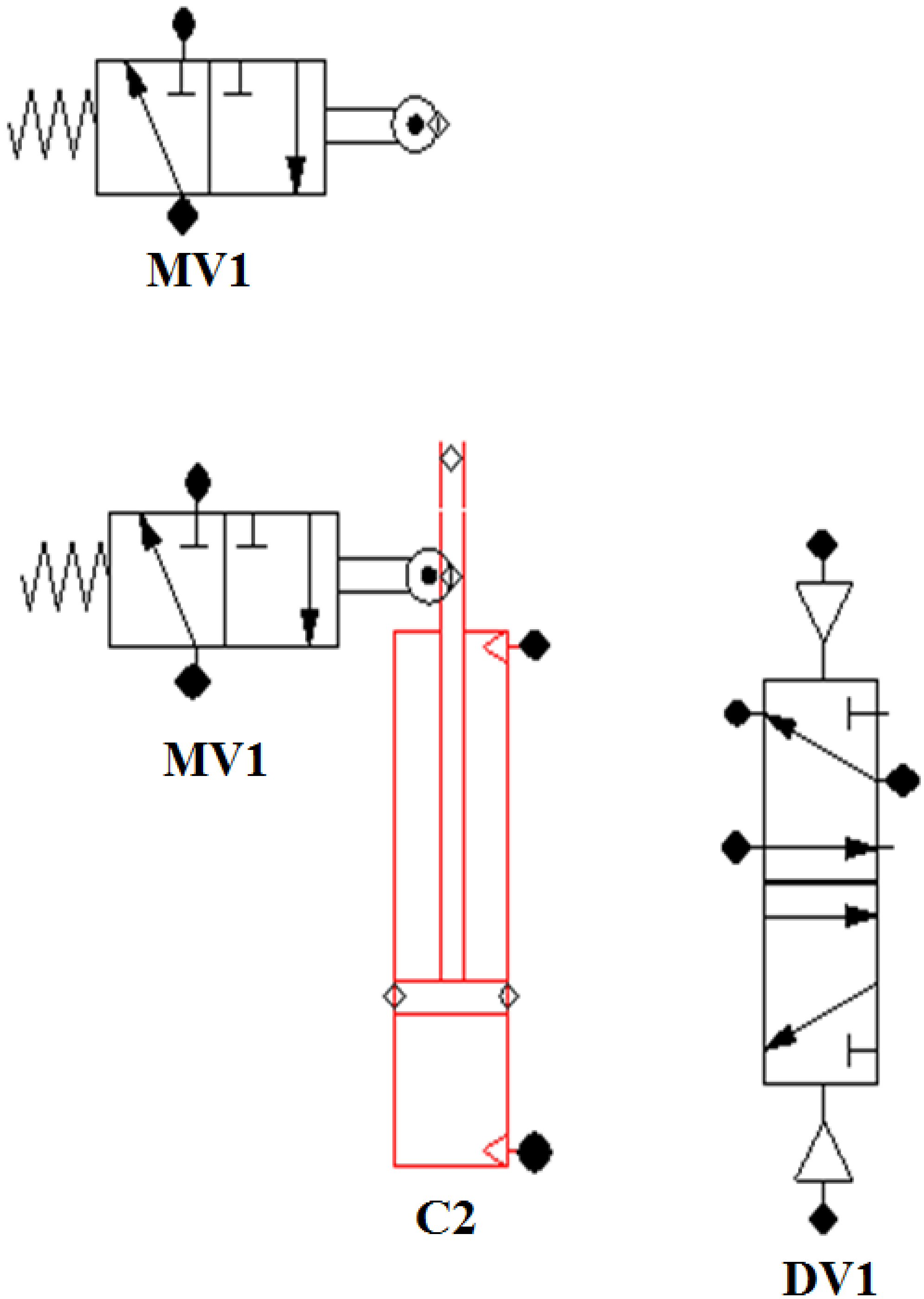


Figure 2: Circuit 2 for Laboratory 2 Automatic Cam Cycling

Laboratory 3

Objective

To be able to design and assemble an "PARTIAL MEMORY" circuit.

Equipment

1. Double Rod Double Acting Cylinder (C3)
2. Bidirectional Motor (M1)
3. 2 X 3/2way valve mechanically triggered (MV1)
4. 5/2 way externally piloted spring return valve (DV2)
5. 3/2 way Solenoid valve (SV1)
6. 2 X Flow Control Valve (FV1)
7. 24V Power Supply
8. Electric push button (EB1)

Application for Demonstration

A gravel yard has a single conveyor that can transport gravel to two different loading docks. In order to shift the out feed of the conveyor to the alternate loading dock the operator must push a button. As a safety precaution, the conveyor will always return to its original shifted position after the release of push button.

Circuit Problem

Using the application above complete the circuit below. Place the FV1 on C3 for smooth flow of the cylinder.

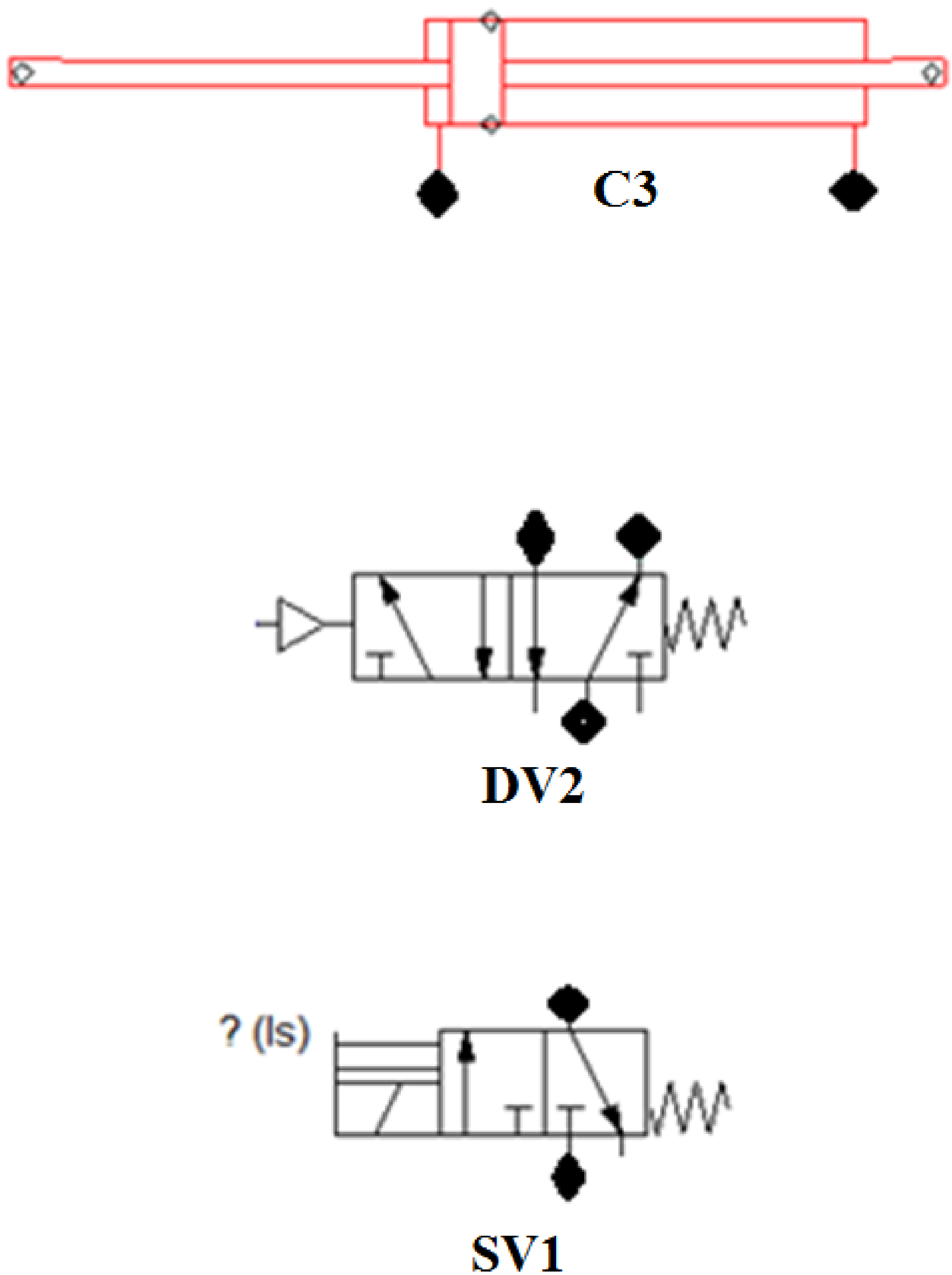


Figure 1: Circuit 1 for Laboratory 3 Partial Memory Circuit

Objective for Laboratory Activity 3

To be albe to control multiple components simultaneouly using “PARTIAL MEMORY” circuit.

Circuit Problem

Using the given components and layout, design a schematic circuit that requires the operator to push one button that in shifts the rod to the other side and motor acts accordinly. The valve is air-piloted in one direction, spring retun in other and operates a double-acting double-rod cylinder. (Circuit 2)

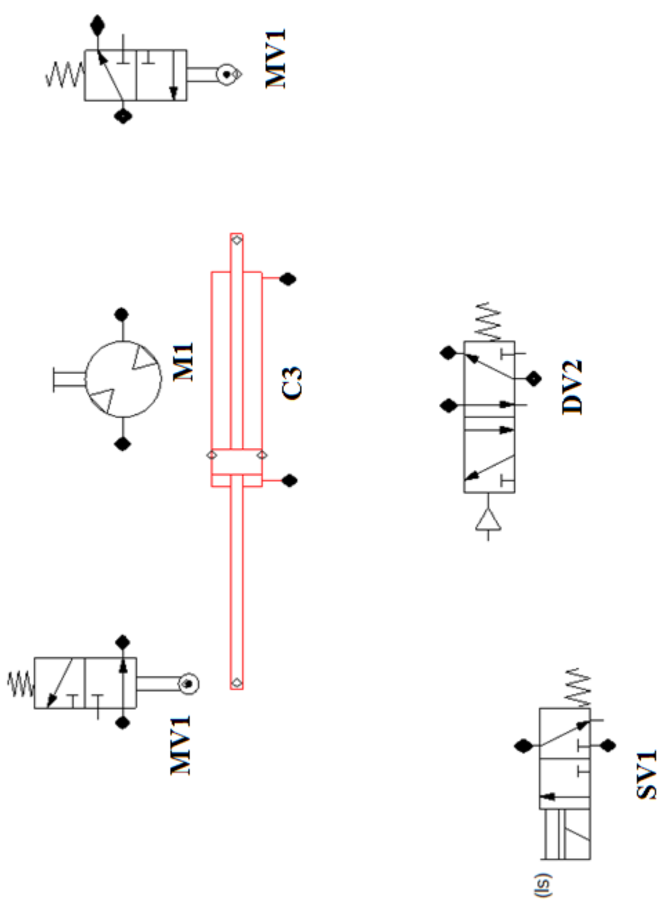


Figure 2: Circuit 2 for Laboratory 3 Complete Circuit

Laboratory 4

Objective

To be able to understand the working of a three position cylinder.

Equipment

1. Rotating Three Position Cylinder (C4)
2. Non-Rotating Three Position Cylinder (C5)
3. 3 X Push button valve (V1)

Application

Mostly cylinder have two positions i.e. fully extended or fully retracted, unless the feedback from a cylinder is controlled using automated systems. A conveyor has three openings at its end with use of push buttons operator must be able to control and divert the flow of items on the conveyor according to their categories/classification.

Circuit Problem

Using the given components, design a schematic circuit which will operate the three position cylinder in partially extended, fully extended and fully retracted. (Circuit 1)

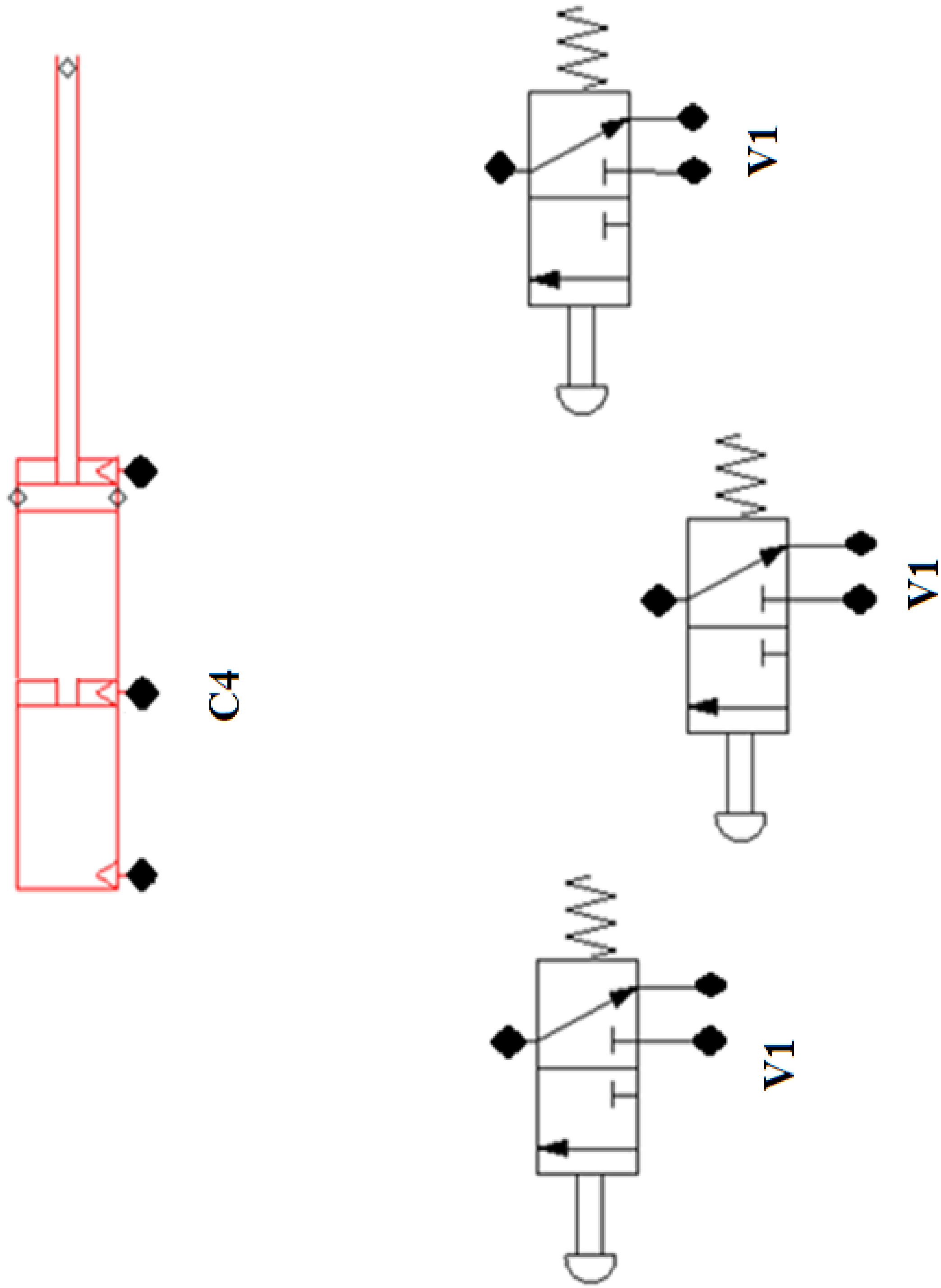


Figure 1: Circuit 1 for Laboratory 4 Three Position Cylinder

Objective for Laboratory Activity 4

To be able to design a sequence of the circuit in which no two positions of the cylinders are same.

Application

Two conveyors are running parallel with different items on them at different time and no two same items travel together. Operator must be able to match two same products into same output of the conveyor.

Circuit Problem

Using the given components, design a schematic circuit which will operate the both the three position cylinder in such a way that if one is partially extended, the other one should not. (Circuit 2)

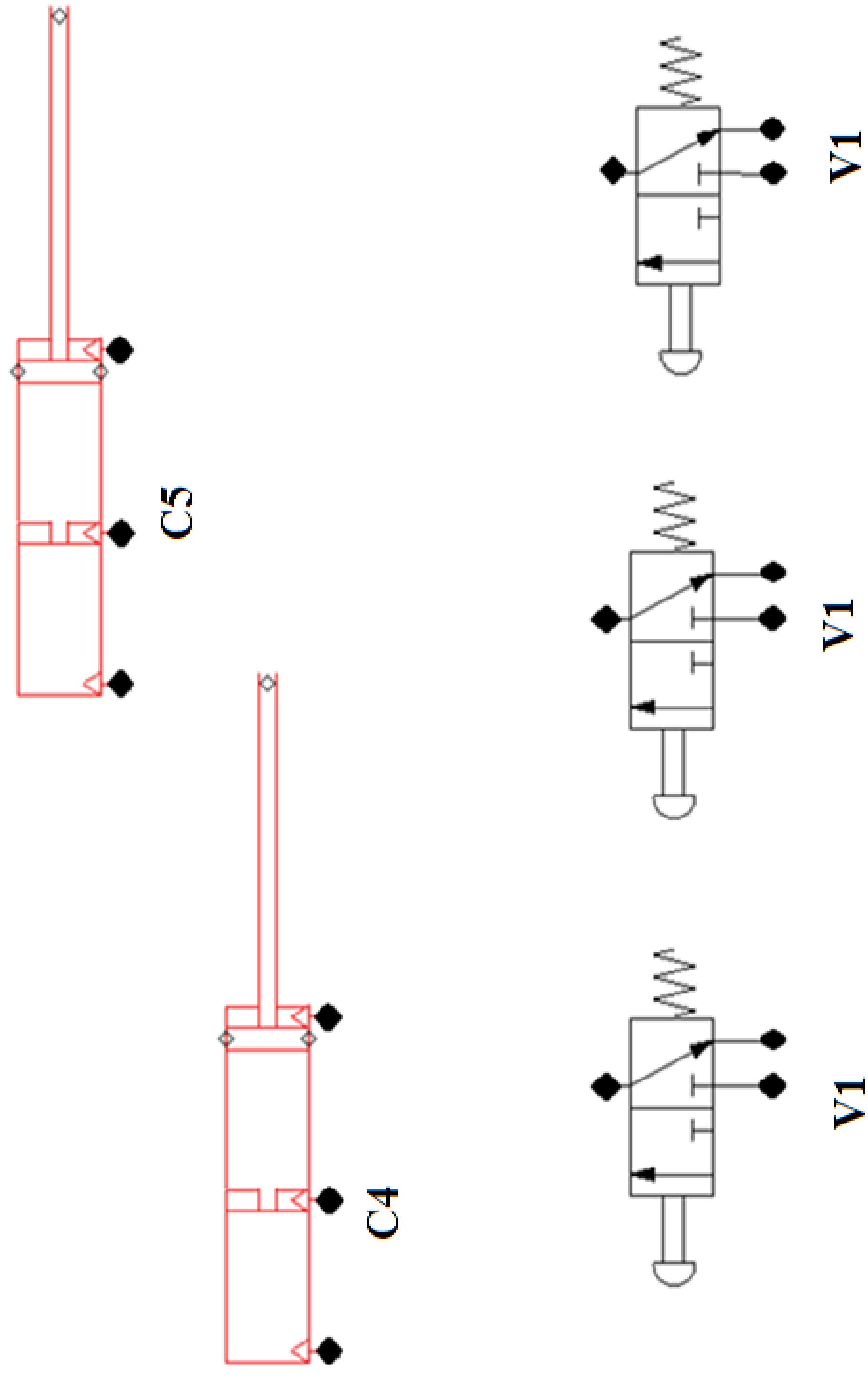


Figure 2: Circuit 2 for Laboratory 4 Sequencing Three Position Cylinder

Appendix E: Conceptual Questions

Conceptual Questions for Laboratory 1:

1. List any tow difference between Hydraulics and Pneumatics?
2. What is the basic difference between a single acting and double acting cylinder?
3. Can this experiment laboratory activity be conducted without the use of DV1? If so, How?

Conceptual Questions for Laboratory 2:

1. What is the difference between “ONE SHOT CYCLE” and “AUTOMATIC CAM CYCLING” circuit?
2. In demonstration part, if you hold the push button longer what happened?
3. Using what component, you can adjust the speed in “AUTOMATIC CAM CYCLING” circuit?

Conceptual Questions for Laboratory 3:

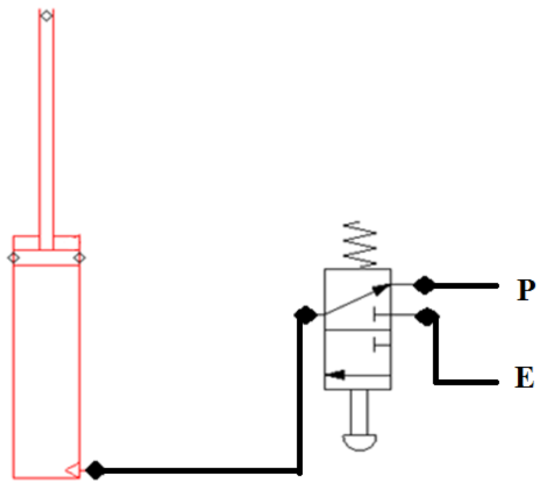
1. What is the difference between DV1 and DV2?
2. In activity part, how can you change the rotational direction of the motor?
3. What is the function of Flow Control Valve (FV1)?

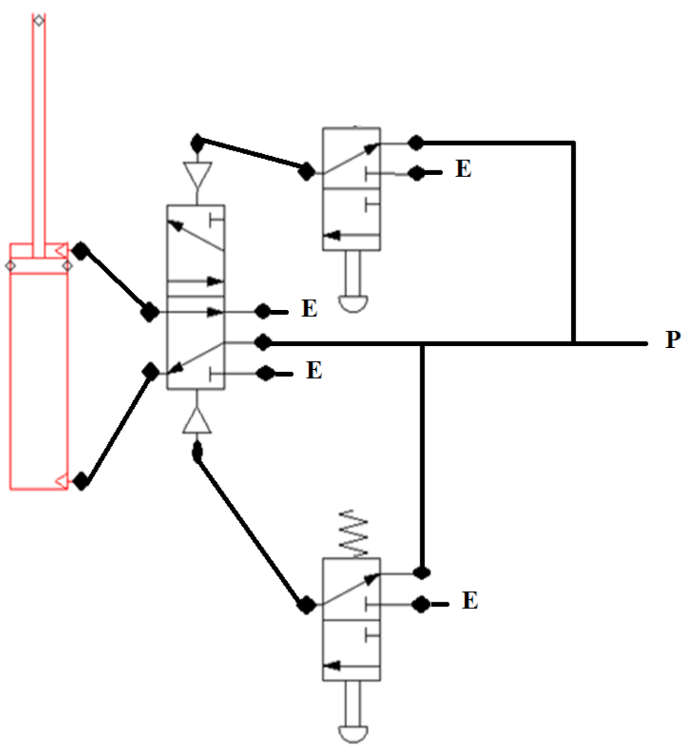
Conceptual Questions for Laboratory 4:

1. What is the advantage of a three position cylinder?
2. In activity part, if you push and hold two buttons together what happened?
3. List advantages of a non-rotating cylinder?

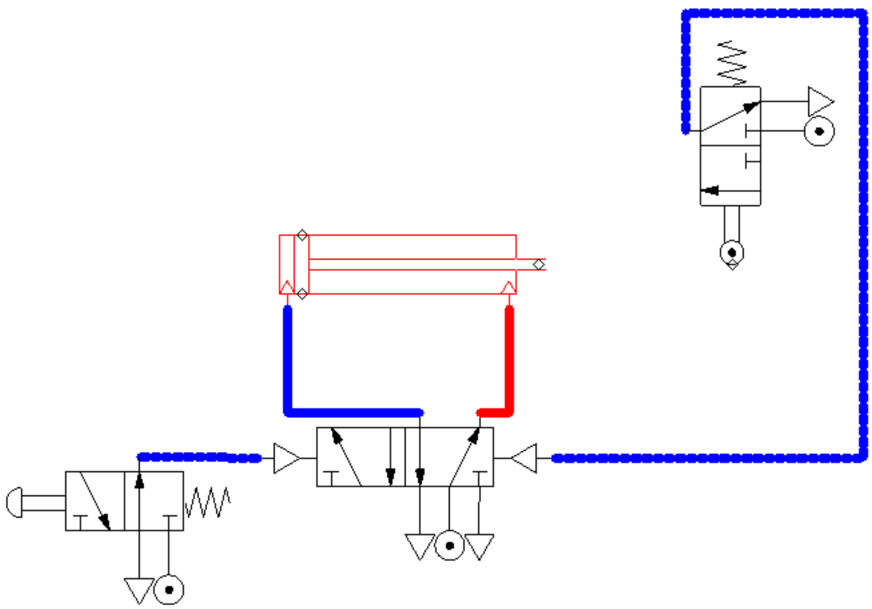
Appendix F: Manual for the Laboratory

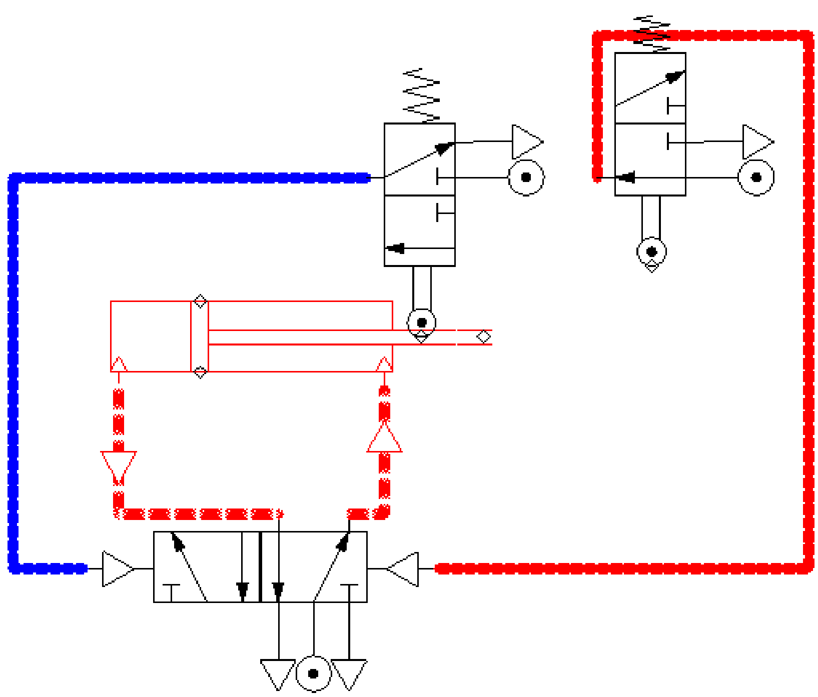
Laboratory 1 Manual

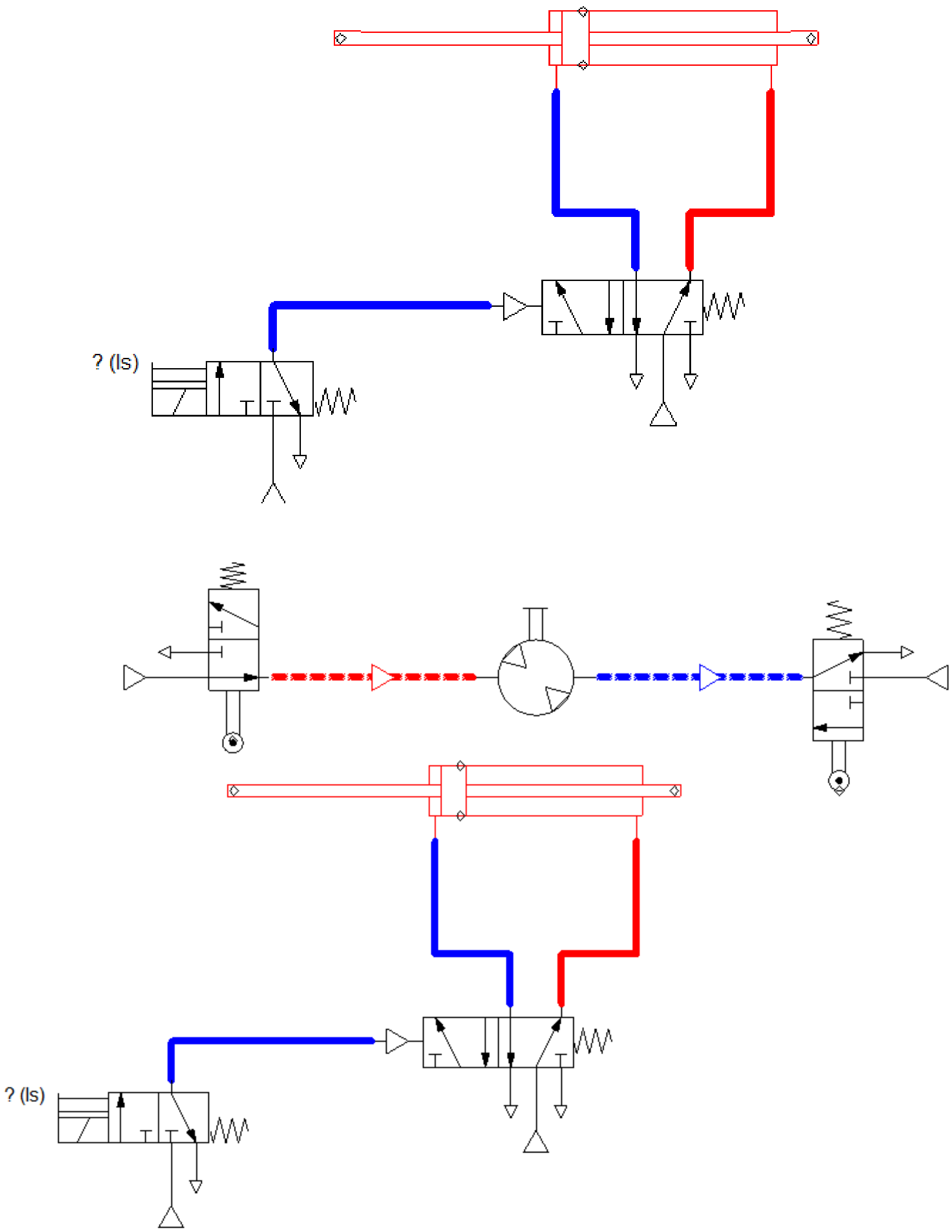




Laboratory 2 Manual



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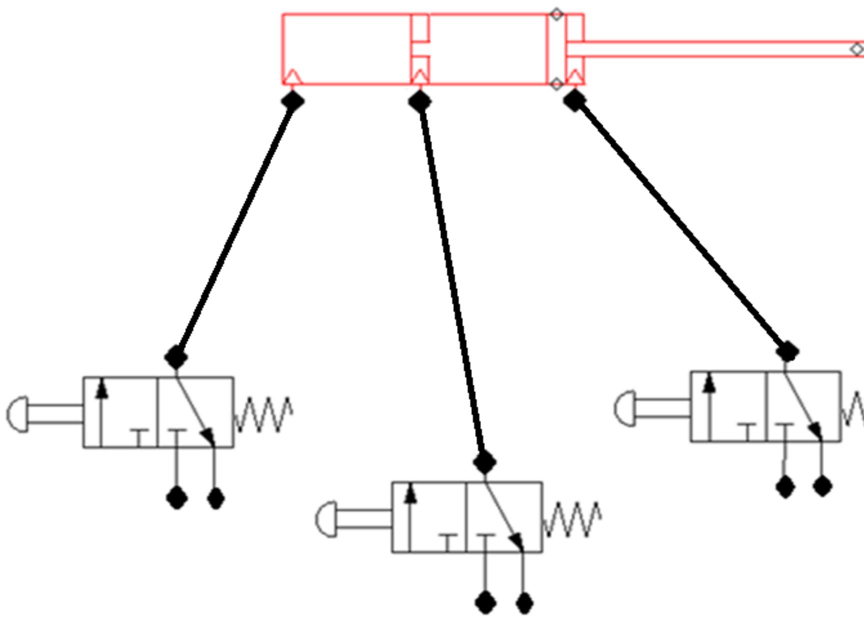
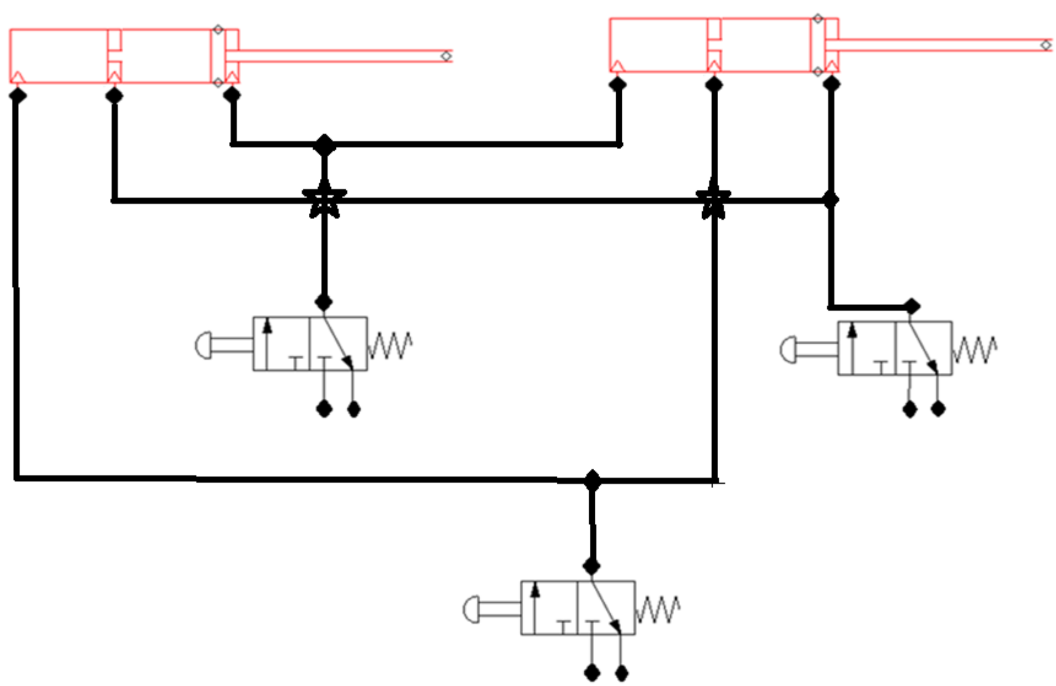
Laboratory 4 Manual





Appendix G: Detailed Components List

Table 3. Detailed Components List

Serial No.	Item or Part No.	Quantity	Description
1	CM-096-DXDET2(2x,D-129)	6	Air Cylinders w/ Adjustable Cushions
2	PT-037180-A1C1MRT	12	Three-Position Pneu-Turn Rotary Actuators
3	MV-15	48	MV-Micro-Line 3-Way Air Switches
4	NRM-172/3-DXPK(2x,D-241)	6	Original Line Three-Position Cylinder
5	M4A220-06	6	M4A-Air Pilot Valve
6	M4A210-06	6	M4A-Air Pilot Valve
7	M3V210-06-NC-24VDC	6	M3V-Solenoid Valve
8	M-172/3-D(F,D-241)	6	Original Line Three-Position Cylinder
9	CM-096-DT2(F,D-129)	12	Air Cylinders w/ Adjustable Cushions
10	DA10-125-55	6	DA10, DA20-Dual Air Manifold
11	MGFC200-06-S	6	MGFC-FRL Combination
12	PWR-150A24	6	PWR-Power Supply 48 VDC
13	PIV-20-025/038	6	PIV-Pneumatic Isolation Valves
14	US-096-B	6	UG, US-Bimba Ultran Rodless Cylinders
15	MV-140	24	Push Button valve
16	MV-35	12	Toggle Valve
17	PU-250F-25	12	Connecting Pipe roll
18	PLS250-1/8	10	Elbow connector pack
19	PB250-1/8	10	Straight connector pack
20	PB250-1/4	5	Manifold connector pack
21	PXC058	12	Pipe Cutter
22	MB-09	12	Bracket for rod less cylinder
23	TEE UNION (CPOS) 1/4 PI	10	T-connectors