School of Engineering

ES2C5 Dynamics & Fluid Mechanics Laboratory
Pneumatics

Bring to the laboratory:
- (i) Laboratory Note Book
- (ii) This handout
- (iii) The Pneumatics Assessment
- (iv) PPE Equipment (safety shoes, safety goggles)
- (v) Pen/ pencil, ruler and calculator

Before the laboratory:
- (i) Read the lab sheet notes
- (ii) Look at the briefing on the ES2C5 web pages
- (iii) Read the Safety sheets for the lab on the ES2C5 web pages
- (iv) Make a start on the Pneumatics Assessment

Summary

By the end of the laboratory assignment the student should be able to:
1. Understand the basic principles of pneumatics, its limitations and potential for practical applications.
2. Create and test pneumatic circuits.
3. Compare pneumatic actuation and control to analogous mechanical and electrical systems.
4. Apply theory to carry out calculations of the forces applied by pneumatic actuators.
5. Create pneumatic circuit diagrams.

CONTENTS

1. BACKGROUND MATERIAL

Pneumatic systems are used extensively in dentistry, construction, mining, and other areas of industrial application, being powered, typically, by compressed air or compressed inert gas. An advantage of transmitting energy pneumatically is the ease by which it can be controlled/manipulated using valves. A pneumatic system, made up of such valves, is a low cost, flexible, and safe alternative to a system with electric motors and actuators.

In Appendix A you will find a practical introduction to pneumatics, which includes a list of common symbols and information on how they can be interpreted and how pneumatic circuits are constructed. Pay particular attention to valve notation and operation as they control the pneumatic actuators.

2. EQUIPMENT

1. A compressed air supply,
2. A “Pneumate 200” Basic Pneumatic Trainer assembly panel (shown in Figure 1) supplied by SMC Pneumatics (UK) Ltd comprising:
   a. Filter Regulator with Gauge (FR),
   b. Piping Module with Check Valves (OV1) and manifold (OZ2),
   c. 1 x 5/2 Single Air Pilot Valve (V3) spring return,
   d. 2 x 5/2 Double Air Pilot Valve (V1 and V2),
   e. 2 x 3/2 Manual Push Button Valves (S1 and S2),
   f. 1 x 3/2 Twist Selector Valve (S3),

g. 1 x Pneumatic OR Function,
h. 1 x Pneumatic AND Function,
i. 3 x 3/2 Pneumatic Cylinder Limit Switches,
j. 2 x Block Mounted Pressure Gauges with Check Valves,
k. 2 x Inline Flow Controls,
l. 2 x Double Acting Cylinders (1A and 3A) with Port Mounted Flow Controls (CD85N12-80-B) (ø 12 mm bore, 80mm stroke),
m. 1 x Single Acting Cylinder (2A) with Port Mounted Flow Controls (C85N12-50S) (ø 12 mm bore, 50mm stroke), Pipe (ø4 mm), & fittings.

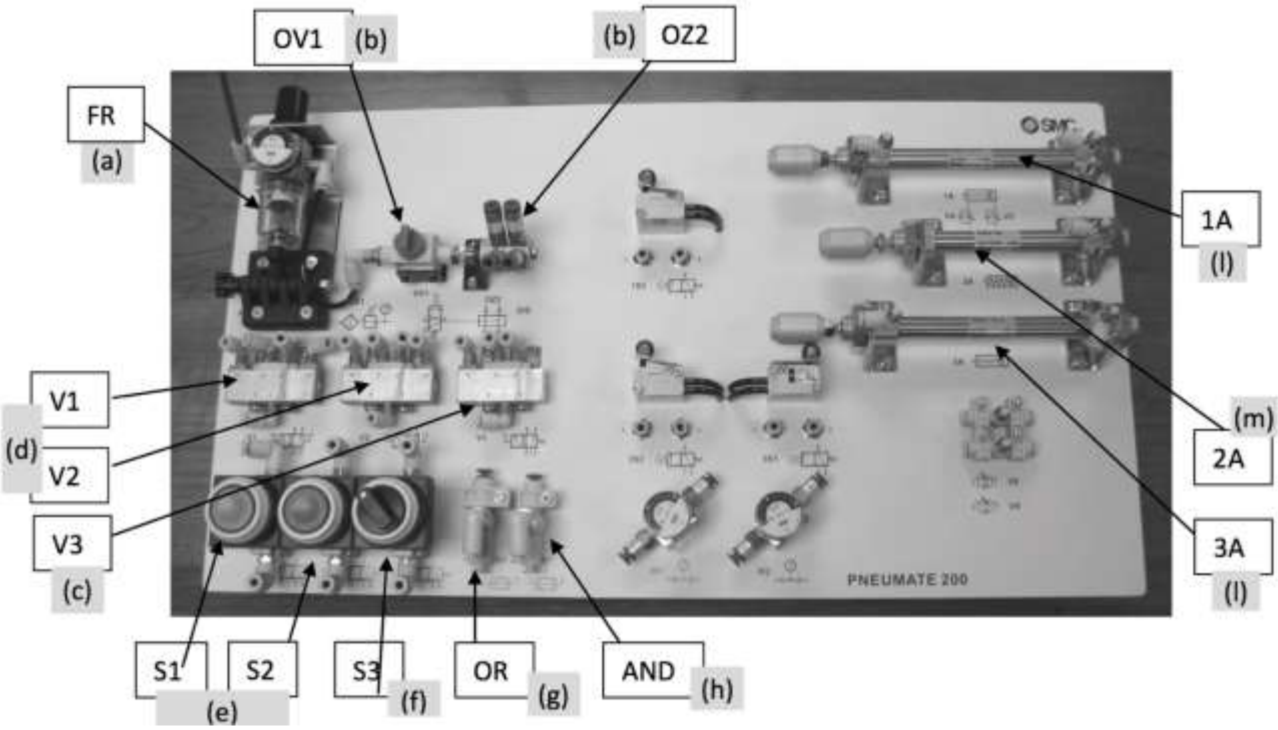


Figure 1. The “Pneumate 200” Basic Pneumatic Trainer.

3. SAFETY

This equipment operates on very low air pressure so the actuators are very unlikely to cause any physical harm. There is the possibility of bruising if fingers are placed in the path of moving parts. Be careful that loose items such as long hair or jewellery does not get caught in the Trainer. It is advisable that no one is in the vicinity of moving parts before the air supply is switched on. Care must also be taken when testing circuits. Compressed air supply can cause injury if used in an unconventional manner. *Do not push open pipes supplied with compressed air to any part of the body, particularly at eyes or on to the skin.* Anyone seen to be behaving in a manner that jeopardises his or her safety or the safety of others will be removed from the lab immediately.

Safety Awareness

Your demonstrator will brief you about Health and Safety awareness. Before beginning the experiment, you should make your own assessment of what might happen during the experiment that could cause a safety issue, and what you are doing / can do to control the risk. You should note this in your log book in a table. Headings are suggested below.

Table 1   Safety Awareness Table

Hazard	Countermeasure

N.B. During your assessment you should have concluded that :

- *Wearing safety shoes will reduce the risk of a slip (e.g., owing to water spillage hazard from another experiment);*
- *Wearing safety glasses in the lab is good practice. In this case it reduces the risk to your eyes of impact from loose pneumatic hose or contamination by lubricating oil from the compressed air;*
- *Wearing a lab. coat will keep you and the equipment clean, and reduce the chances of loose material getting caught in the experimental apparatus.*

In summary:
You must wear your safety shoes in the lab during the experiment to reduce the slip hazard;
You must wear safety glasses to protect yourself from flailing hoses/ jets of compressed air;
You can wear your coat to keep the equipment and yourself clean

- ***You must also wear gloves and a mask in order to protect yourself and others from the risk of infection by COVID19***

4. METHOD

1. Ensure the compressed air supply is connected to the Filter Regulator (FR) (see (a) in Figure 1) on your “Pneumate 200” Basic Pneumatic Trainer board. Ensure the pressure gauge is reading about 2 bar (0.2 MPa) – **do not exceed this pressure**. Connect FR output to switch OV1 (see (b) in Figure 1) with a short length of pipe (4mm in diameter).
2. Carry out as many of the 6 exercises (Exercise 1 to 6) within the time allowed. They must be carried out in order as each exercise may facilitate the next. For each exercise follow this procedure:
   i. Read and understand the exercise problem
   ii. Accurately sketch and label your solution as a pneumatic circuit diagram using the standard symbols (see Appendix A and symbols on trainer unit).
   iii. With switch OV1 turned off, connect the pneumatic elements in the assembly panel together using the pipe provided, following your sketched circuit. All air supplies should originate from the manifold OZ2.
   iv. The assembly panel comprises three manually operated 3/2 way NC valves hereinafter called switches S1, S2 and S3 (see Figure 1), three 5/2 valves V1, V2 and V3 (see Figure 1), three pneumatic cylinders 1A, 2A and 3A (see Figure 1) and two logic valves AND and OR (see Figure 1).
   v. Switch the air supply on and check the operation matches the desired result, particularly the phase diagrams. If necessary, alter circuit and update your sketch accordingly. Record the phase diagram of the system you built if it does not exactly match the phase diagram given for the exercise.
3. On completion of the lab: tidy up equipment and leave it as you found it; ensure you have all the necessary information to carry out calculations.

5. EXERCISES

5.1 Exercise 1. Directional control of a single acting cylinder

Using a 3/2 way valve (S1 in Figure 1), control a single acting cylinder (2A in Figure 1) so that when S1 is pressed the cylinder extends and when the S1 is released the cylinder retracts to its starting position (shown as 2A in Figure 2).

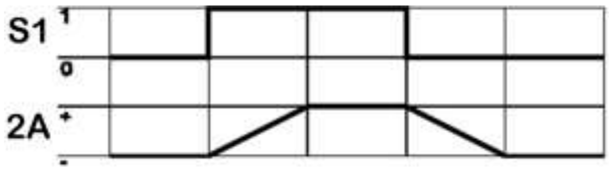


Figure 2. Phase Diagram for Exercise 1. [1]

HINT: The pneumatic circuit for this exercise is shown in Figure 2A on page 8 of this briefing

5.2 Exercise 2. Using a valve to control a double acting cylinder

Use a 3/2-way valve (S1 in Figure 1) to operate a 5/2-way valve with pneumatic opening and spring return (V3 in Figure 1) to control the opening and closing of a double acting cylinder (3A in Figure 1) to achieve the phase diagram shown in Figure 3, where S1 is the operation of the switch (3/2 way valve) and 3A the action of the double acting cylinder.

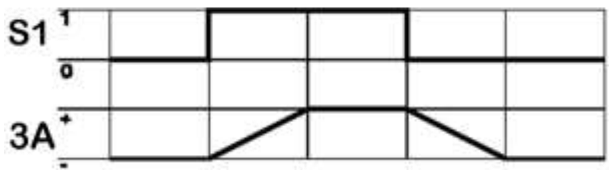


Figure 3. Phase Diagram for Exercise 2. [1]

5.3 Exercise 3. Pneumatic actuation of a door using a double acting cylinder

This is to create a system that represents the control of an automated sliding door. The cylinder 1A (see Figure 1) should extend (and as such close the door) when switch S1 (see Figure 1) is pressed and retract (open the door) when switch S2 (see Figure 1) is pressed. If one switch is held down, pressing the other should have no effect. The assembly is shown in Figure 4 and the phase diagram in Figure 5.

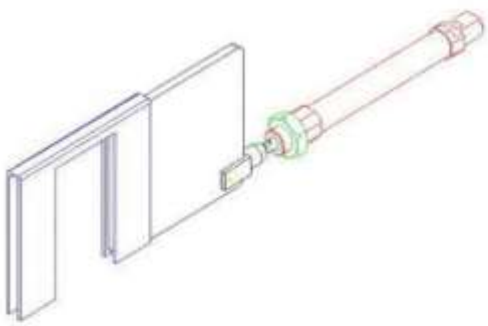


Figure 4. Sliding door [1].

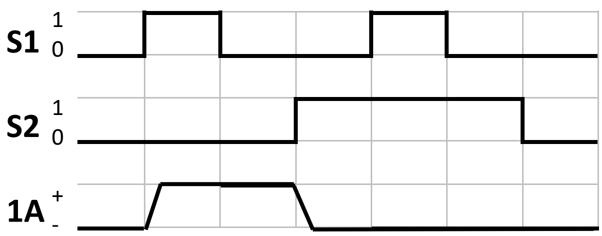


Figure 5. Phase Diagram for Exercise 3 [1].

5.4 Exercise 4. Control of a double acting cylinder from two independent locations

Use a valve block (V3) to control a double acting cylinder (1A or 3A) so that it will extend when either of 2 push-buttons (S1 or S2) are pressed or both pressed at the same time. The cylinder should always retract when no button is pressed, as indicated by the phase diagram is Figure 6. Is it enough to use the valve V3 and the two buttons (S1, S2) only?

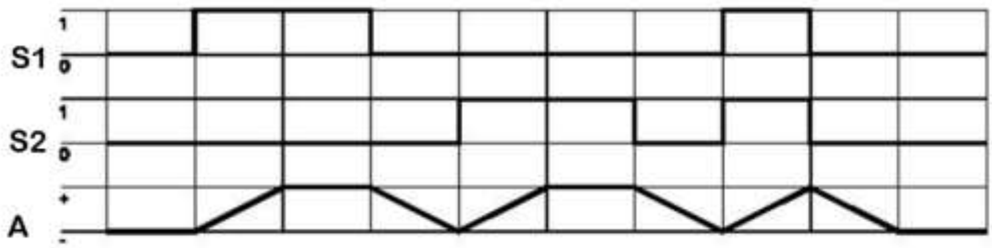


Figure 6. Phase Diagram for Exercise 4 [1].

HINT: Determine and record the Boolean logic equations for A+ (cylinder extended) and A- (cylinder retracted)? What type of logic operation is this? -Look for components that are logical operators.

5.5 Exercise 5. Pneumatic press with safety actuation (with two push buttons)

Consider a machine that uses a pneumatic double acting cylinder to press parts into a die (shown in Figure 7), e.g. sheet metal into car body panels. To ensure the machine operator is away from the danger area (where they could get crushed) he/she must press two switches (S1 and S2) together for the cylinder (1A) to extend. A third switch (S3) is used to retract the cylinder. The phase diagram is shown in Figure 8.

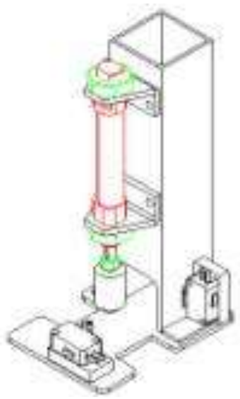


Figure 7. Pneumatic Press [1].

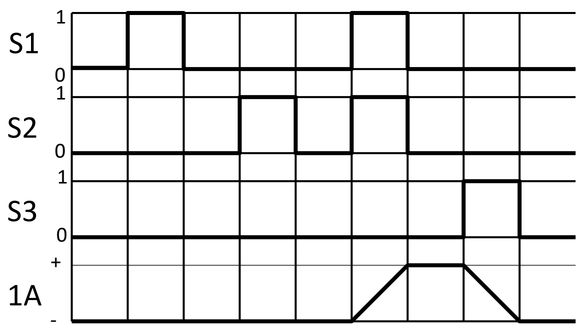


Figure 8. Phase Diagram: Exercise 5 [1].

You may want to have a go at constructing the truth table(s) for the operation of the circuit.

Determine and record the Boolean logic equations for A+ (cylinder extended) and A- (cylinder retracted)?

HINT: You may need to look up ‘sequential logic’.

5.6 Exercise 6. Alternating Piston Movement with Feedback through Limit Switches

Consider a machine with two cylinders that move in an alternating fashion. Once started through switch S3, the cylinders keep moving, whereby piston 1A extends only when piston 3A reaches a limit switch. The same applies to the retraction process. The system can be stopped with S3.

Note: Once the system is stopped, the cylinders should be vented for safety reasons (no crush hazard). Figure 9 shows the phase diagram.

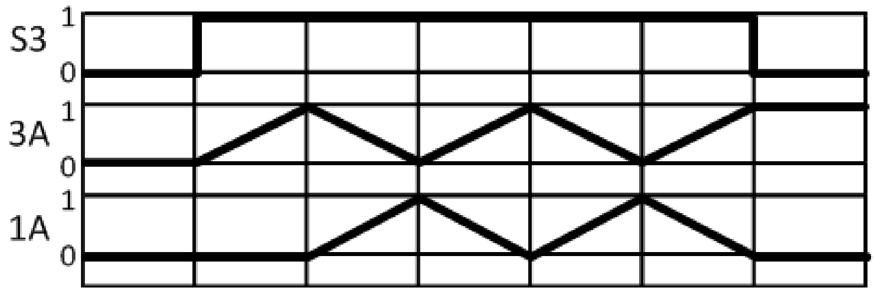


Figure 9. Phase Diagram: Exercise 6

HINT: You may want to get cylinder 3A working before you try to build in cylinder 1A

Try using the flow control valves on each cylinder to reduce/ control the speed of actuation.

REFERENCES

1. SMC International. "Pneumate 200" Documentation

Further reading

- SMC Pneumatics (suppliers of the "Pneumate 200"). Specification of actuators.
    - http://content2.smcetech.com/pdf/VDMA-C85_EU.pdf
- Mead USA – who supplies pneumatic equipment in USA but sadly this useful guide is all in imperial units so don't use it for calculations as it will just confuse you:
    - http://www.mead-usa.com/reference/media/pneumatic_handbook.pdf
- Library Books:
    - Do not just search for 'pneumatics', try 'fluid power', 'pneumatic control' as well.
- Antony Barber, "Pneumatic Handbook" (Eight Edition), 1997 Elsevier Ltd. [electronic resource available through the University of Warwick online library catalogue], Section 9 "Applied Pneumatics".
- Andrew Parr, "Hydraulics and pneumatics: a technician's and engineer's guide", 1999 Butterworth-Heinemann, [electronic resource available through the University of Warwick online library catalogue].
- Wojtecki, Rudy, "Air logic control for automated systems", CRC Press, 1999, [electronic resource available through the University of Warwick online library catalogue].
- Krivts, Igor Lazar, Krejnin, German Vladimir "Pneumatic actuating systems for automatic equipment", Taylor & Francis, 2006 [electronic resource available through the University of Warwick online library catalogue].
- Pinches, Michael J., and Callear, Brian, "Power pneumatics" Prentice Hall, 1997, TJ 950.P4.

APPENDIX A – Pneumatic Symbols

Pneumatic cylinders (actuators)

The pneumatic cylinder converts the potential energy stored in compressed air into linear displacement. They are typically hermetically sealed cylinders which house a piston that divides the interior into two sections. By applying compressed air to one or both sections, the piston moves. You can see this happen as the cylinder's 'rod' extends from or contracts into the cylinder. Cylinders are typically round and their internal radius can be deciphered from their part number. There are 2 types:

1. Single acting cylinders – air input induces a force in one direction only, the return is caused by a fitted spring when the air pressure is stopped. The pneumatic symbol for this is shown in Figure A.1 with further details shown in Figure A.2.

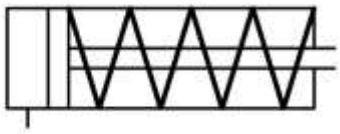


Figure A.1. Symbol for single acting cylinder with spring return.

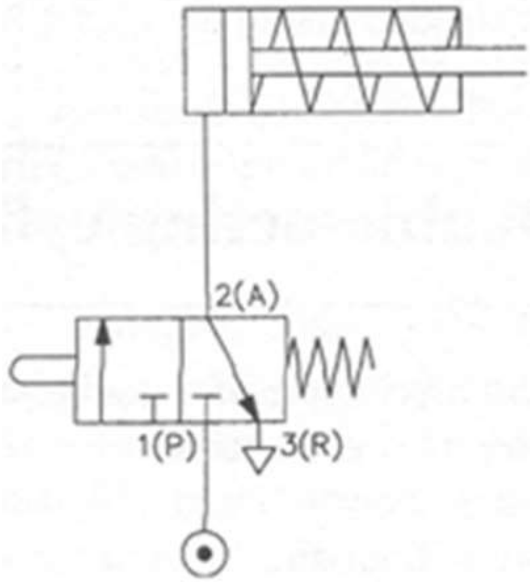


Figure A.2. Valve control of a single acting cylinder with spring return.

2. Double acting cylinders. Here, a force can be induced in both extending and retracting directions by air pressure applied to either side of the cylinder. A cross section of a typical double acting cylinder is shown in Figure A.3.

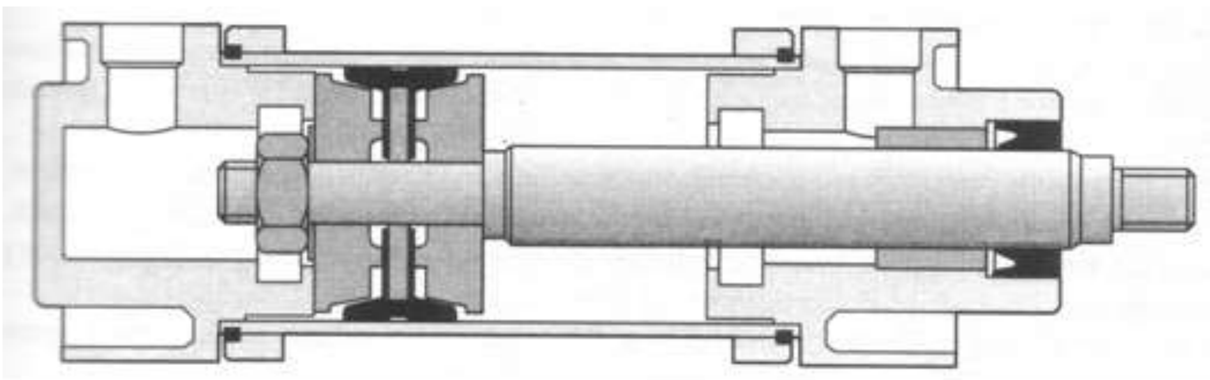


Figure A.3. Cross section of a double acting cylinder

Rubber Bumper/Single Rod

Air Cushion/Single Rod

Rubber Bumper/Double Rod

Air Cushion/Double Rod

Non-rotating rod/Single Rod

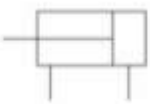
Specifications

Bore size (mm)		8	10	12	16	20	25
Piston rod dia. (mm)		4	4	6	6	8	10
Piston rod thread		M4	M4	M6	M6	M8	M10 X 1.25
Ports		M5	M5	M5	M5	G1/8	G1/8
Action		Double acting/Single or Double rod					
Fluid		Air					
Proof pressure		1.5MPa					
Max operating pressure		1.0MPa					
Min operating pressure		0.1MPa	0.08MPa		0.05MPa		
Ambient and fluid temperature		−20 to 80°C (Built-in magnet: −10 to 60°C)					
Cushion		Rubber bumper, Air cushion (Except for ø8) (Non-rotating: only rubber bumper)					
Lubrication		Not required. If necessary turbine oil no.1 ISOVG32 is recommended					
Rod boot	Nylon tarpaulin	—				Max ambient temperature 60°C	
	Neoprene cloth	—				Max ambient temperature 110°C*	
Piston speed		50 to 1500mm/s					
Allowable kinetic energy	Rubber bumper	0.02J	0.03J	0.04J	0.09J	0.27J	0.4J
	Air cushion	—	0.17J	0.19J	0.4J	0.66J	0.97J
Non-rotating accuracy**		±1° 30'	±1° 30'	± 1°	±1°	±0° 42'	±0° 42'
Stroke tolerance		0/+1				0/+1.4	

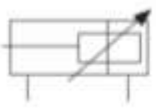
* Maximum ambient temperature of gaiters only.
** Applicable to non-rotating models only.

Symbol

Double Acting/Single Rod

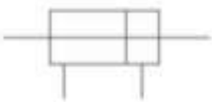


Rubber Bumper

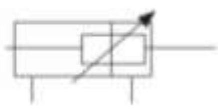


Air Cushion

Double Acting/Double Rod

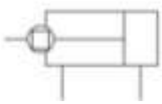


Rubber Bumper



Air Cushion

Non-rotating rod: Double Acting/Single Rod



Weight (Standard, Non-rotating rod)

(g)

Bore size (mm)			8	10	12	16	20	25
Double action	Basic weight		45	49	96	109	183(203)	258(286)
Double rod	Add'l weight for each 10mm of stroke		3	3.2	6.2	7.2	11.8	18.4
Mounting bracket		C85L□A	20		40		95	
		C85L□B	55		105		210	
		C85F□	12		25		90	
		C85T□	20		50		75	
		C85C□	20		40		85	
Accessories	Single knuckle joint	KJ□D	17		25		45	70
	Double knuckle joint	GKM□-□	10		20		50	100
	Floating joint	JA□-□-□	10		20		50	70

Calculation Example: C85N10-50, C85F10
Basic weight············49 (ø10)
Additional weight······3.2/10mm of stroke
Cylinder stroke·········50mm
Mounting bracket······12
49+3.2 X 50/10=65   65+12=77

( ): In case of air cushion

Spring return

Spring extend

Rubber bumper

Non-rotating rod

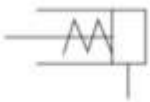
Specifications

Bore size (mm)		8	10	12	16	20	25
Piston rod dia. (mm)		4	4	6	6	8	10
Piston rod thread		M4	M4	M6	M6	M8	M10 X 1.25
Ports		M5	M5	M5	M5	G1/8	G1/8
Action		Single acting/Single rod, Spring return, Spring extend					
Fluid		Air					
Proof pressure		1.5MPa					
Max. operating pressure		1.0MPa					
Min. operating pressure	Spring return	0.22MPa	0.18MPa		0.13MPa	0.18MPa	
	Spring extended					0.23MPa	
Ambient and fluid temperature		–20 to 80°C (Built-in magnet style: –10 to 60°C)					
Cushion		Rubber bumper (Standard)					
Lubrication		Not required. If necessary, turbine oil no.1 ISOVG32 is recommended					
Piston speed		50 to 1500mm/s					
Allowable kinetic energy		0.02J	0.03J	0.04J	0.09J	0.27J	0.4J
Non-rotating accuracy*		±1° 30'	±1° 30'	± 1°	±1°	±0° 42'	±0° 42'
Stroke tolerance		0/+1				0/+1.4	

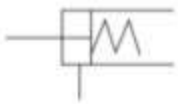
* Applicable to non-rotating models only.

Symbol

Standard

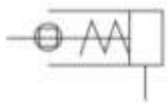


Spring return

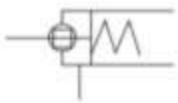


Spring extend

Non-rotating rod



Spring return



Spring extend

Spring Retracting Force (Standard, Non-rotating rod)

Spring Return

Unit: N

Bore (mm)	Standard stroke (mm)	Spring force									
		10		25		50		100		150	
		Retracted	Extended	Retracted	Extended	Retracted	Extended	Retracted	Extended	Retracted	Extended
8	10, 25, 50	4.41	4.02	4.41	3.43	4.41	2.45	—	—	—	—
10		6.28	5.69	6.28	4.90	6.28	3.53	—	—	—	—
12		7.16	6.57	7.16	5.79	7.16	4.41	—	—	—	—
16	10, 25, 50, 100, 150	13.2	12.1	13.2	10.3	13.2	7.45	13.2	7.45	13.2	7.45
20		21.6	18.6	21.6	16.7	21.6	11.8	39.2	9.81	39.2	9.81
25		27.5	25.3	27.5	22.1	27.5	16.7	47.1	13.7	47.1	15.7

Spring Extend

Unit: N

Bore (mm)	Standard stroke (mm)	Spring force									
		10		25		50		100		150	
		Retracted	Extended	Retracted	Extended	Retracted	Extended	Retracted	Extended	Retracted	Extended
8	10, 25, 50	5.30	3.92	5.30	3.14	5.30	2.65	—	—	—	—
10		5.98	4.81	5.98	4.02	5.98	3.53	—	—	—	—
12		6.57	5.59	6.57	4.90	6.57	4.51	—	—	—	—
16	10, 25, 50, 100, 150	14.7	11.3	14.7	9.22	14.7	7.85	14.7	7.85	14.7	7.85
20		39.2	33.0	39.2	23.5	39.2	9.81	39.2	9.81	39.2	9.81
25		47.1	40.4	47.1	30.4	47.1	13.7	47.1	13.7	47.1	15.7

Directional control valves

Directional control valves are devices that distribute compressed air to cylinders and other valves and devices. Pneumatic cylinders are the actuators and valves are the controllers. They operate by opening and/or closing different holes (or ports) hence allowing compressed air to flow to various devices or pipes in the circuit. It is therefore important to connect them correctly to ensure the circuit functions as desired. Connection is logical and the symbols used to represent valve configurations and positions are detailed below.

The directional control valve is represented by the number of controlled connections and the number of positions. Each position is shown as a separate square (see Figure A.4).

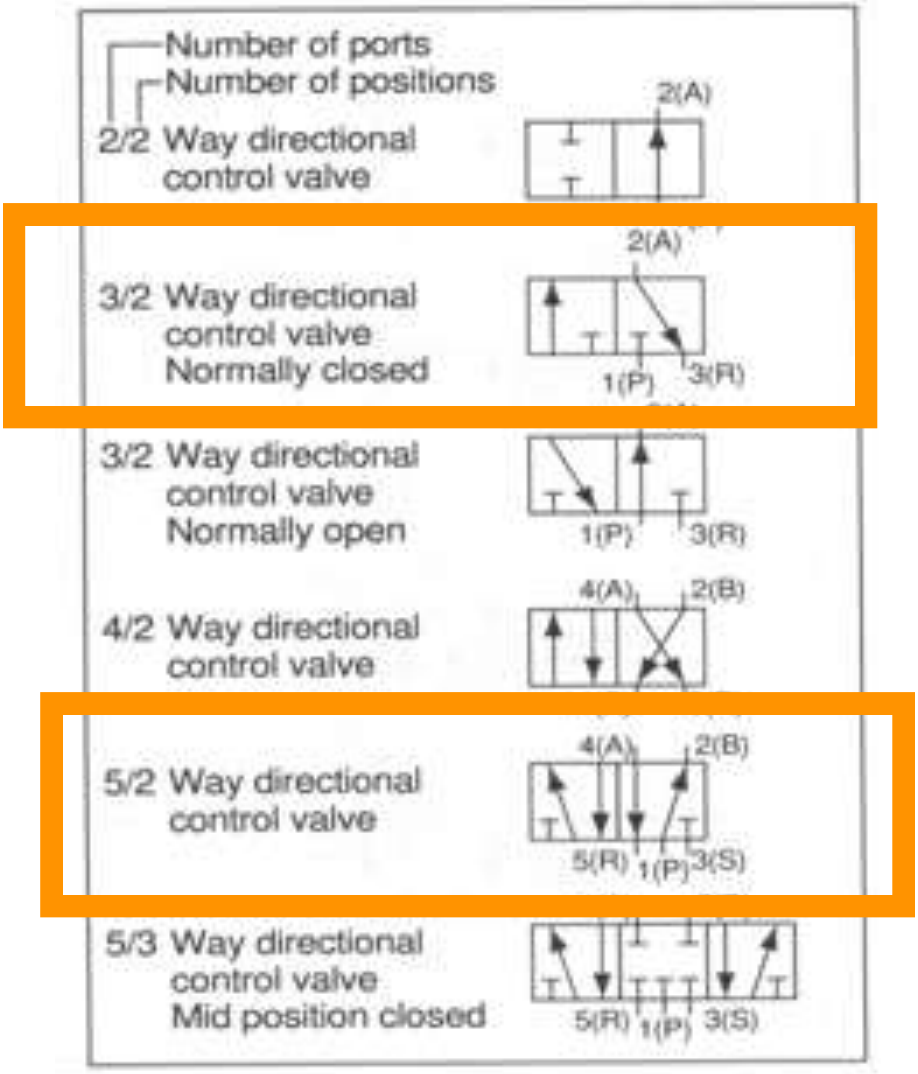
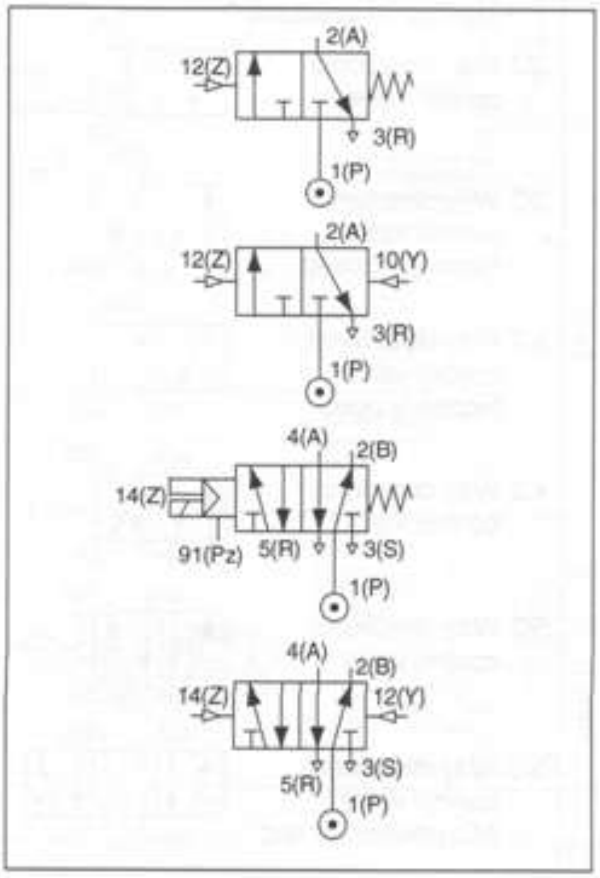


Figure A.4. Directional Control Valves.

The designation of the ports is important when interpreting the circuit symbols and the valve as fitted to the physical system. To ensure that the correct lines, connections and valves are physically in place, symbols on the circuit must be designated and the components used should be labelled with the correct symbol and designations. A numbering system is used to designate directional control valves and is in accordance with ISO 5599. Prior to this a lettering system was used. Both systems of designation are shown in Figure A.5.

Port or connection	ISO 5599 Numbering system	Lettering system
Pressure port	1	P
Exhaust port	3	R (3/2-way valve)
Exhaust ports	5, 3	R, S (5/2-way valve)
Signal outputs	2, 4	B, A
Pilot line opens flow 1 to 2	12	Z (single pilot 3/2-way valve)
Pilot line opens flow 1 to 2	12	Y (5/2-way valve)
Pilot line opens flow 1 to 4	14	Z (5/2-way valve)
Pilot line flow closed	10	Z, Y
Auxiliary pilot air	81, 91	Pz



3/2 Way Valve with pneumatic opening and spring return.

3/2 Way Valve with double pneumatic operation (i.e. opening and closing).

5/2 Way Valve with single solenoid operation and pilot operation with manual override.

5/2 Way Valve with double pneumatic operation.

Figure A.5. Designation of Ports.

Valves can be triggered (or actuated) in many ways. Normally a solenoid is used which is triggered by an electrical signal issued by a microprocessor driven controller. Like cylinders they can have single actuation with a spring return or double actuation where two inputs are required. Apart from solenoids, there are a multitude of ways in which a valve can be triggered, including mechanical (e.g. button, lever), pneumatic (which is used on this trainer board) and hydraulic. These, with their symbols, are all shown in Figure A.6, as the left hand column and the right hand column shows other devices which are similar to valves for controlling air flow (OR and AND function logic valves).

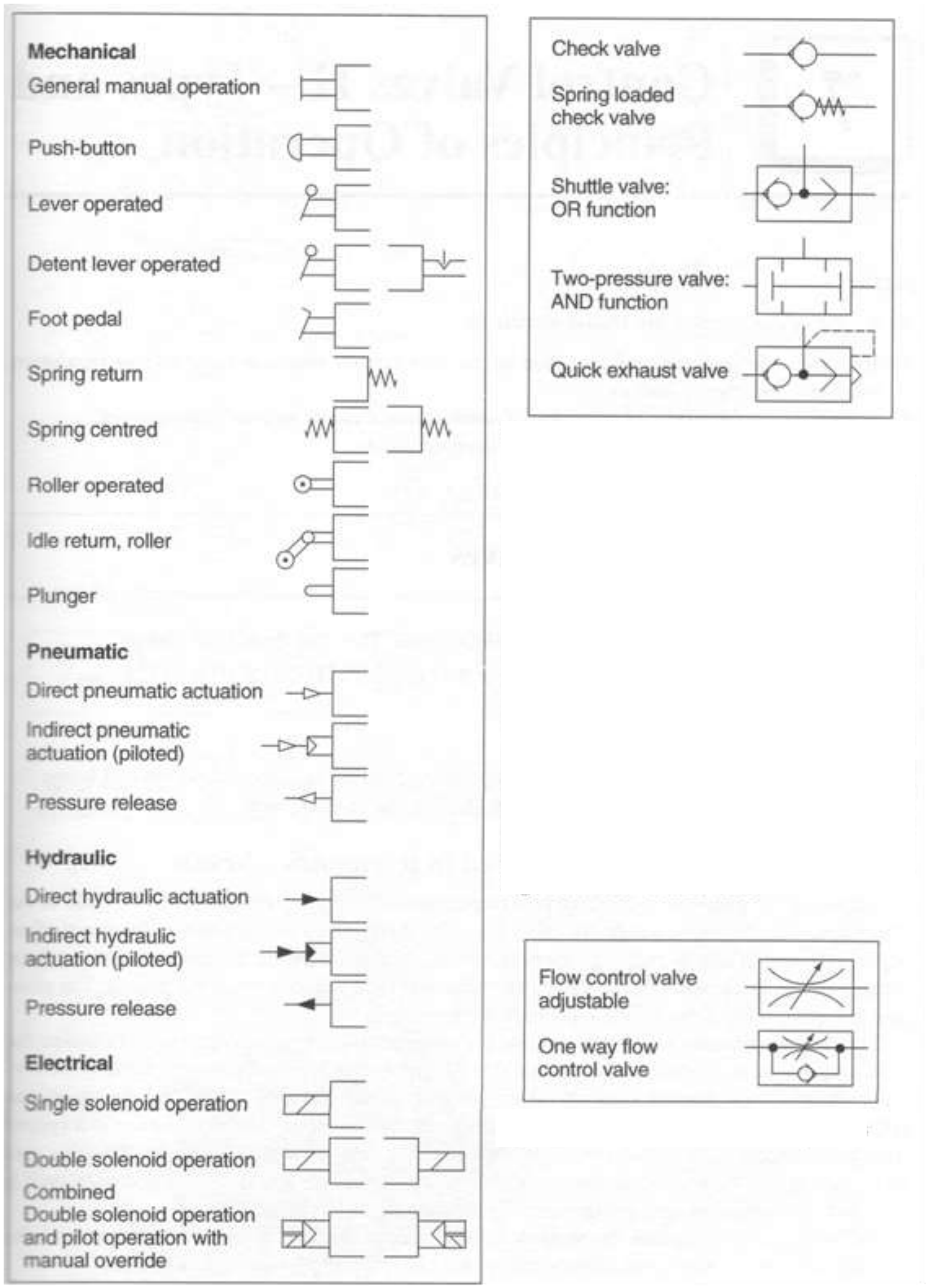


Figure A.6. Symbols and Logic Functions.

APPENDIX B – Pneumatic Calculations

Information taken from - SMC Pneumatics (suppliers of the "Pneumate 200"). Pneumatic Calculations.
http://www.smc.eu/portal/WebContent/local/UK/Pneu_Book/Sizing_Pneumatic_.jsp?tree_title=Products&tree_image=menu_products.jpg&tree_options=tree_products.js&box=box_locations.htm (Last viewed December 2015.)

A cylinder's efficiency has been shown to be related to the pressure (see Figure B.1).

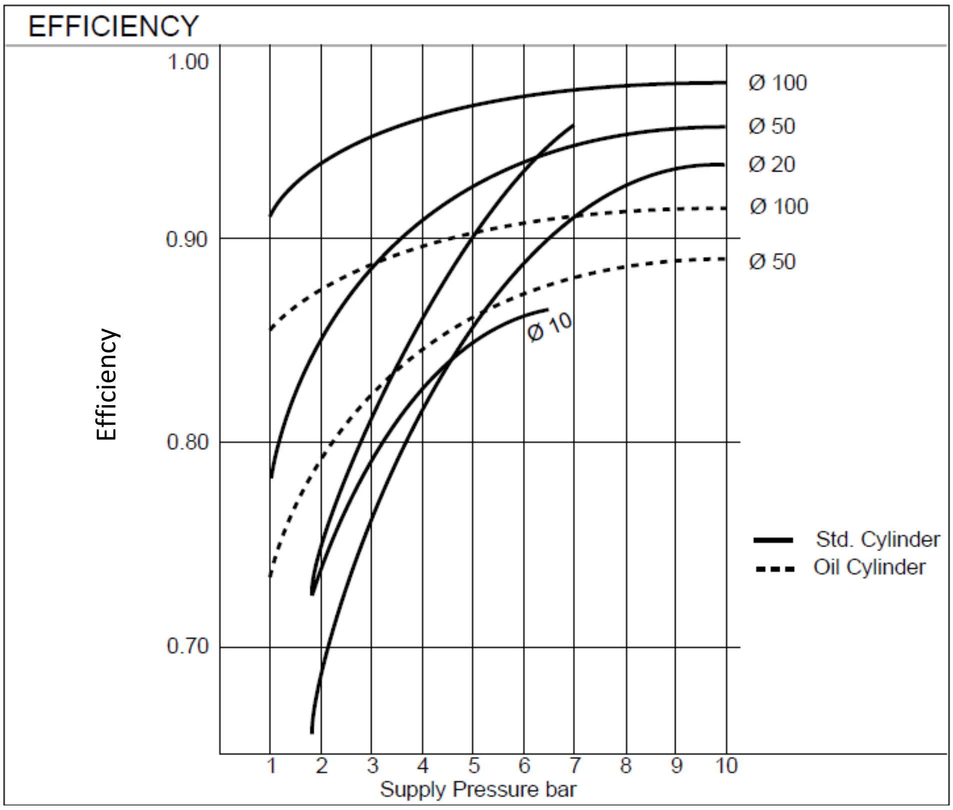


Figure B.1. Cylinder Efficiency.