

Fluid Power

Pneumatics Fundamentals

Courseware Sample

31290-F0

Order no.: 31290-00

First Edition

Revision level: 01/2015

By the staff of Festo Didactic

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Printed in Canada

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ISBN 978-2-89289-383-0 (Printed version)

ISBN 978-2-89640-652-4 (CD-ROM)

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Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
	DANGER indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
	WARNING indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
	CAUTION indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
	CAUTION used without the <i>Caution, risk of danger</i> sign  , indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
	Direct current
	Alternating current
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

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Introduction

The Lab-Volt Pneumatics Training System, Model 6081, is a modular program in pneumatics and its applications. The system is divided into five subsystems: Pneumatics Fundamentals, Electrical Control of Pneumatic Systems, Pneumatics Applications – PLC, Servo/Proportional Control of Pneumatic Systems.

In Pneumatics Fundamentals, the students are introduced to the basic principles and components of pneumatics. Electrical Control of Pneumatic Systems covers electrical control of pneumatic systems with ladder diagrams. Pneumatics Applications – PLC expands upon the others with pneumatics applications demonstrating programmable logic controllers (PLCs). In Servo/Proportional Control of Pneumatic Systems, students are introduced to servo-proportional control systems and their associated circuitry.

Most of the components used for electrical control of the Lab-Volt Pneumatics Training System are also intended to be used with the Lab-Volt Hydraulics Training System, Model 6080, allowing interconnection of both systems to perform more complete functions.

Innovative design

Engineered for extreme ease of use, the basic system comes with a work surface assembly consisting of a solid metal, universal drip-tray hinged to a perforated, tiltable work surface on which pneumatic components can be mounted. The work surface can be configured to accommodate a wide variety of space and teaching needs. Lying flat over the drip tray, or tilted at 45°, the work surface provides a large area on which pneumatic components and space-expanding work surfaces can be mounted at any location, either at 0° or 90°.

Mounting and removal of components is especially easy with push-lock fasteners that snap effortlessly into the perforations of the work surface.

Although the system is designed to operate atop a regular work table, an optional bench is available to provide mobility and storage space. Mounted on four heavy-duty, swivelling, lockable castors, the bench provides shelving for extra work surfaces and components. Optional dressing panels are also available to fully enclose the bench and provide storage area for components. The work surfaces may also be linked together for more complete electro-pneumatic/hydraulic circuits. By utilizing the optional work surfaces, exercise setups can be saved. All components meet industrial safety standards, are identified with the proper ANSI symbols on their base, and are equipped with quick-connect fittings.

Virtual Laboratory Equipment

All components contained in Pneumatics Fundamentals and Electrical Control of Pneumatic Systems can be simulated by the Windows™-based simulation software Lab-Volt Pneumatics Simulation Software (LVSIM®-PNEU), Model 6485.

Courseware

The Pneumatics courseware consists of a student manual for each subsystem and an instructor guide. Student manuals are divided into several units, each consisting of a series of hands-on exercises dealing with one of the pneumatics fields. Each exercise provides a clearly stated objective, a discussion, textbook references, a summary of the exercise procedure, a conclusion, and a set of review questions. A ten-question test at the end of each unit allows the student to verify what was learned in the unit.

The instructor guides contain the measurement results as well as the answers for each hands-on exercise of the student manuals, and the answers to the unit test questions.

The Pneumatics courseware also includes a reference textbook, optional video tapes and courseware figures. These figures are available in the form of transparencies and on CD-ROM.

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Unit 1 Introduction to Pneumatics

Explore the trainer and components included in the Lab-Volt Pneumatics Training System. Safety rules, component identification, description and general operation. Introduction to air conditioning and distributing equipment.

Ex. 1-1 Familiarization with the Lab-Volt Pneumatics Trainer

Description of the Lab-Volt Pneumatics Trainer. Configuration of the work surface. Identification of the various components. Familiarization with the symbols, characteristics and uses of each component. Safety rules.

Ex. 1-2 Introduction to Pneumatics

To introduce pneumatic power characteristics, applications, advantages and disadvantages. To investigate a demo circuit using a directional control valve and a cylinder.

Ex. 1-3 Air Conditioning and Distributing Equipment

To introduce the Conditioning Unit and its components: shutoff valves, filter, pressure gauge, pressure regulator and muffler. To learn about receivers, accumulators and safety relief valves. To observe the effect of friction in a demo circuit using an accumulator, a directional control valve, a flow control valve and a cylinder.

Unit 2 Basic Physical Concepts

To introduce pressure, force, volume and flow relationships. Vacuum generation. Measurements using pneumatic components. Introduction to flowmeters, needle valves, check valves, flow control valves and vacuum generators.

Ex. 2-1 Pressure vs Force Relationship

To introduce the relationship between pressure and force. To verify the formula $F = P \times A$. To measure the force delivered by a cylinder in demo circuits using a cylinder, a pressure gauge and a load device. To observe that the force exerted on a given surface is directly proportional to the pressure applied on this surface.

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PNEUMATICS FUNDAMENTALS

Ex. 2-2 Pressure vs Volume Relationship

To introduce the relationship between pressure and volume. To verify the formula $(P1 \times V1)/T1 = (P2 \times V2)/T2$ by compressing air in a cylinder chamber in demo circuits using a cylinder and a pressure gauge.

Ex. 2-3 Pressure Drop vs Flow Relationship

To introduce the relationship between pressure drop and generated flow. To see the effect of a load on the flow in demo circuits using a flowmeter, a flow control valve and a pressure gauge. To introduce flowmeters, needle valves, check valves and flow control valves.

Ex. 2-4 Vacuum Generation

To introduce vacuum generation in demo circuits using a vacuum generator, cylinders, an air bearing and a pressure gauge. To demonstrate manometer operating principles by measuring the height of a column of water in a demo circuit.

Unit 3 Basic Controls of Cylinders

To introduce components used in fundamental circuits featuring directional control valves and cylinders. Introduction to the methods for controlling speed, force and synchronization.

Ex. 3-1 Directional Control Valves

To introduce the operation of directional control valves. To learn about symbols, operators, construction and classification. To learn about normally passing and normally non-passing valves. To learn how to select circuit branches and power sources in demo circuits using a flowmeter, a flow control valve and a 3-way, 2-position directional control valve.

Ex. 3-2 Directional and Speed Control of Cylinders

To introduce the operation of cylinders. To learn about symbols, dimension parameters, construction and classification. To learn how to control the speed of cylinders using flow control valves. To verify the meter-in and meter-out methods of control in demo circuits using flow control valves, directional control and cylinders.

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PNEUMATICS FUNDAMENTALS

Ex. 3-3 Cylinders in Series

To describe the operation of a series circuit and cylinder synchronization. To demonstrate pressure intensification in demo circuits using a directional control valve and cylinders.

Ex. 3-4 Cylinders in Parallel

To describe the operation of a parallel circuit, to learn about the extension sequence of parallel cylinders having different loads. To show how to synchronize the extension of parallel cylinders in demo circuits using directional control valves, cylinders and flow control valves.

Unit 4 Basic Controls of Pneumatic Motors

To introduce pilot-operated directional control valves and pneumatic motors. To learn the methods for controlling torque, speed and direction of rotation of pneumatic motors.

Ex. 4-1 Indirect Control Using Pilot-Operated Valves

To introduce the operation of pilot-operated directional control valves. To learn about construction and classification. To show the advantages of indirect control in demo circuits using a long line device, cylinders and a 4-way, 5-port, 2-position pilot-operated directional control valve.

Ex. 4-2 Pneumatic Motor Circuits

To introduce symbols, construction and classification of pneumatic motors. To show how to control torque, direction and speed control of a motor in a test circuit using directional control valves, flow control valves and a pneumatic motor.

Ex. 4-3 Pneumatic Motor Performance

To introduce how to use manufacturer's data sheets. To learn how to evaluate the performance of a pneumatic motor in demo circuits using a flowmeter, a flow control valve and a motor.

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 B Care of the Pneumatics Trainer
 C Hydraulics and Pneumatics Graphic Symbols
 D Conversion Factors
 E New Terms and Words

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ELECTRICAL CONTROL OF PNEUMATIC SYSTEMS

Unit 1 Introduction to Electrical Control of Pneumatic Systems

An introduction to electrically-controlled pneumatic systems. Description of the function of each part of an electrical control circuit.

Ex. 1-1 Familiarization with the Equipment

Identification of the components used for electrical control of the Lab-Volt Pneumatics Trainer. Classifying the components as input element, controller element, or actuating mechanism.

Unit 2 Electrical Concepts

Basic concepts of electricity. How to read, draw and connect simple ladder diagrams. Experiment typical basic circuits involving logic function valves.

Ex. 2-1 Basic Electricity

Measurement of the voltage, resistance, and current in an electrical control circuit. Connection and operation of an electrical control circuit.

Ex. 2-2 Ladder Diagrams

Definition of a ladder diagram. Description of how a ladder diagram operates and how it relates to the pneumatic equipment. Rules for drawing ladder diagrams. Connection and operation of basic ladder diagrams using series (AND) logic, parallel (OR) logic and control relays.

Ex. 2-3 Basic Electrically-Controlled Pneumatic Circuits

To show the advantage of indirect control where a main directional valve is actuated by a pressure signal delivered by another directional valve or by an electrical signal provided by an input device. How to improve reciprocating time response using a quick exhaust valve. Introduction to magnetic proximity switches and solenoid-operated directional valves.

Ex. 2-4 Basic AND and OR Logic Function Circuits

To introduce the AND function valve and the shuttle valve (OR). To assemble and test circuits using these logic functions.

Courseware Outline

ELECTRICAL CONTROL OF PNEUMATIC SYSTEMS

Unit 3 Functional Systems

Connection and operation of functional electrically-controlled pneumatic systems.

Ex. 3-1 Basic Memory and Priority Electropneumatic Circuits

To show how a directional valve can memorize a signal and maintain a position. To demonstrate how to pneumatically lock and unlock an electropneumatic circuit. Comparison between air-locked and electrically-locked circuits. Introduction to limit switches.

Ex. 3-2 Multi-Pressure Systems

To use a pressure regulating valve to show how to get a lower pressure at one point of a circuit while the working pressure of the circuit remains at a higher value. See how to manage multiple-pressure control in order to create a shift in the force exerted by an actuator in choosing a different pressure setting. Introduction to pressure-switches.

Ex. 3-3 Sequencing Pneumatic Circuits

To learn basic circuits involving sequencing to control actuators in a specific order. How to electrically create a sequence without having a sequence valve in the circuit. Introduction to cascade circuits.

Ex. 3-4 Time-Delay Electropneumatic Applications

To create an alternating circuit to simulate a cycle-operating application featuring a time-delay relay. Learn how to use air compression to control a time-delay application. Introduction to time-delay relay.

Unit 4 Industrial Applications

To introduce industrial-type circuits and sensors used in different applications. Simulate conditions involved and show advantage and flexibility of an electropneumatic control.

Ex. 4-1 Pneumatic Actuator Deceleration Circuits

To reproduce a typical industrial application involving shift in velocity or braking of an actuator. Comparison between air-actuated circuit and electrically-actuated circuit.

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ELECTRICAL CONTROL OF PNEUMATIC SYSTEMS

Ex. 4-2 Counting of Actuator Cycles

To create an alternating circuit to simulate a cycle-operating application. Learn basic rules involved in that type of control. Introduction to counters.

Ex. 4-3 Industrial Drilling System and Safety Circuits

To build a drilling machine circuit to reproduce typical industrial applications.

Ex. 4-4 Garbage Compactor Simulation Circuit

To build a garbage compactor circuit to simulate a well-known application as a synthesis of the notions previously learned and how to set up multiple control devices to make them work properly in a large electropneumatic circuit.

Unit 5 Troubleshooting

To use simple and logical methods to perform troubleshooting applied to both electric and pneumatic circuits.

Ex. 5-1 Troubleshooting Electrical Control Circuits

Description of the voltmeter and ohmmeter methods of troubleshooting an electrical control circuit. Location of instructor-inserted faults in the electrical section of an electrically-controlled system.

Ex. 5-2 Troubleshooting Electrically-Controlled Pneumatic Systems

Learning an efficient troubleshooting method for locating faults in an electrically-controlled pneumatic system. Location of instructor-inserted faults in the pneumatic and electrical sections of a circuit.

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 - E Conversion Factors**
 - F Trainer Status Verification Procedure**
 - G Time-Delay Relay/Counter Specifications**
 - H New Terms and Words**

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Exercise 1 Programmable Logic Controller Review

Revision of the PLC relay-type instructions. Entering and testing a program that uses relay-type instructions to control the turning on and turning off of two lamps.

Exercise 2 Timer Instructions

Revision of the PLC timer instructions. Entering and testing a program that uses timer-on instructions to turn on three lamps in a programmed order and for a definite period of time.

Exercise 3 Counter Instructions

Revision of the PLC counter instructions. Entering and testing a program that uses two counters in cascade to turn on a lamp after another lamp has turned on a definite number of times.

Exercise 4 Latching and Comparison Instructions

Revision of the PLC latching and comparison instructions. Entering and testing a program that uses latching and counter-driven comparison instructions to turn on a lamp after another lamp has blinked a definite number of times.

Exercise 5 Time-Delay Control of Pneumatic Actuators

Connection and operation of a PLC-controlled pneumatic system that continuously reciprocates a cylinder and makes it dwell in two predetermined positions for some period of time.

Exercise 6 Counting of Pneumatic Actuator Cycles

Connection and operation of a PLC-controlled pneumatic system that makes a motor rotate 200 turns and then reciprocates a cylinder 5 times.

Exercise 7 Safety Control of Pneumatic Actuators

Connection and operation of a PLC-controlled pneumatic system that uses a STOP/RESET pushbutton, a pressure switch, and an alarm lamp to provide safety control of a press cylinder.

Exercise 8 PLC-Controlled Clamp and Work System

Connection and operation of an industrial-type clamp and work system that monitors the pressure applied by the clamp cylinder to ensure the workpiece remains firmly clamped while being worked on.

Courseware Outline

PNEUMATICS APPLICATIONS – PLC

Exercise 9 Troubleshooting

Location of instructor-inserted faults in the pneumatic and PLC-control sections of the clamp and work system studied in Exercise 8.

Exercise 10 Designing a PLC-Controlled Stamping Machine

Designing a PLC-controlled stamping machine that embosses thin metal sheets.

Exercise 11 Designing a PLC-Controlled Conveyor System

Designing a PLC-controlled conveyor system that circulates manufactured parts and loads them on a packing machine.

Exercise 12 Designing a PLC-Controlled Injection Molding Machine

Designing a PLC-controlled injection molding machine used to produce plastic dice.

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SERVO/PROPORTIONAL CONTROL OF PNEUMATIC SYSTEMS

Exercise 1 Introduction to Servo Control Valves 1-1

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Exercise 3 Open-Loop Position Control 3-1

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Exercise 4 Closed-Loop Position Control, Proportional Mode 4-1

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Exercise 5 Closed-Loop Position Control, Proportional-Plus-Integral Mode 5-1

Description of the integral control mode. Definition of the terms integral gain, overshoot, and oscillation. Advantages and disadvantages of integral control. Comparison of the proportional, integral and proportional-plus-integral control modes.

Exercise 6 Open-Loop Speed Control 6-1

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SERVO/PROPORTIONAL CONTROL OF PNEUMATIC SYSTEMS

Exercise 7 Closed-Loop Speed Control, Proportional-Plus-Integral-Plus-Derivative Mode 7-1

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Exercise 8 Closed-Loop Pressure Control, Proportional-Plus-Integral Mode 8-1

Description of open-loop and closed-loop control of circuit pressure. Sensing the pressure using a pressure transducer.

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Sample Exercise
from
Pneumatics Fundamentals

Exercise 4-1

Indirect Control Using Pilot-Operated Valves

EXERCISE OBJECTIVE

- To learn about pilot-operated valves;
- To show the advantages of indirect control of a single acting cylinder.

DISCUSSION

The main difference between pilot-operated directional control valves and direct-operated valves is in how their spools are shifted. On a pilot-operated valve, an air signal replaces the mechanical force used to shift the spool in a direct-operated valve. Other than this, the housings and spools of both valve types are so similar that these parts are often interchangeable.

The greatest advantage of a pilot-operated valve is that it permits the remote-actuation of large valves with inexpensive pilot lines. The more expensive working lines of the larger valves can then be kept short to save money. Cheaper pilot-lines can be run for some distance without any loss of circuit performance. Since pilot-operated valves do not need to be manually actuated, they can be controlled with outside devices or systems. This makes process automation possible. Also, because pilots require minimum pressures and volumes to shift against the working pressures, they reduce the delays caused by compressibility of air and friction in long tubing lines.

Pilot-operated valves can be 3-way and 4-way (4 ports or 5 ports). They can be either 2-position or 3-position. Usually, 3-way pilot valves are used to remotely control linear or rotary actuators in one direction and then exhaust their working lines. The 4-way pilot valves are used to remotely control linear and rotary actuators in two directions, as well as exhausting their working lines.

Pilot-operated valves may move their spools using one or two pilots along with a return spring. If a 2-position valve uses only one pilot, the pilot moves the valve spool against a spring and into the housing opposite the pilot. The spring will return the spool when pilot pressure is removed.

Double-piloted valves have a pilot at each end of the housing. Opposing pilots are used to shift the spool back and forth, but the circuit must exhaust one pilot before the other pilot can shift the spool. The lack of return springs in double-piloted valves, allows the spool position to be maintained, or memorized, without maintaining pilot pressure.

The pilot-operated valve supplied with your Trainer is a double-piloted, 4-way, 5-port, 2-position directional control valve. It is called a 4-way valve instead of a

Indirect Control Using Pilot-Operated Valves

5-way valve because one of the exhaust ports is usually not used in a given valve position. It is illustrated in Figure 4-1.

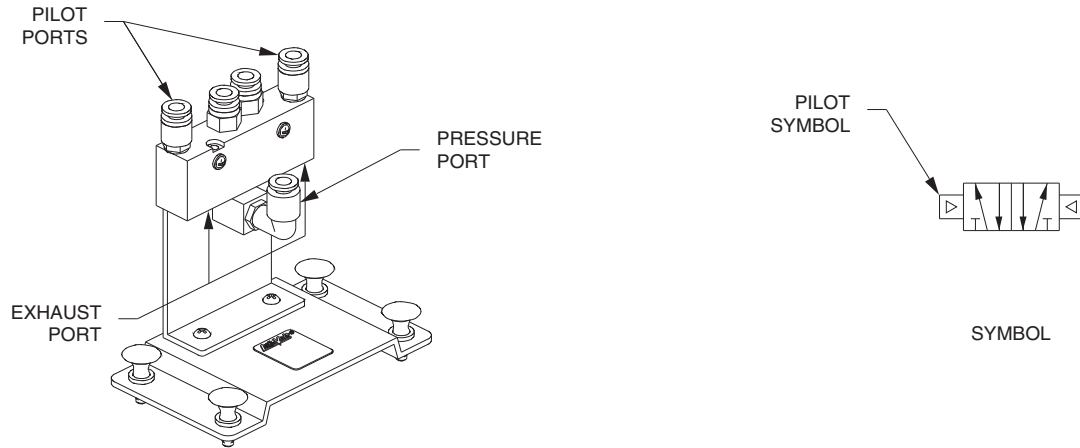


Figure 4-1. Double-pilot, 4-way, 2-position Directional Control Valve.

The operation of a double-piloted, 4-way, 2-position directional control valve is illustrated in Figure 4-2. When pilot port A is pressurized, ports 1 and 2 are interconnected through the valve, supplying the branch circuit with compressed air. Ports 3 and 4 are also interconnected through the valve, connecting the branch circuit to atmosphere. When the spool is shifted by pressurizing pilot port B, ports 1 and 4 are interconnected to supply the branch circuit with compressed air. Compressed air is exhausted from the branch circuit to atmosphere through interconnected ports 2 and 3. Pilot-operated valves can have manual overrides to move the spool without pilot pressure for system setup and troubleshooting.

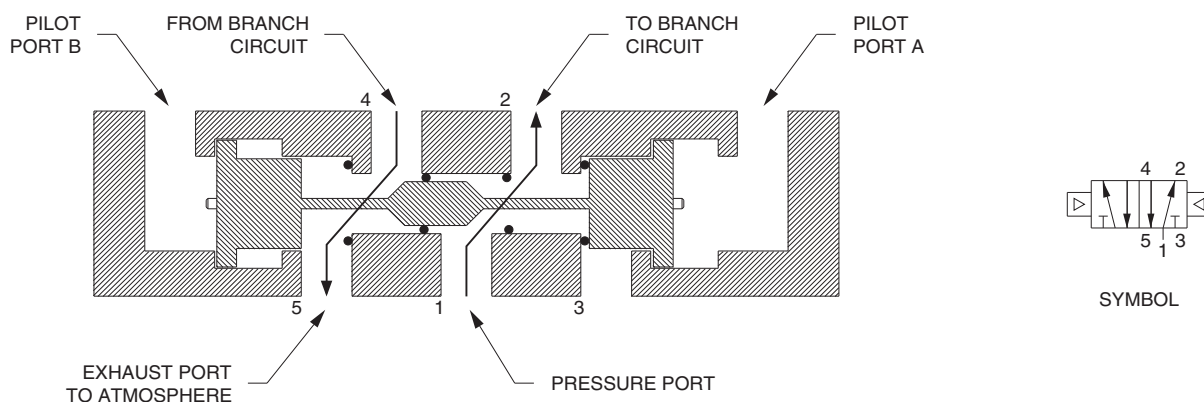


Figure 4-2. Operation of a Double-pilot, 4-way, 2-position Directional Control Valve.

The circuit shown in Figure 4-3 shows that a 3-way, 2-position pilot-operated valve allows the use of shorter expensive working lines. The cheaper pilot-lines can be

Indirect Control Using Pilot-Operated Valves

run for some distance without any loss of circuit performance while minimizing delays.

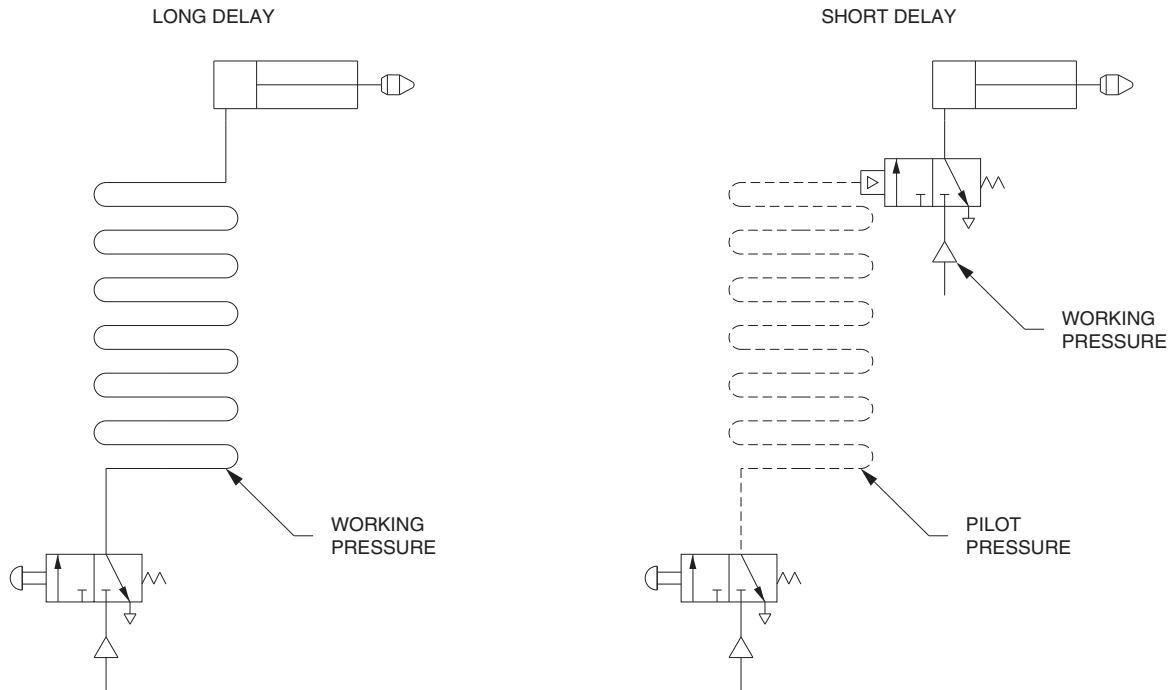


Figure 4-3. Indirect Control Using a 3-way, 2-position Piloted Directional Control Valve.

REFERENCE MATERIAL

For additional information on directional control valves, refer to the chapter entitled *Directional Control Valves* in the Parker-Hannifin manual *Industrial Pneumatic Technology*.

Procedure summary

In this exercise, you will verify the operation of a 4-way, 5-port, 2-position directional control valve by operating a double-acting cylinder.

In the second part you will use the long line device to verify that pilot lines require minimum pressure and volume to shift the spool.

You will verify that priority can be maintained on a position when the pilot port remains pressurized. You will also verify that indirect control reduces delays caused by compressibility of air and friction in long tubing lines.

Indirect Control Using Pilot-Operated Valves

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

- ☐ 1. Verify the status of the trainer according to the procedure given in Exercise 1-2.
- ☐ 2. Retract the piston rod of the Double-Acting Cylinder and connect the circuit shown in Figure 4-4.

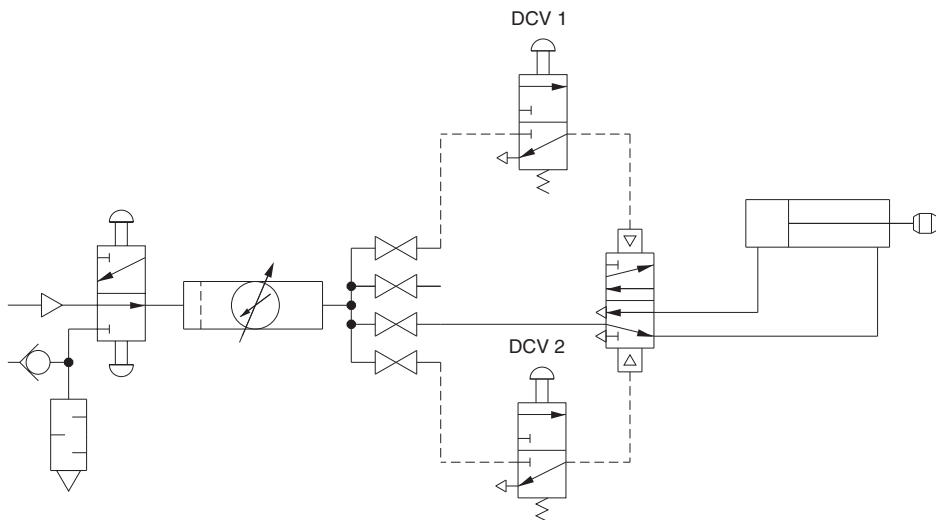


Figure 4-4. Schematic Diagram of a Pilot-Operated Circuit.

- ☐ 3. From the schematic diagram shown in Figure 4-4, predict which of the valves DCV1 or DCV2 controls the extension and/or the retraction of the piston rod?

- ☐ 4. Open the main shutoff valve and the branch shutoff valves at the manifold and set the pressure regulator at 100 kPa (or 15 psi) on the regulated Pressure Gauge.

Indirect Control Using Pilot-Operated Valves

- ☐ 5. Push down the button on the directional control valve DCV2 to set the spool in the pilot-operated valve as illustrated in Figure 4-4. The piston rod should be retracted.

- ☐ 6. Actuate the cylinder using the directional control valves DCV1 and DCV2. Do the valves DCV1 and DCV2 control the extension and retraction of the cylinder piston rod as predicted? If not, explain why.

- ☐ 7. Push down the button on the directional control valve DCV2 and maintain this position. With your other hand, push down the button on the directional control valve DCV1. Does the piston rod extend?

☐ Yes ☐ No

- ☐ 8. Release the button on the directional control valve DCV2, then push down the button on the directional control valve DCV1 and maintain this position. With your other hand, push down the button on the directional control valve DCV2. Does the piston rod retract? Explain why.

- ☐ 9. Close the shutoff valves and turn the regulator adjusting knob completely counterclockwise.

- ☐ 10. Modify your circuit as shown in Figure 4-5.

Indirect Control Using Pilot-Operated Valves

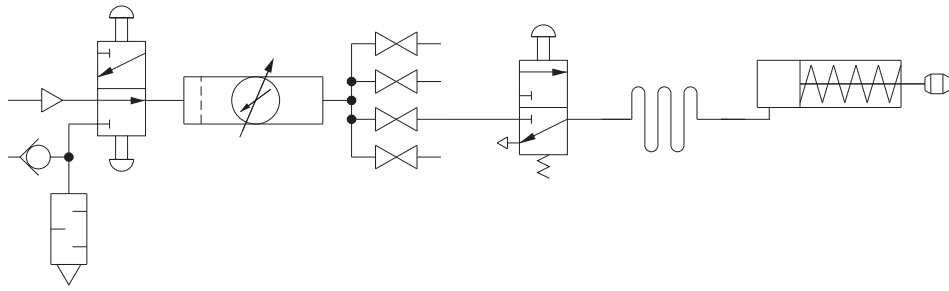


Figure 4-5. Schematic Diagram of a Circuit Using a Long Tubing Line.

- ☐ 11. Open the shutoff valves and set the pressure regulator at 100 kPa (or 15 psi) on the regulated Pressure Gauge.
- ☐ 12. Push down the button on the directional control valve while observing the time taken by the rod to extend fully. Estimate the time taken by the rod to extend fully and record your result in Table 4-1. Repeat your observation three times, then calculate the mean value.
- ☐ 13. Close the shutoff valves and turn the regulator adjusting knob completely counterclockwise.
- ☐ 14. Modify your circuit as shown in Figure 4-6.

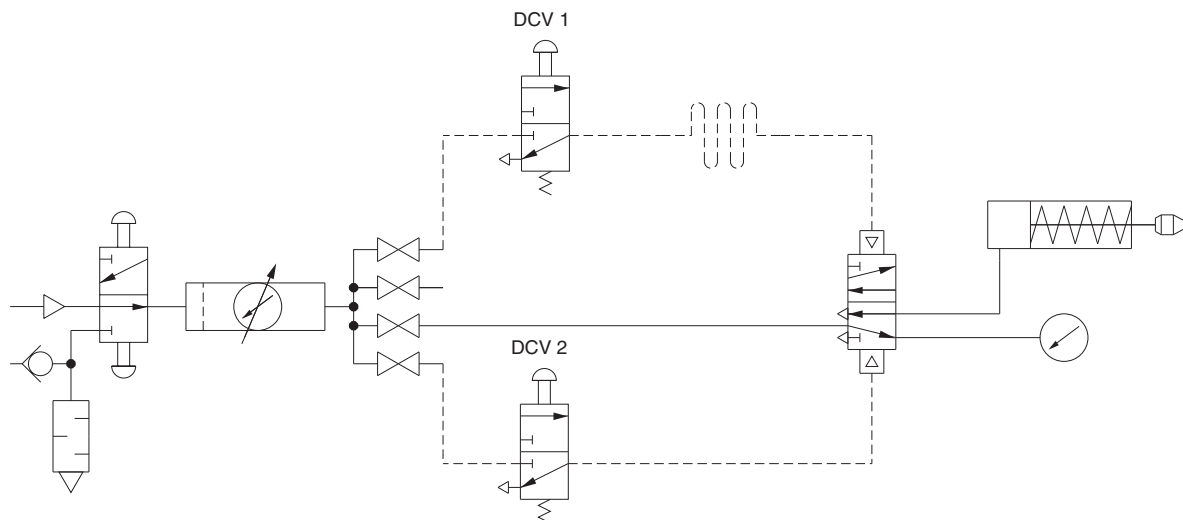


Figure 4-6. Schematic Diagram of an Indirect Control Circuit.

Indirect Control Using Pilot-Operated Valves

- ☐ 15. Open the main shutoff valve and set the pressure regulator at 100 kPa (or 15 psi) on the regulated Pressure Gauge.
- ☐ 16. Push down the button on the directional control valve DCV2 to set the spool in the pilot-operated valve as illustrated in Figure 4-6. The piston rod should be retracted.
- ☐ 17. Push down the button on the directional control valve DCV1 while observing the time taken by the rod to extend fully. Estimate the time taken by the rod to extend fully and record your result in Table 4-1. Repeat your observation three times, then calculate the mean value.

READING	EXTENSION TIME OF THE PISTON ROD	
	DIRECT CONTROL	INDIRECT CONTROL
First Reading		
Second Reading		
Third Reading		
Mean Value		

Table 4-1. Extension Time of The Piston Rod

- ☐ 18. Compare the results shown in Table 4-1. Does the rod extend faster when the valve is controlled indirectly?

☐ Yes ☐ No

- ☐ 19. Since the same Long Line was first used to power the cylinder and then to pilot the directional control valve, what can you conclude?

- ☐ 20. Does the piston rod retract when the button on the directional control valve DCV1 is released? Explain why.

Indirect Control Using Pilot-Operated Valves

- ☐ 21. On the Conditioning Unit, close the shutoff valves and turn the regulator adjusting knob completely counterclockwise. You should read 0 kPa (or 0 psi) on the regulated Pressure Gauge.
- ☐ 22. Disconnect and store all tubing and components.

CONCLUSION

In this exercise, you verified the operation of a 4-way, 5-port, 2-position pilot-operated directional control valve. You have seen that the piloted valve supplied with your trainer can be used to remotely control linear and rotary actuators in two directions.

You have seen that when a pilot port is maintained pressurized, priority is maintained on that position although the other port becomes pressurized.

You have seen that pilots require minimum pressures and volumes to shift against the working pressures, minimizing delays caused by compressibility of air and friction in long tubing lines.

REVIEW QUESTIONS

1. What is the greatest advantage of pilot-operated valves over manually operated valves?
 - a. They require a high pressure to operate.
 - b. They permit the remote actuation of large valves.
 - c. They can be made smaller than other valves.
 - d. They can be made larger than other valves.
2. What is the purpose of the 4-way piloted-operated valves?
 - a. To control linear actuators in one direction remotely.
 - b. To control rotary actuators in one direction remotely.
 - c. To control linear and rotary actuators in one direction remotely.
 - d. To control linear and rotary actuators in two directions remotely.
3. What is the main difference between pilot-operated and direct-operated control valves?
 - a. Pilot-operated control valves are smaller.
 - b. The way their spools are shifted.
 - c. Pilot-operated control valves can work in both directions.
 - d. Pilot-operated control valves cannot be spring return.

Indirect Control Using Pilot-Operated Valves

4. What is the purpose of the manual override on a pilot-operated valve?
 - a. To bleed off excess compressed air.
 - b. To reverse the direction of the valve.
 - c. To reverse pilot operation.
 - d. To manually duplicate the operation of the valve.

5. Give the reason why double pilot-operated valves can memorize a position?
 - a. They need a pilot signal to shift the spool.
 - b. They do not need a pilot signal to shift the spool.
 - c. It is a characteristic of pilot-operated valve.
 - d. Because they are remotely-controlled.

Sample Exercise
from
Electrical Control of
Pneumatic Systems

Exercise 3-1

Basic Memory and Priority Electropneumatic Circuits

EXERCISE OBJECTIVE

- To show how a directional valve can memorize a signal and maintain a position;
- To demonstrate how to lock and unlock electropneumatic circuits;
- To describe the function and operation of limit switches.

DISCUSSION

As seen in Exercise 4-1 in the *Pneumatics Fundamentals* manual, the lack of return springs, in double-air-piloted directional valves, allows to maintain or memorize the spool position without maintaining pilot pressure. However, when a pilot port is maintained pressurized, priority is maintained on that position although the other pilot port becomes pressurized. The circuit must exhaust one pilot before the other pilot can shift the spool.

In the circuit shown in Figure 3-1, directional valve DV2 acts as a memory control valve. Before operating the circuit, the spool position of DV2 is unknown, and it corresponds to the last position the valve was used. To maintain the cylinder retracted when starting the circuit, the spool must be positioned by a manual override or by a pilot signal.

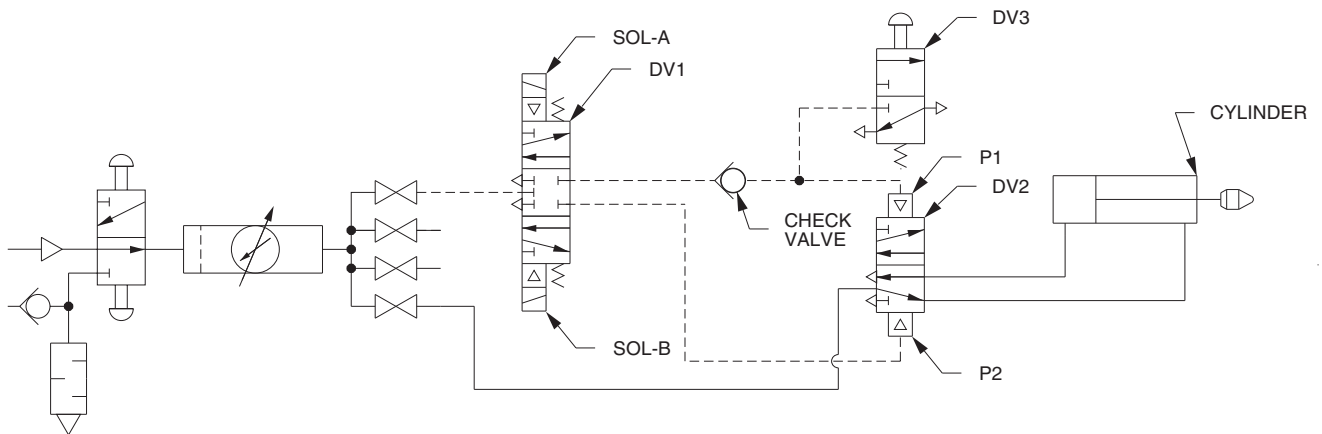


Figure 3-1. Memory and Priority Basic Circuit.

When solenoid SOL-A of directional valve DV1 is energized, the spool of the valve shifts and compressed air flows to pilot P1 of DV2. This causes the spool of DV2 to shift and the cylinder to extend. The lack of return springs causes DV2 to

Basic Memory and Priority Electropneumatic Circuits

memorize and maintain its position so the cylinder will continue to extend and will remain extended although SOL-A is de-energized.

When solenoid DV1-SOL-B is energized to retract the cylinder, compressed air flows to pilot P2 of DV2 but the spool of DV2 does not shift. It is blocked by compressed air which is trapped by the check valve in the pilot line of P1. Directional valve DV3 is then used to bleed the compressed air.

Since the retraction of the cylinder must be confirmed by a second command (DV3), this type of circuit is often used to prevent unwanted operations. The operation of this air-locked circuit is similar to the interlock circuit shown in Figure 2-19 in Exercise 2-3 where it is necessary to depress the STOP pushbutton, as a second command, before energizing the opposite solenoid.

Limit Switches

A command can also be confirmed using the electrical signal provided by sensing devices which detect the position of the cylinder rod. As an example, the retraction command of the cylinder rod shown in Figure 3-2, could not be executed by PB2 if the rod is not fully extended and its position confirmed by the limit switch LS2. When LS2 is mechanically activated by the presence of the rod, its NO contact goes closed, and it is therefore possible to energize CR2 using PB2. Energizing relay coil CR2 causes NC contact CR2-A to go open and relay coil CR1 to de-energize.

Limit switches are used extensively in industrial pneumatic equipment. They are reliable, small in size, simple to use, and generally cheaper than the other types of switches. A limit switch consists of an actuator and one or more sets of NO and NC contacts. It is activated when a moving part, such as a cylinder rod or machine member, strikes the actuating mechanism, shifting the contacts to their activated state.

Figure 3-3 shows the limit switch assembly supplied with your trainer. Each switch has a roller-type actuator and a set of SPDT contacts. When the cylinder tip travels across one of the switches, it pushes against the roller, depressing the lever arm. The lever arm acts on an internal plunger, causing the SPDT contacts to activate. The NO contact goes closed while the NC contact goes open. When the cylinder tip moves away from the roller actuator, a spring returns the lever arm and the contacts to their normal condition.

Basic Memory and Priority Electropneumatic Circuits

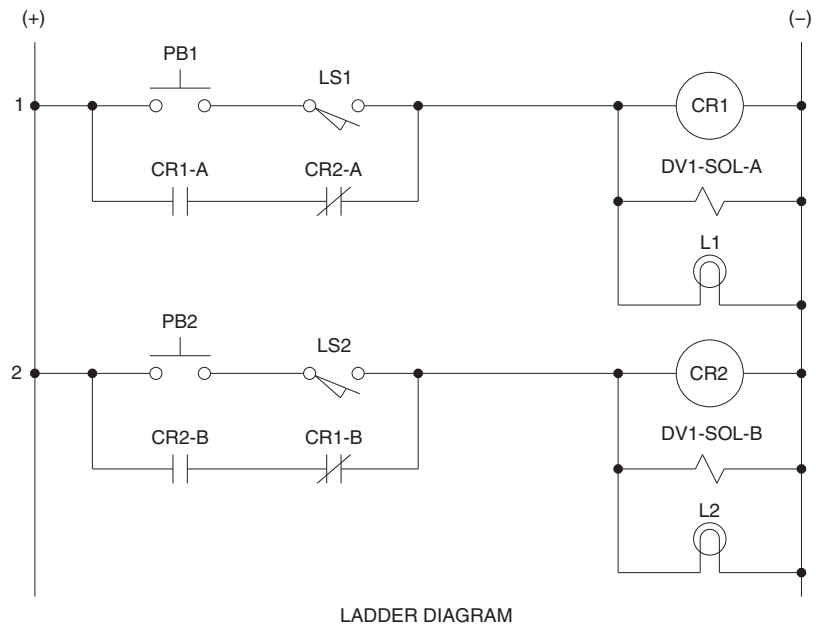
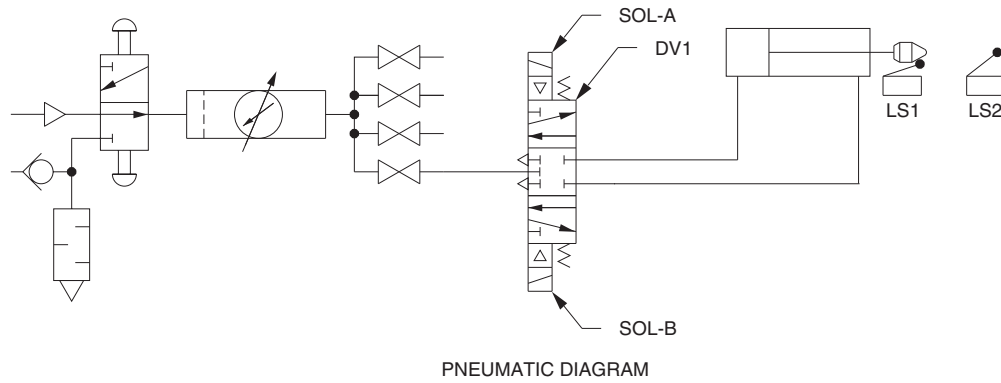


Figure 3-2. Electropneumatic Circuit Using Limit Switches.

Basic Memory and Priority Electropneumatic Circuits

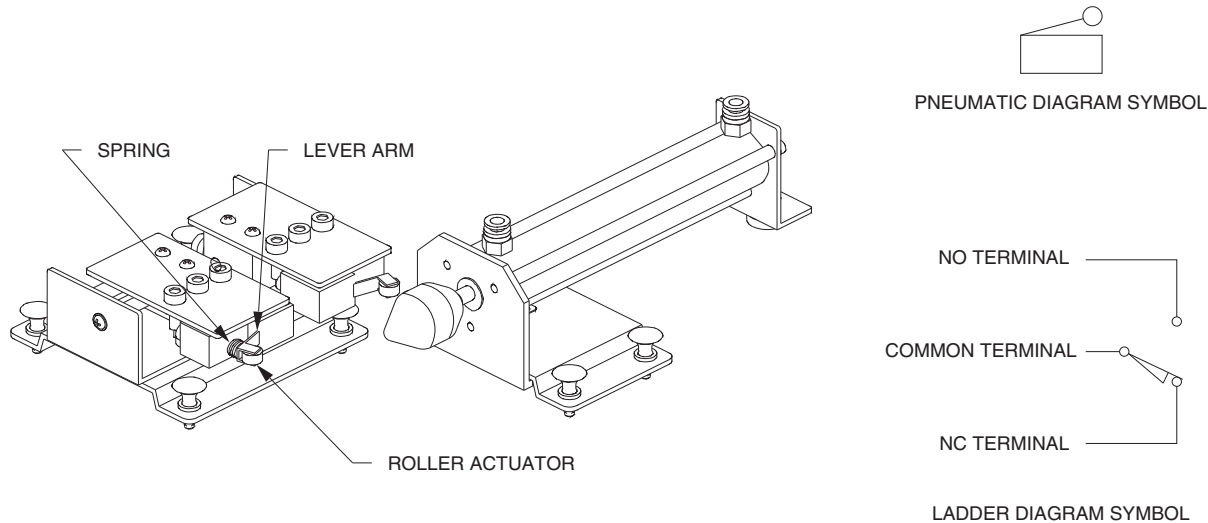


Figure 3-3. Limit Switch with Roller Arm Actuator.

Limit switches are often available as a multiple-switch assembly with two or more limit switches mounted on the same supporting frame. The two limit switches supplied with your trainer are mounted on the same supporting frame. This design is ideal for situations which require two switches mounted side by side.

REFERENCE MATERIAL

Procedure Summary

In the first part of the exercise, you will test the operation of a basic memory and priority circuit using a double-air-piloted directional valve.

In the second part, you will test a locking circuit, using compressed air trapped in a pilot line by a check valve, to maintain the pilot port pressurized and to maintain the position of the valve.

In the third part, you will learn how to mount the limit switches supplied with your trainer.

In the last part of the exercise, you will test a priority locking circuit using limit switches to confirm the position of the cylinder rod.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

Basic Memory and Priority Electropneumatic Circuits

PROCEDURE

Basic Memory and Priority Circuit

- ☐ 1. Connect the circuit shown in Figure 3-4. Screw a tip to the cylinder rod.

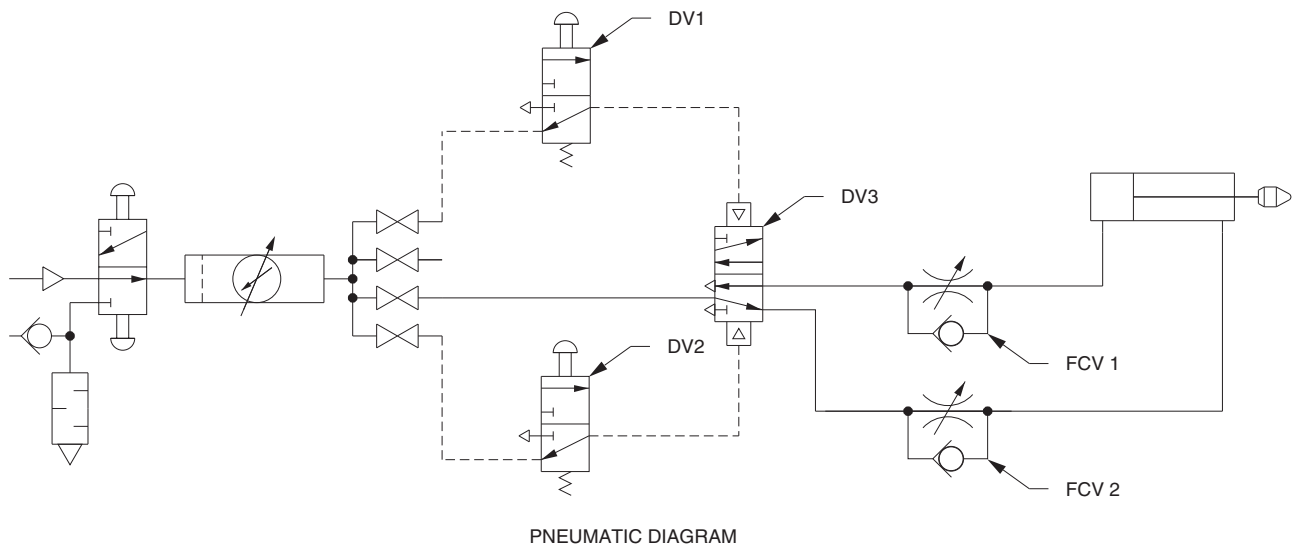


Figure 3-4. Schematic Diagram of a Memory Circuit.

- ☐ 2. Verify the status of the trainer according to the procedure given in Appendix F.
- ☐ 3. Close the flow control valves by turning the control knobs fully clockwise. Then open each valve by turning the knobs two turns counterclockwise. Refer to the mark on the knobs to help you set the correct position.

Note: The flow control valves are used to control the extension and retraction speeds of the cylinder.

- ☐ 4. Will the cylinder rod extend, or retract, when compressed air will be applied to the circuit? Explain.

Basic Memory and Priority Electropneumatic Circuits

- ☐ 5. On the conditioning unit, open the main shutoff valve and the branch shutoff valves at the manifold. Set the pressure regulator at 400 kPa (or 60 psi) on the regulated pressure gauge.
- ☐ 6. If necessary, depress the control button of directional valve DV2 to retract the cylinder rod.
- ☐ 7. Depress the control button of directional valve DV1. Does the cylinder rod extend?

- ☐ 8. Depress the control button of directional valve DV1 and hold this position. With your other hand, depress the control button of DV2. Does the cylinder rod retract? Explain why.

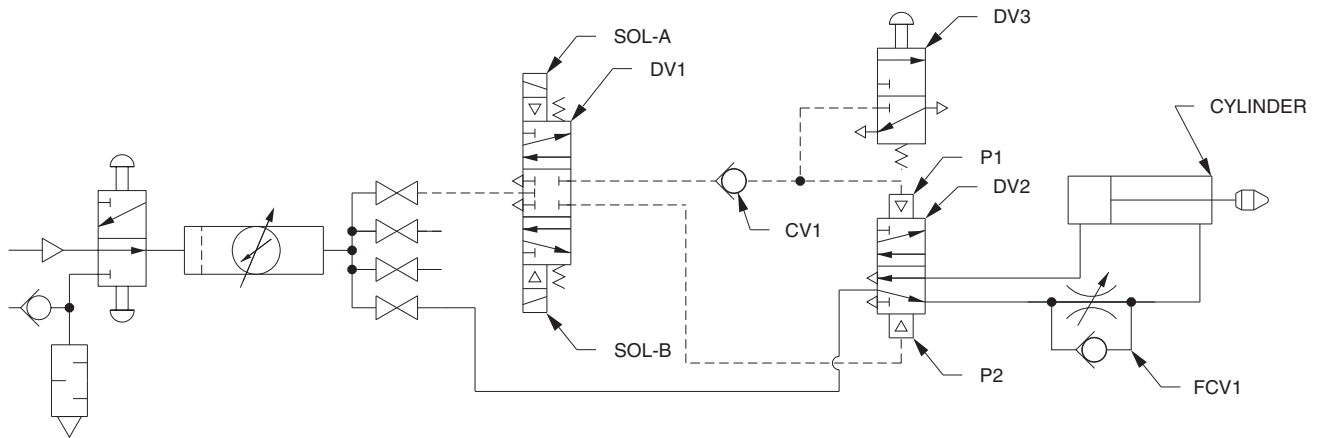
- ☐ 9. Does the operation of the circuit confirm that priority can be maintained on a position when the pilot port remains pressurized?

☐ Yes ☐ No
- ☐ 10. On the conditioning unit, close the shutoff valves, and turn the regulator adjusting knob completely counterclockwise.

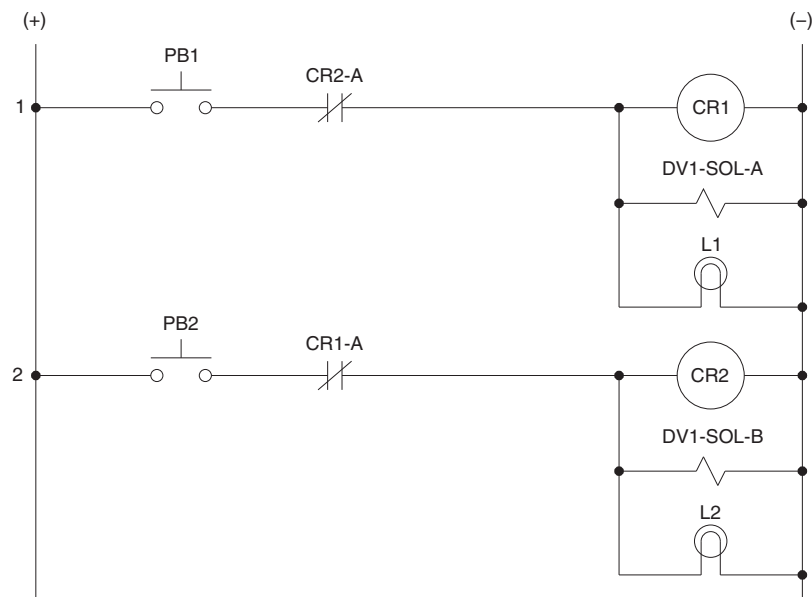
Priority Locking Circuit

- ☐ 11. Connect the priority locking circuit shown in Figure 3-5. Use a closed flow control valve (turn the control knob fully clockwise) as check valve in the pilot line of P1. Ensure that the cylinder rod is retracted. Screw a tip to the cylinder rod.

Basic Memory and Priority Electropneumatic Circuits



PNEUMATIC DIAGRAM



LADDER DIAGRAM

Figure 3-5. Schematic Diagram of a Priority Locking Circuit.

- ☐ 12. Close flow control valve FCV1 by turning the control knob fully clockwise. Then open the valve two turns counterclockwise.
- ☐ 13. On the conditioning unit, open the shutoff valves, and set the pressure at 400 kPa (or 60 psi).

Basic Memory and Priority Electropneumatic Circuits

- ☐ 14. Turn on the DC power supply.
- ☐ 15. If the cylinder rod extends when applying pressure in the circuit, depress simultaneously PB2 and the control button of directional valve DV3 to retract the cylinder rod.
- ☐ 16. Depress pushbutton PB1. Does the cylinder rod extend?

☐ Yes ☐ No
- ☐ 17. Depress pushbutton PB2. Does the cylinder rod retract? If not, explain.

- ☐ 18. Depress simultaneously pushbutton PB2 and the control button of directional valve DV3. Does the cylinder rod retract?

☐ Yes ☐ No
- ☐ 19. Does the operation of the circuit confirm that priority is maintained on a position when the pilot port remains pressurized?

☐ Yes ☐ No
- ☐ 20. Explain how the circuit will operate if the check valve is removed from the circuit.

- ☐ 21. On the conditioning unit, close the shutoff valves, and turn the regulator adjusting knob completely counterclockwise.
- ☐ 22. Turn off the DC power supply.

Basic Memory and Priority Electropneumatic Circuits

Mounting of the Limit Switch Assembly

- ☐ 23. Remove all components except the double-acting cylinder from your work surface.

- ☐ 24. Mount the limit switch assembly as indicated in the following steps:
 - Screw the cylinder tip onto the rod end of the cylinder.
 - Manually extend the cylinder rod completely.
 - Clamp the limit switch assembly along the cylinder rod as shown in Figure 3-6.
 - Loosen the limit switch positioning screws. Position the switches side by side at the center of the support bracket, as shown in Figure 3-6 (a). Tighten the limit-switch positioning screws.
 - Loosen the support-bracket positioning screws until you are able to slide the bracket over the mounting base as shown in Figure 3-6 (b). Adjust the position of the bracket so that the switches are activated when the cylinder tip pushes against the switch arm and deactivated when the cylinder tip releases the switch arm. To test this out, manually extend and retract the cylinder rod, and listen for the "click". Then, tighten the support-bracket positioning screws on the mounting base.
 - Loosen the positioning screw on each limit switch. Adjust the positioning of the switches so that they are activated when the cylinder rod is fully extended and fully retracted, as shown in Figure 3-6 (c). To test this out, manually extend and retract the cylinder rod, and listen for the click. Then, tighten the limit-switch positioning screws.
 - Retract the cylinder rod completely, as shown in Figure 3-6 (d).

- ☐ 25. Your limit switch assembly is now set to detect the fully-extended and fully-retracted positions of the cylinder rod.

Basic Memory and Priority Electropneumatic Circuits

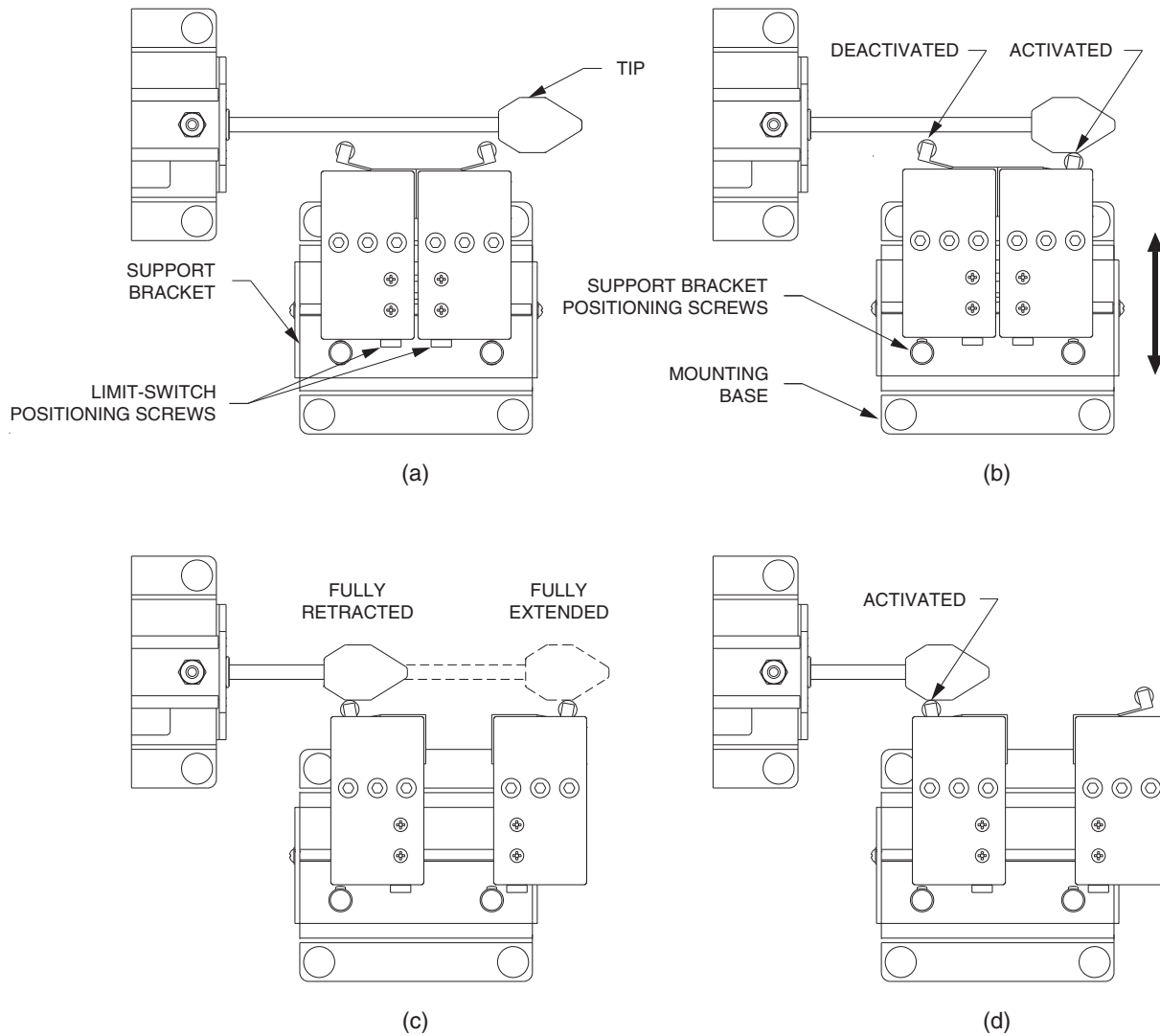


Figure 3-6. Mounting of the Limit Switch Assembly.

Priority Locking Circuit Using Limit Switches

- 26. Connect the circuit shown in Figure 3-7. As you do this, be careful not to modify the mounting of the limit switches LS1 and LS2.

Basic Memory and Priority Electropneumatic Circuits

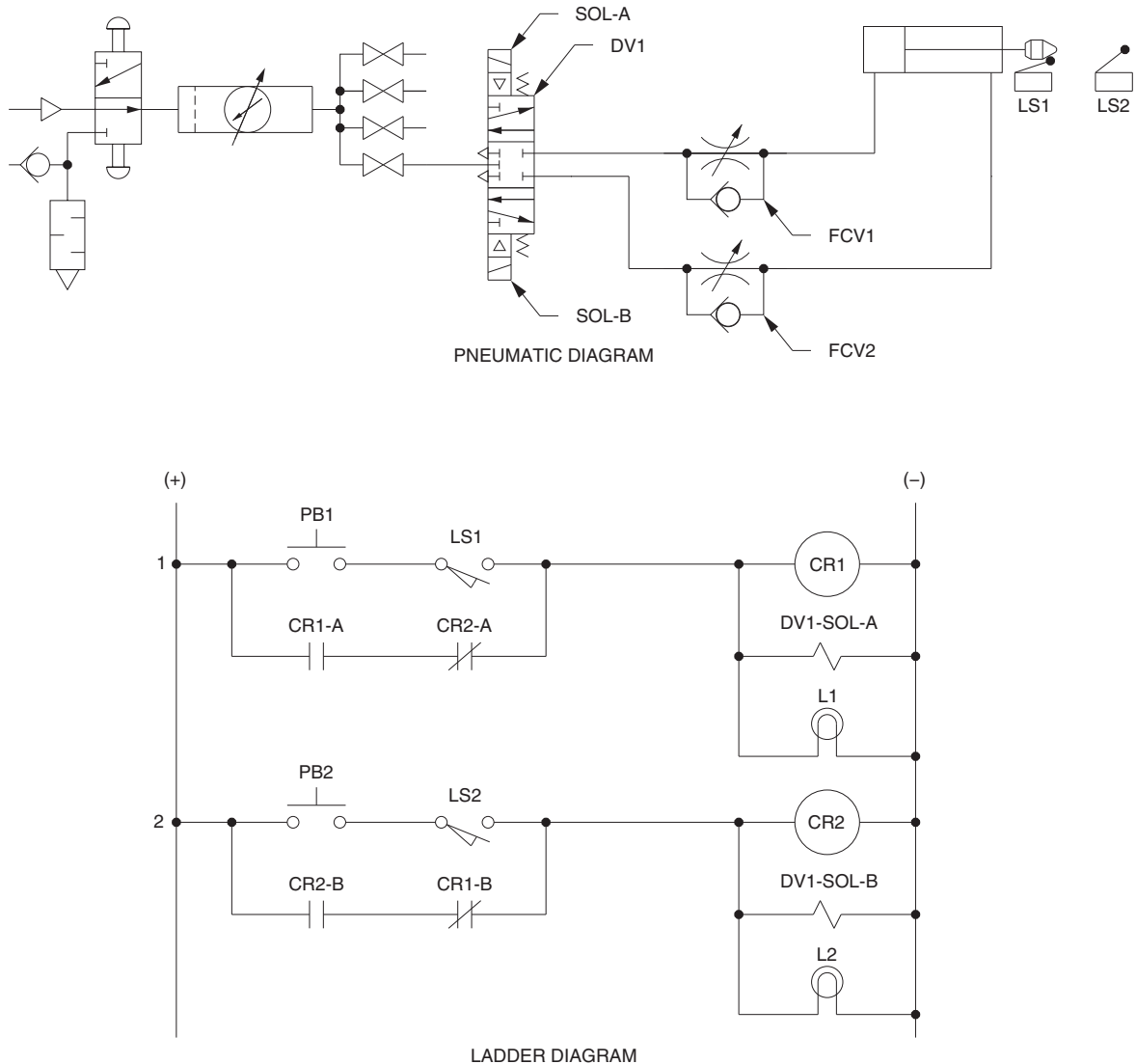


Figure 3-7. Schematic Diagram of a Priority Locking Circuit Using Limit Switches.

- ☐ 27. Close the flow control valves by turning the control knobs fully clockwise. Then open each valve by turning the knobs two turns counterclockwise. Refer to the mark on the knobs to help you set the correct position.
- ☐ 28. On the conditioning unit, open the main shutoff valve and the branch shutoff valves at the manifold. Set the pressure regulator at 400 kPa (or 60 psi) on the regulated pressure gauge.
- ☐ 29. Turn on the DC power supply.

Basic Memory and Priority Electropneumatic Circuits

- ☐ 30. Depress pushbutton PB1. Does the cylinder rod extend?

☐ Yes ☐ No

- ☐ 31. Depress pushbutton PB2. Does the cylinder rod retract?

☐ Yes ☐ No

- ☐ 32. Loosen the positioning screw of the limit switch which detects the position fully extended and pull up the limit switch.

- ☐ 33. Depress pushbutton PB1 to extend the cylinder rod, then depress pushbutton PB2. Does the cylinder rod retract? If not, explain by referring to the ladder diagram.

- ☐ 34. Does the operation of the circuit confirm that the limit switch must confirm the position of the cylinder rod to allow the spool of directional valve DV1 to be shifted?

☐ Yes ☐ No

- ☐ 35. On the conditioning unit, close the shutoff valves, and turn the regulator adjusting knob completely counterclockwise.

- ☐ 36. Turn off the DC power supply.

- ☐ 37. Disconnect and store all leads and components.

CONCLUSION

In this exercise, you learned how priority can be determined and maintained in a pneumatic circuit, using a double-air-piloted directional valve.

You tested a locking circuit using compressed air trapped in a pilot line. You saw that the circuit must exhaust one pilot before the other pilot can shift the spool. You saw that the circuit remains locked even though compressed air supply falls.

Basic Memory and Priority Electropneumatic Circuits

You learned how to mount the limit switch assembly supplied with your trainer.

You tested an interlock circuit which needs a confirmation command, supplied by a limit switch, to allow a new sequence to be started.

REVIEW QUESTIONS

1. What is the purpose of directional valve DV3 in Figure 3-5?

2. What care should be take before shifting the spool of a double-air-piloted directional valve?

3. What is the purpose of a limit switch in an electropneumatic circuit?

4. What characteristic of a double-air-piloted directional valve allows to maintain or memorize the spool position without maintaining pilot pressure?

5. What are the purposes of contacts CR1-A and CR2-A in the ladder diagram of Figure 3-7?

Sample Exercise
from
Pneumatics Applications – PLC

Counting of Pneumatic Actuator Cycles

EXERCISE OBJECTIVE

- To connect and test a PLC-controlled pneumatic system that makes a motor rotate 200 turns and then reciprocates a cylinder 5 times.

DISCUSSION

Counting of pneumatic actuator cycles is required when a portion of a system must be activated or deactivated after an actuator has completed a definite number of cycles. A typical application is an automated packing machine that stacks and counts production items into groups. The usual method is for a cylinder to continuously extend and retract, picking and stacking one item on each cycle, and for a counter to count the number of cycles which have been completed by the cylinder. When the required count is reached, a switching signal causes another cylinder to push the stack away.

Counting of pneumatic actuator cycles is also required for machine maintenance scheduling. The PLC keeps track of the number of items the machine manufactures to determine when a part should be replaced.

The PLC counter instructions are ideally suited for counting the number of cycles completed by an actuator. They allow monitoring of automatic production machines at high efficiency rates.

Procedure Summary

In this exercise, you will connect a PLC-controlled pneumatic system that makes a motor rotate 200 turns and then reciprocates a cylinder 5 times.

EQUIPMENT REQUIRED

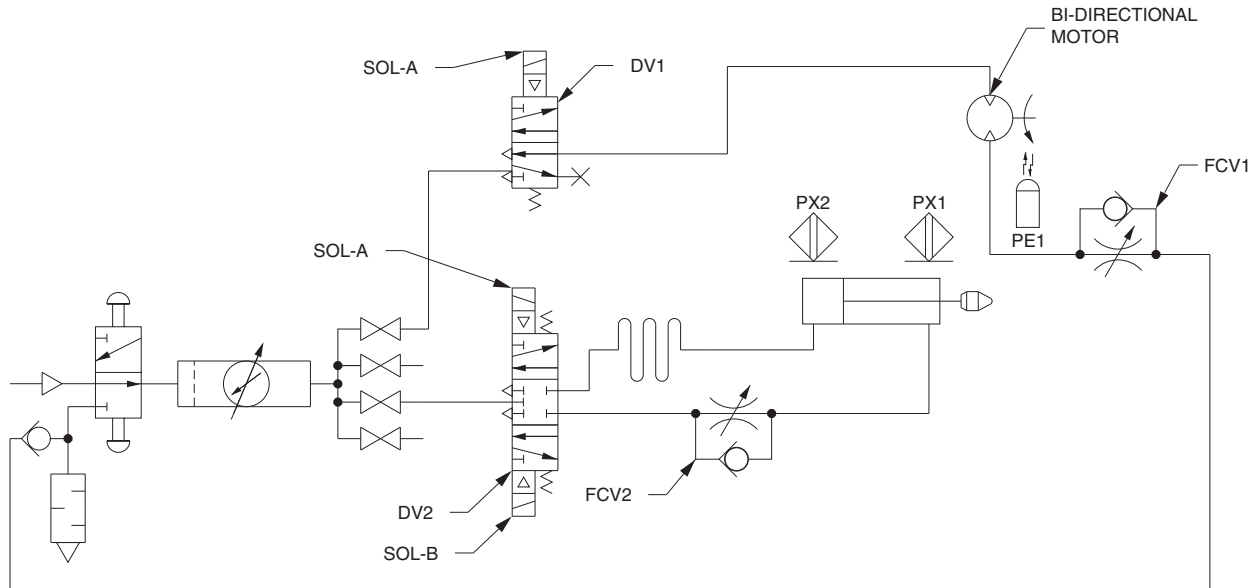
Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

Counting of Pneumatic Actuator Cycles

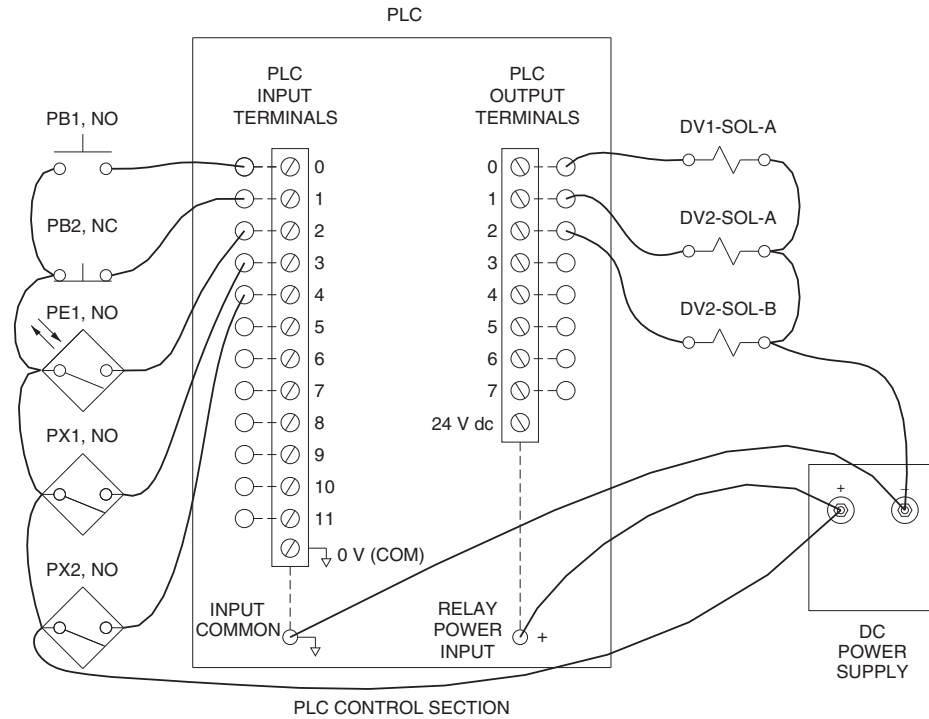
PROCEDURE

- ☐ 1. Connect the PLC-controlled pneumatic system shown in Figure 6-1. Note that the long line device is used to decrease the retraction speed of the cylinder rod.

Counting of Pneumatic Actuator Cycles



PNEUMATIC DIAGRAM



PLC CONTROL SECTION

Figure 6-1. PLC-controlled pneumatic system.

Counting of Pneumatic Actuator Cycles

- ☐ 2. Position the pneumatic motor so that it is perpendicular to the photoelectric switch at a distance of 10 cm (4 in) between the switch and the motor axis (2 rows of perforations). The photoelectric switch beam must be pointing in the direction of the white sticker on the motor shaft.
- ☐ 3. Mount magnetic proximity switches PX1 and PX2 so that they are activated when the cylinder rod is fully extended and fully retracted, as shown in Figure 6-1.
- ☐ 4. Enter the PLC ladder program shown in Figure 6-2, using the instruction address format appropriate to your model of PLC.
- ☐ 5. Download your program to the PLC. Place the PLC in Run mode.
- ☐ 6. Verify the status of the trainer according to the procedure given in Appendix F.
- ☐ 7. Open flow control valve FCV1 by turning the control knob fully counterclockwise. Close flow control valve FCV2 by turning the control knob fully clockwise. Then open the valve by turning the knob two turns counterclockwise.
- ☐ 8. On the conditioning unit, open the main shutoff valve and the branch shutoff valves at the manifold. Set the pressure regulator at 400 kPa (or 60 psi) on the regulated pressure gauge.
- ☐ 9. Turn on the DC power supply.

Counting of Pneumatic Actuator Cycles

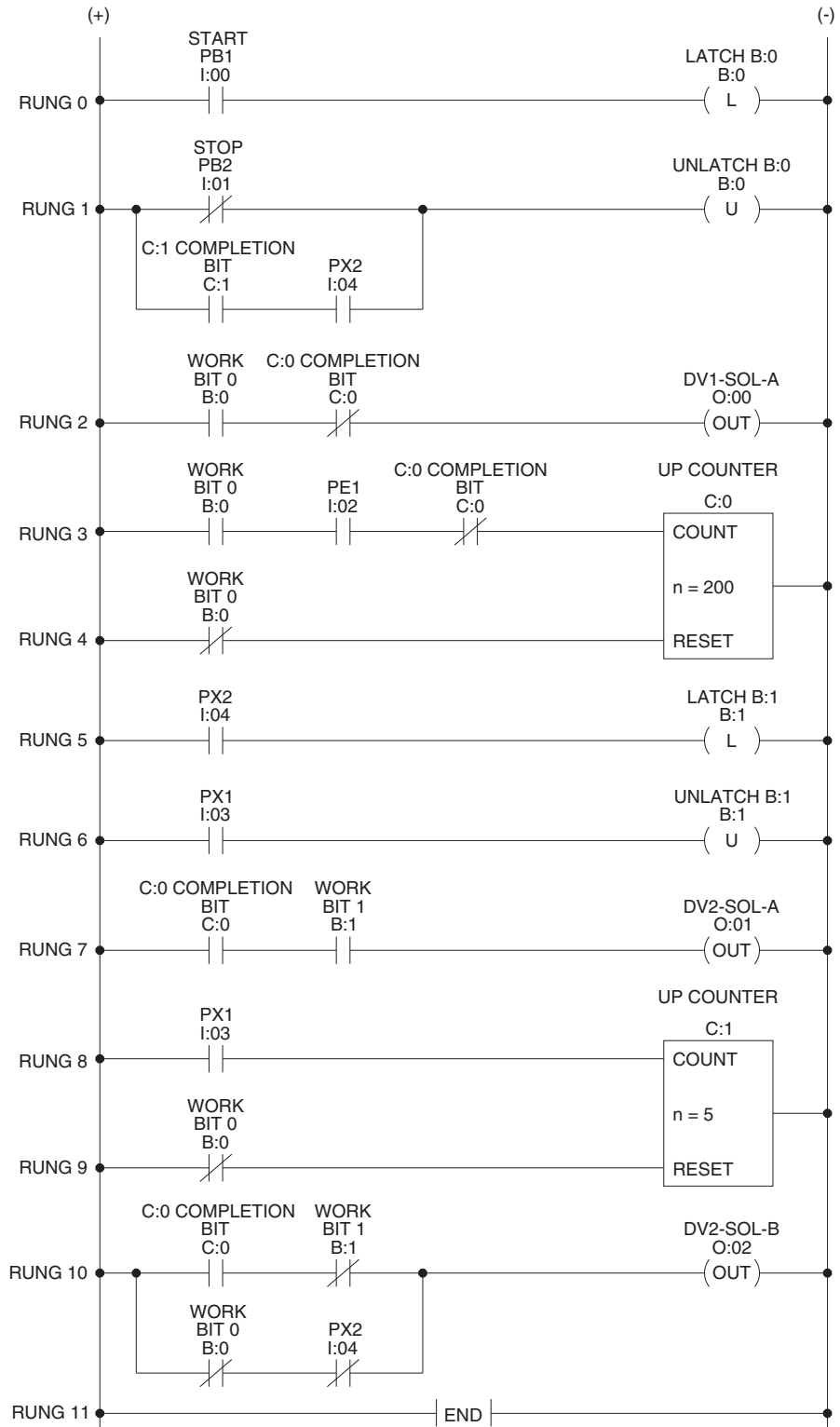


Figure 6-2. PLC ladder program.

Counting of Pneumatic Actuator Cycles

- ☐ 10. Test the operation of the system, using the following verification steps:

- Momentarily depress the START pushbutton PB1. The motor should start rotating, while the cylinder rod should remain immobile;

Note: *If the LED on the photoelectric switch seems to skip, reduce the rotation speed of the motor by decreasing the air flow with FCV1.*

- Monitor PLC counter instruction C:0 in ladder rung 3. When the counter accumulated value reaches 200, the motor should stop, while the cylinder rod should start to reciprocate (extend and retract);
- When the cylinder rod has reciprocated 5 times, it should stop in the fully retracted position, allowing a new cycle to be initiated.

If the operation of the system is not as indicated, check the circuit connections and the PLC program. Perform the required modifications, then verify that the system operates correctly.

- ☐ 11. Cycle the system a few times and monitor the PLC program as it is executed. What causes the motor to start rotating when PB1 is depressed? Explain by referring to the PLC ladder program shown in Figure 6-2.

- ☐ 12. What causes counter instruction C:0 in rung 3 to increment its accumulated value when the motor rotates? Explain.

Counting of Pneumatic Actuator Cycles

- ☐ 13. What causes the motor to stop and the cylinder rod to start reciprocating when the accumulated value of counter instruction C:0 reaches 200? Explain.

- ☐ 14. What causes counter instruction C:1 in rung 8 to increment its accumulated value every time the cylinder rod becomes fully extended?

- ☐ 15. What causes the cylinder rod to stop in the fully retracted position after it has reciprocated 5 times? Explain.

- ☐ 16. Start the system by depressing PB1, then depress PB2 while the motor is rotating. Does the motor stop immediately when PB2 is depressed? Why?

Counting of Pneumatic Actuator Cycles

- ☐ 17. Start the system by depressing PB1, then depress PB2 while the cylinder rod is extending and in mid-stroke. Does the cylinder rod return to the fully retracted position before it stops? Why?

- ☐ 18. Use Figure 6-3 to draw the timing diagram of the system.



Figure 6-3. Timing diagram.

- ☐ 19. Modify your PLC program so that the system will operate as follows:
- Depressing the START pushbutton causes the cylinder rod to start reciprocating, while the motor remains stopped.
 - When the rod has reciprocated 5 times, it stops, while the motor starts to rotate.
 - When the motor has rotated 200 turns, it stops and the system becomes ready for a new cycle.

Counting of Pneumatic Actuator Cycles

Use Figure 6-4 to draw the modified PLC program. Enter your program and test system operation.

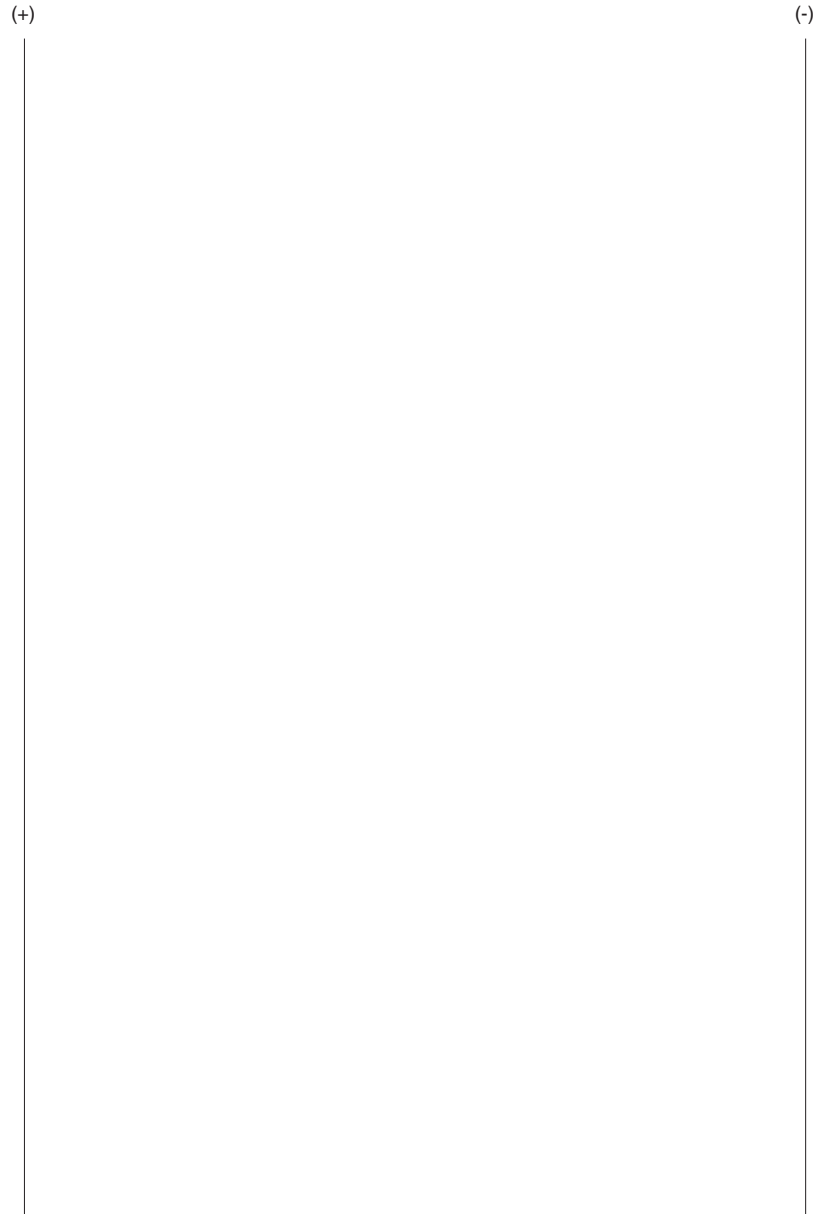


Figure 6-4. New modified program.

- ☐ 20. Turn off the PLC, the DC power supply and the host computer, if any.
- ☐ 21. On the conditioning unit, close the shutoff valves, and turn the regulator adjusting knob completely counterclockwise.

Counting of Pneumatic Actuator Cycles

- ☐ 22. Disconnect and store all leads and components.

CONCLUSION

In this exercise, you connected a PLC-controlled pneumatic system that makes a motor rotate 200 turns and then reciprocates a cylinder 5 times.

You saw that the PLC counter instruction is incremented by false-to-true rung transitions of the counter rung. These rung transitions are caused by events occurring in the system, such as a cylinder piston traveling past a magnetic proximity switch or a motor flywheel activating a photoelectric switch. After a definite number of events have occurred, the counter completion bit turns on, which activates or deactivates a directional valve solenoid.

REVIEW QUESTIONS

1. When is counting of pneumatic actuator cycles required?

2. Describe a typical pneumatic application where counting of actuator cycles is required.

3. How can the PLC counter instruction be used to activate a directional valve solenoid after a cylinder has reciprocated a definite number of times?

Counting of Pneumatic Actuator Cycles

4. In the PLC ladder program of Figure 6-2, what purpose is served by NC contact instruction C:0 in rung 3?

5. In the PLC ladder program of Figure 6-2, what purpose is served by NC contact instruction B:0 in rung 4?

Sample Exercise
from
Servo/Proportional Control
of Pneumatic Systems

Closed-Loop Position Control, Proportional-Plus-Integral Mode

EXERCISE OBJECTIVE

- To describe the integral control mode;
- To define the terms integral gain and overshoot;
- To describe the advantages and disadvantages of integral control;
- To describe the proportional-plus-integral control mode.

DISCUSSION

The Integral (I) Control mode

While the proportional control mode looks at the "present" value of the process error, the integral (I) control mode regards the "past history" of the error by continuously integrating it until it is eliminated. Thus, the integral control mode automatically reduces the residual error to zero for any load change within the limitations of the system design, thereby eliminating the need for manual reset associated with the proportional control mode.

Figure 5-1 shows the simplified diagram of a controller operating in the integral mode:

- The "error detector" compares the measured position to the setpoint and produces an error signal equal to the difference between the two;
- The "integral amplifier", integrates the error to produce the controller output signal.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

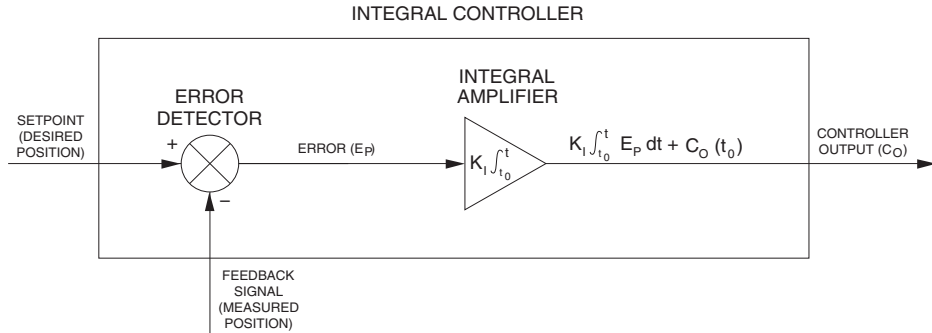


Figure 5-1. Simplified diagram of a controller operating in the integral (I) mode.

The output of the controller at any specified point in time, is given by:

$$C_O(t) = K_I \int_{t_0}^t E_p dt + C_O(t_0)$$

where $C_O(t)$ is the controller output at a specified time;

K_I is the integral gain;

E_p is the error at a specified time;

$C_O(t_0)$ is the controller output at the time the observation starts ($t = 0$).

The controller output signal is at all times proportional to the time integral of the error, hence the name integral mode.

Figure 5-2 shows an example of what happens to the signal at the output of an integral controller when the error is positive, negative, and null. The controller is in the open-loop mode. As you can see, when the error is positive, the controller output increases. When the error is negative, the controller output decreases. When the error is null, the controller output remains at the same level.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

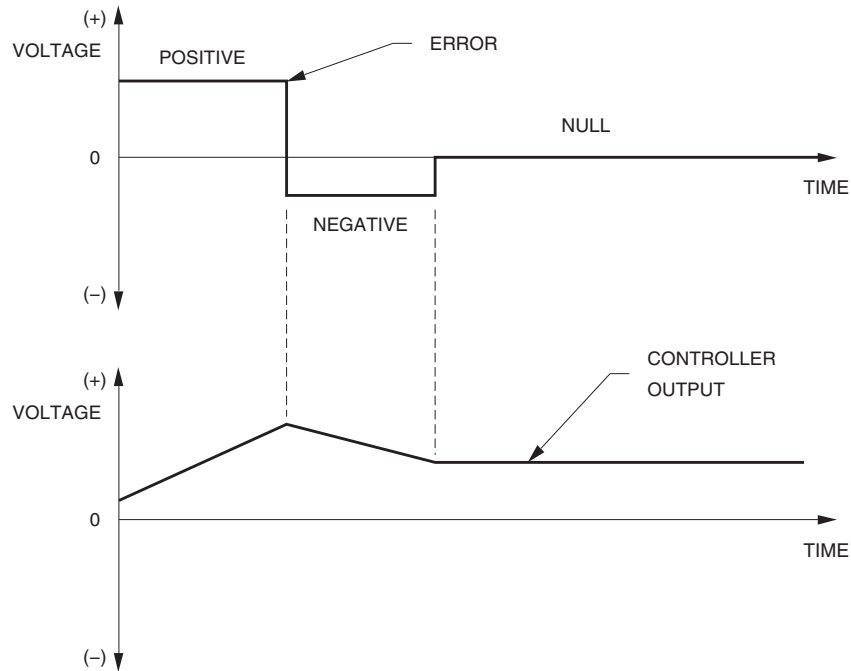


Figure 5-2. Controller output signals with positive, negative and null errors.

Integral gain

Figure 5-3 shows the output signal of an integral controller for different integral gain settings when the error changes suddenly. The controller is in the open-loop mode. The integral action causes the error signal to be transformed into a gradually changing signal at the controller output. The greater the integral gain K_i , the greater the rate of change of the controller output.

The integral gain is expressed in number of repeats per minute (rpt/min). It corresponds to the number of times the magnitude of the error is duplicated at the controller output in a period of 1 minute:

- With a gain of 5 rpt/min, the 1.0-V error magnitude is duplicated 5 times in 1 min. This means the controller output will be 5.0 V after 1 min (see Figure 5-3);
- With a gain of 10 rpt/min, the 1.0-V error magnitude is duplicated 10 times in 1 min. This means the controller output will be 10.0 V after 1 min.
- With a gain of 50 rpt/min, the 1.0-V error magnitude is duplicated 50 times in 1 min. This means the controller output will be 10.0 V after 0.2 min.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

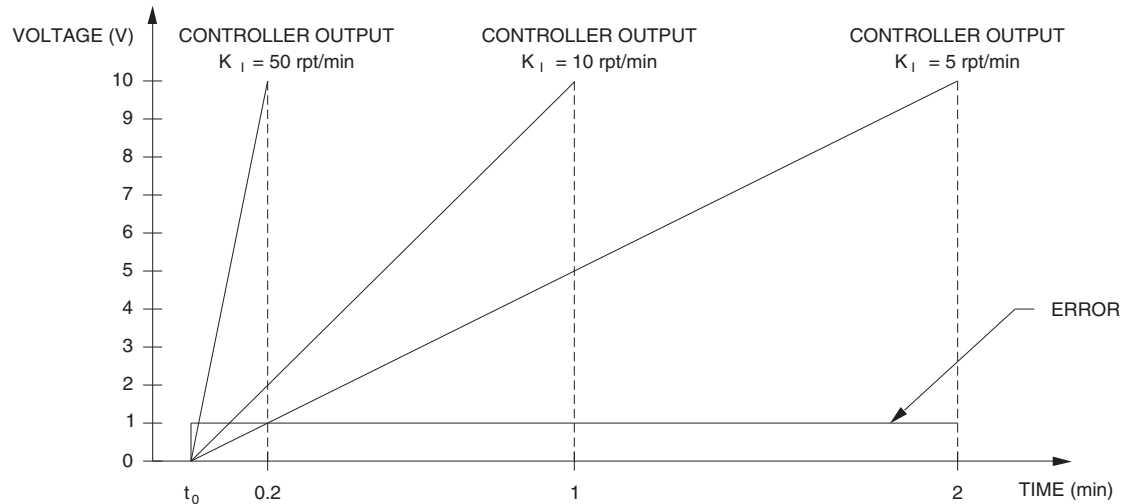


Figure 5-3. Output signal of an integral controller in the open-loop mode when the error changes suddenly.

Now suppose the integral controller is placed in the "closed-loop mode" in order to control a process. Figure 5-4 shows the effect of increasing the integral gain on the response of the controlled variable to a sudden change in setpoint. The higher the integral gain is, the shorter the time required to eliminate the error will be.

- With a low integral gain as in waveform (a), the controlled variable is brought back to the new setpoint relatively slowly but with no overshoots. The system response is said to be "damped". A damped response may be desirable in some applications.
- Increasing the integral gain as in waveforms (b) reduces the time required to eliminate the error, but may also cause the controlled variable to overshoot the new setpoint before it stabilizes. However, small overshoots are usually tolerated in most applications.
- Further increasing the integral gain results in higher overshoots, as in waveform (c). Worse still, the time required to eliminate the error, instead of decreasing, actually gets longer because the controlled variable performs a number of oscillations about the setpoint before it stabilizes.
- At very high integral gains, the system may even start to oscillate without being able to return to equilibrium, as in waveform (d).

Closed-Loop Position Control, Proportional-Plus-Integral Mode

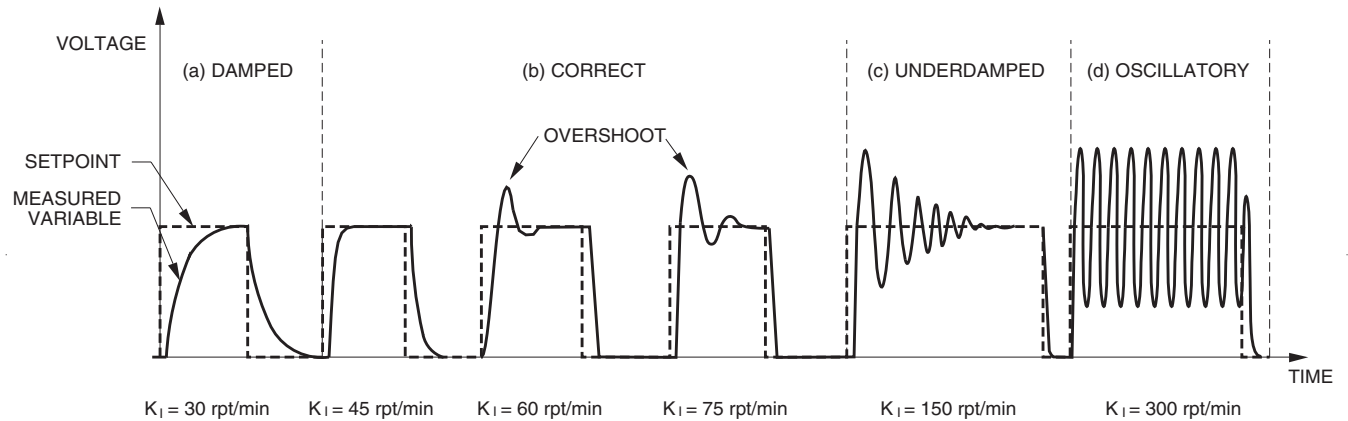


Figure 5-4. Effect of increasing the integral gain on the step response of a controlled variable.

The ability to reestablish a zero error is a unique characteristic of the integral control mode and is found in no other mode. However, the integral mode is normally not used alone, because of its relatively slow response at low integral gains, and because of the overshoots and increased risks of oscillation at higher integral gains. Instead, the integral mode is combined with the proportional mode to form the “proportional-plus-integral” control mode.

Proportional-Plus-Integral (P.I.) Control mode

The proportional-plus-integral control mode combines the fast transient response of proportional control with the zero residual error characteristic of integral control. It looks at the current value of the error and the integral of the error over a recent time interval to determine how much of a correction to apply, and also for how long.

Figure 5-5 shows the simplified diagram of a controller operating in the proportional-plus-integral mode. The error produced by the error detector is first amplified by a factor K_P by the proportional amplifier. The proportionally amplified error ($E_P \cdot K_P$) is then time integrated by the integral amplifier. Finally, the output signals of the proportional and integral amplifiers are added at a summing point to produce the controller output signal.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

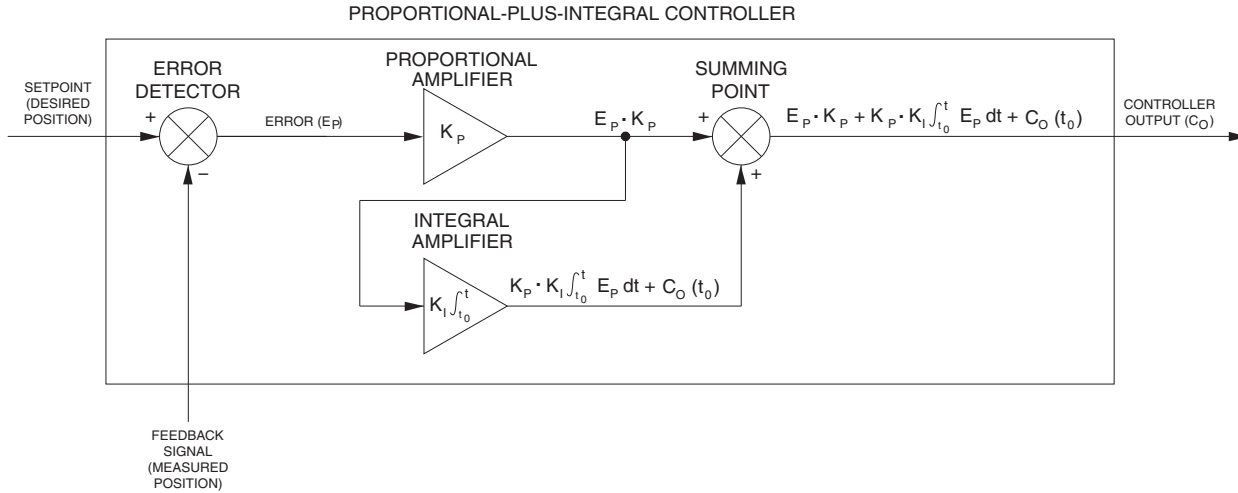


Figure 5-5. Simplified diagram of a controller operating in the proportional-plus-integral (P.I.) mode.

The controller output at any specified time, t , is given by:

$$C_O(t) = E_P \times K_P + K_P \times K_I \int_{t_0}^t E_P dt + C_O(t_0)$$

where $C_O(t)$ is the controller output at a specified time;

E_P is the error at a specified time;

K_P is the proportional gain;

K_I is the integral gain;

$C_O(t_0)$ is the controller output at the time the observation starts ($t = 0$).

In this equation, the term " $E_P \times K_P$ " describes the proportional action of the controller, while the rest of the equation describes the integral action of the controller, starting at time $t = 0$. Thus, the controller output is not only proportional to the error, but also to the time integral of the error.

Figure 5-6 shows what happens in a proportional-plus-integral control system when the error changes suddenly, due to a sudden increase in setpoint or actuator load. The proportional action quickly responds to the sudden change in error, while the integral action integrates the error until it becomes null. The higher the integral and proportional gains are, the faster the error will be eliminated. However, these gains must be kept low enough to prevent excessive overshoots, and to ensure system stability.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

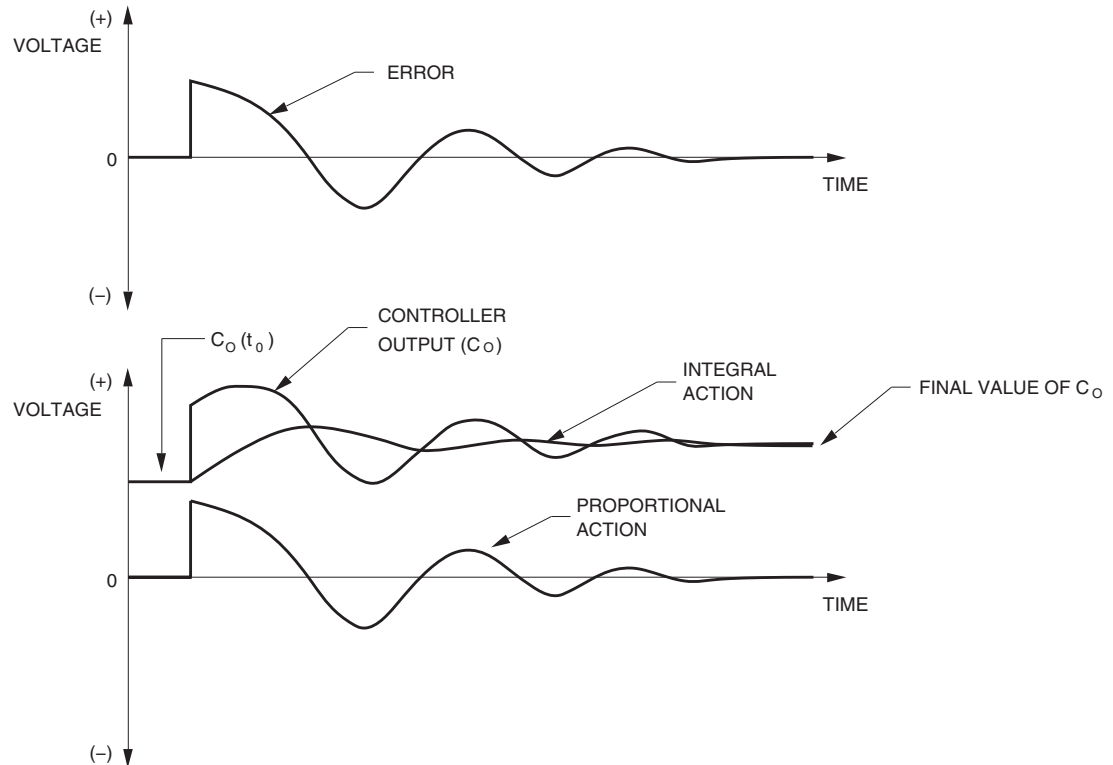


Figure 5-6. Example of what happens in a proportional-plus-integral control system when the error changes suddenly.

A problem related to the use of integral control is the "reset windup". Reset windup occurs when the error remains large during a long interval of time, causing the controller output to increase to the upper saturation limit (positive error) or decrease to the lower saturation limit (negative error). Afterwards, the controller cannot return to normal operation until the error reverses polarity, resulting in high overshoots of the controlled variable. For that reason, controllers usually have an "anti-reset" function that turns off the integral action as soon as the controller output reaches the upper or lower saturation limit, thus minimizing overshoots of the actuator position.

Comparison of the Proportional, Integral, and Proportional-Plus-Integral Control Modes

Figure 5-7 shows an example of the response of a typical process to a step change in setpoint with proportional, integral, and proportional-plus-integral control modes :

- The proportional mode reacts much faster than the integral mode. However, the proportional mode results in a residual error between the actual rod position and the new setpoint;

Closed-Loop Position Control, Proportional-Plus-Integral Mode

- The integral mode eliminates the residual error, but it reacts slower than the proportional mode, and it requires a longer time to reach the final value;
- The proportional-plus-integral mode reacts much faster than the integral mode, and it eliminates the residual error of the proportional mode. However, the addition of integral action to proportional action increases the overshoot and stabilization time.

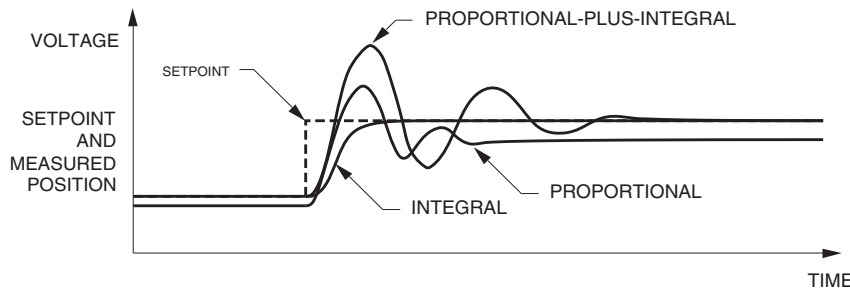


Figure 5-7. Response to a step change in setpoint with proportional, integral, and proportional-plus-integral control modes.

Procedure summary

In the first part of the exercise, *Familiarization with the Proportional-Plus-Integral (P.I.) Controller*, you will familiarize yourself with the components and operation of a proportional-plus-integral controller.

In the second part of the exercise, *Proportional-Plus-Integral (P.I.) Control of Cylinder Rod Position*, you will study proportional-plus-integral control of cylinder rod position. You will observe the effect of increasing the integral and proportional gains on the response of the rod position (feedback voltage) when the setpoint changes suddenly.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of the manual, to obtain the list of equipment required to perform this exercise.

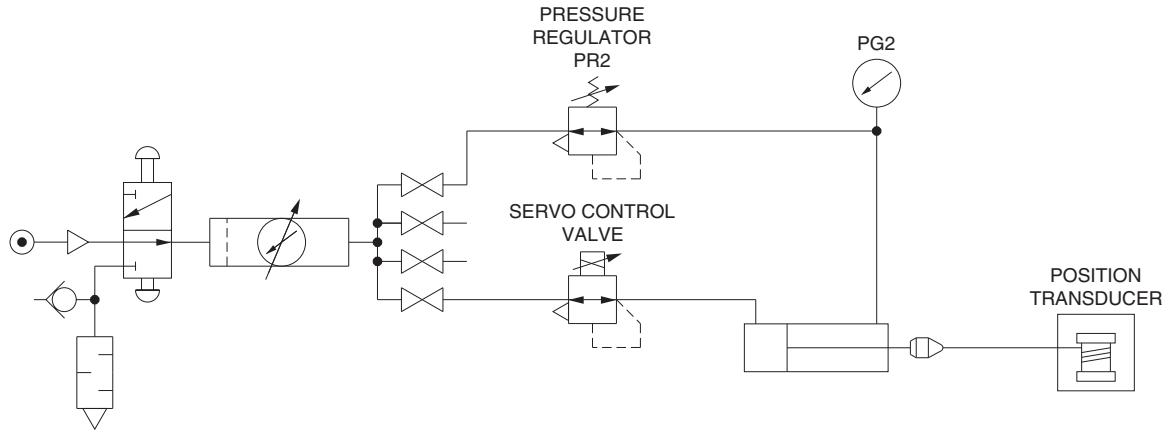
PROCEDURE

Familiarization with the Proportional-Plus-Integral (P.I.) Controller

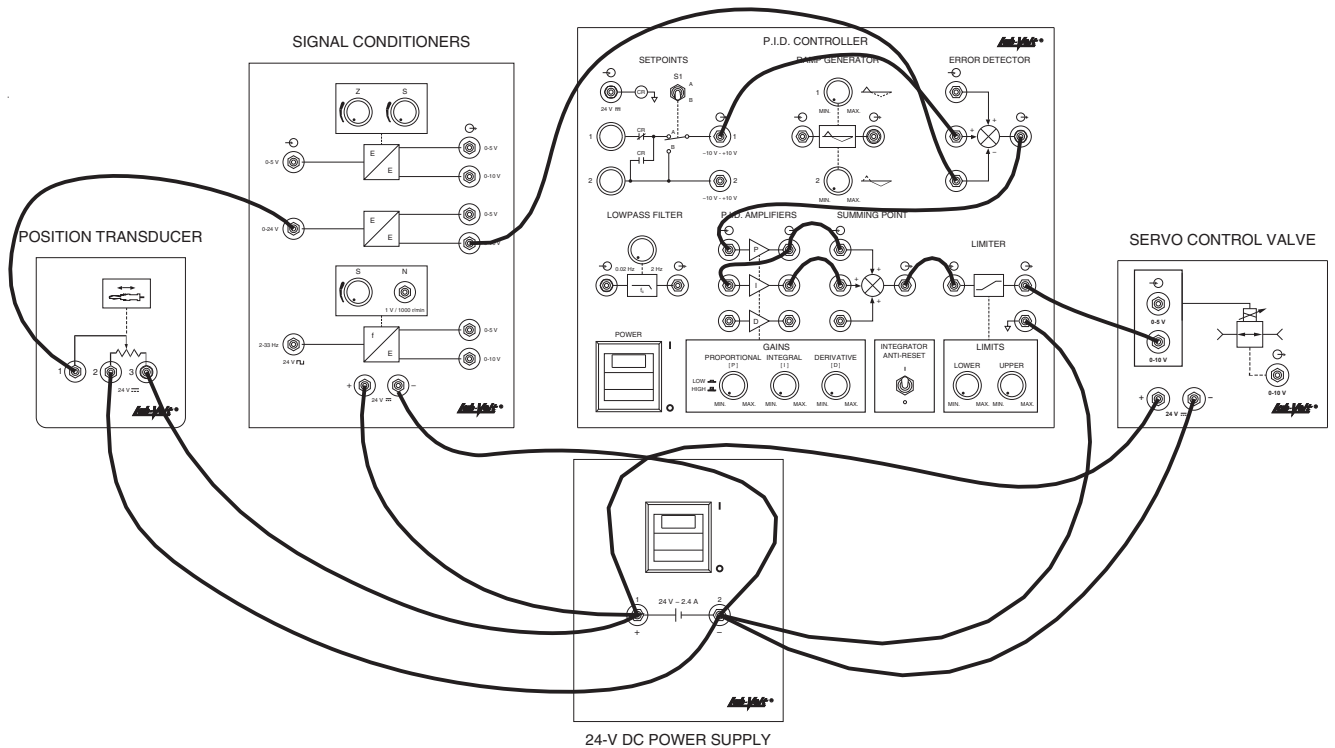
1. Connect the circuit shown in Figure 5-8. In this system, a P.I. controller is built with the ERROR DETECTOR, the PROPORTIONAL and INTEGRAL AMPLIFIERS, the SUMMING POINT, and the LIMITER of the PID Controller.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

Note: Do not connect the 0-10 V output of the [0-24 V] E/E converter to the negative input of the ERROR DETECTOR at this time. This will be done later in the exercise.



PNEUMATIC DIAGRAM



CONNECTION DIAGRAM

Figure 5-8. Proportional-plus-integral (P.I.) control of cylinder rod position.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

- ☐ 2. Make the following settings on the PID Controller:

PROPORTIONAL [P] GAIN range	LOW
PROPORTIONAL [P] GAIN	MIN.
INTEGRAL [I] GAIN	MIN.
INTEGRATOR ANTI-RESET	O
LOWER LIMIT	$\frac{1}{2}$ of MAX.
UPPER LIMIT	$\frac{1}{2}$ of MAX.

- ☐ 3. Turn on the DC Power Supply and PID Controller.

- ☐ 4. On the PID Controller, set the SETPOINT potentiometers 1 and 2 to obtain 0.25 V and -0.25 V, respectively, at the SETPOINT output 1. Then select the SETPOINT potentiometer 1.

- ☐ 5. On the PID Controller, set the PROPORTIONAL GAIN to obtain 0.25 V at the proportional amplifier output. This will set the gain of the proportional amplifier at about 1 and will apply a positive voltage of 0.25 V at the integral amplifier input.

- ☐ 6. Monitor the DC voltage at the integral amplifier output. You should observe that the voltage slowly increases because the voltage, at the integral amplifier input, is positive.

You should also observe that the voltage stops increasing when it reaches the positive saturation level of the integral amplifier (about 14 V). Is this your observation?

☐ Yes ☐ No

- ☐ 7. Set the INTEGRATOR ANTI-RESET switch at I. Is the integral amplifier output voltage still 14.0 V or is it now limited to the UPPER LIMIT potentiometer setting of approximately 7 V?

- ☐ 8. Adjust the UPPER LIMIT potentiometer in order to obtain a stable voltage of 10.0 V at the integral amplifier output. This sets the upper limit at 10.0 V.

- ☐ 9. Set the INTEGRATOR ANTI-RESET switch at O.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

- ☐ 10. Select SETPOINT potentiometer 2. This will apply a negative voltage of about -0.25 V at the integral amplifier input.
- ☐ 11. Monitor the DC voltage at the integral amplifier output. You should observe that the voltage slowly decreases because the voltage, at the integral amplifier input, is negative.

You should also observe that the voltage stops decreasing when it reaches the negative saturation level of the integral amplifier (about -14 V). Is this your observation?

☐ Yes ☐ No

- ☐ 12. Set the INTEGRATOR ANTI-RESET switch at I. Is the integral amplifier output voltage still -14.0 V or is it now limited to the LOWER LIMIT potentiometer setting of approximately -7 V?

- ☐ 13. Set the LOWER LIMIT potentiometer to MIN. This sets the lower limit at 0.0 V.
- ☐ 14. Select SETPOINT potentiometer 1 and set the potentiometer to obtain a null voltage (0.0 V) at the integral amplifier input.

Now monitor the voltage at the output of the integral amplifier. You should observe that the voltage is constant (or increasing very slowly) at some intermediate value. This shows that the output voltage of an integral amplifier is constant when the input voltage is null. Is this your observation?

☐ Yes ☐ No

- ☐ 15. Set the SETPOINT potentiometer 1 to obtain 1.0 V at the integral amplifier input.
- ☐ 16. Now observe the effect of increasing the INTEGRAL GAIN on the rate of change of the integral amplifier output voltage.

With the DC voltmeter connected to the integral amplifier output, set the INTEGRAL GAIN potentiometer at $\frac{1}{2}$ of MAX., then at $\frac{3}{4}$ of MAX., and then to MAX. For each setting, alternately select SETPOINT potentiometers 1 and 2.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

You should observe that the rate of change of the integral amplifier output voltage increases as the INTEGRAL GAIN is increased. Is this your observation?

☐ Yes ☐ No

- ☐ 17. Select SETPOINT potentiometer 1 and set the INTEGRAL GAIN to MAX.
- ☐ 18. Measure the output voltages of the proportional and integral amplifiers. These voltages should be about 1 V, and 10 V, respectively.

Now measure the voltage at the SUMMING POINT output. Is this voltage about 11 V? Explain.

- ☐ 19. Measure the voltage at the LIMITER output. This voltage should be limited to the UPPER LIMIT potentiometer current setting of 10.0 V. Is this your observation?
- ☐ Yes ☐ No

Proportional-Plus-Integral (P.I.) Control of Cylinder Rod Position

- ☐ 20. On the PID Controller, set the SETPOINT potentiometers 1 and 2, the PROPORTIONAL GAIN and the INTEGRAL GAIN as follow:
- Set the SETPOINT potentiometers 1 and 2 to obtain 0.0 V and 5.0 V respectively, at the SETPOINT output 1;
 - Select the SETPOINT potentiometer 2, and set the PROPORTIONAL GAIN to obtain 5.0 V at the proportional amplifier output.
 - Set the INTEGRAL GAIN at $\frac{1}{2}$ of MAX.
- ☐ 21. Verify the status of the trainer according to the procedure given in Appendix B.
- ☐ 22. On the Conditioning Unit, open the main shutoff valve and the required branch shutoff valves at the manifold.

Set the main pressure regulator to obtain 630 kPa (90 psi) on the regulated pressure gauge.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

Set the pressure regulator PR2 to obtain 420 kPa (60 psi) on the pressure gauge PG2.

- ☐ 23. Place the system in the closed-loop mode. To do so, connect a lead between the 0-10 V output of the [0-24 V] E/E converter and the negative input of the ERROR DETECTOR.

- ☐ 24. Measure the voltage at the ERROR DETECTOR output. Is the voltage null, indicating that the cylinder rod position corresponds to the position called by the SETPOINT potentiometer 2? Explain.

- ☐ 25. Simulate an increase in cylinder load by setting the Pressure Regulator PR2 to obtain 560 kPa (80 psi) on the Pressure Gauge PG2. Is the error automatically eliminated at the ERROR DETECTOR output?

☐ Yes ☐ No

- ☐ 26. Simulate a decrease in cylinder load by setting the Pressure Regulator PR2 to obtain 280 kPa (40 psi) on the Pressure Gauge PG2. Is the error voltage at the ERROR DETECTOR output still null?

☐ Yes ☐ No

- ☐ 27. Do your observations confirm that the proportional-plus-integral control is appropriate for eliminating the error in systems where the load varies?

☐ Yes ☐ No

Effect of an increase in the integral gain on the step response of the rod position

- ☐ 28. Connect the DC voltmeter at the feedback (-) input of the ERROR DETECTOR.

- ☐ 29. Set the INTEGRAL GAIN to MIN. and select SETPOINT potentiometer 1.

With a stopwatch in hand, select SETPOINT 2 and measure the time it takes for the feedback voltage to stabilize to the 5-V setpoint. Record your

Closed-Loop Position Control, Proportional-Plus-Integral Mode

result in the appropriate row of the column *FEEDBACK VOLTAGE STABILIZATION TIME* in Table 5-1.

Also, record whether or not the feedback voltage overshoots (exceeds) the setpoint before it stabilizes.

INTEGRAL GAIN POTENTIOMETER SETTING	FEEDBACK VOLTAGE STABILIZATION TIME	OVERSHOOT THE 5-V SETPOINT BEFORE STABILIZATION?
MIN.		
$\frac{1}{2}$ of MAX.		
$\frac{3}{4}$ of MAX.		
MAX.		

Table 5-1. Response of the feedback voltage for different INTEGRAL GAIN settings.

- ☐ 30. Repeat the previous step for the other INTEGRAL GAIN settings listed in Table 5-1 and record your results.

- ☐ 31. Based on the data recorded in Table 5-1, what effect does increasing the integral gain have on the stabilization time and overshooting of the feedback voltage? Explain.

- ☐ 32. Now experiment further with proportional-plus-integral control.

Set the INTEGRAL GAIN at $\frac{1}{2}$ of MAX. Vary the PROPORTIONAL GAIN setting from MIN. to MAX. by increments of $\frac{1}{4}$ of a turn.

For each setting, measure the time it takes for the feedback voltage to stabilize to the 5-V setpoint. Also, observe if the feedback voltage overshoots the setpoint before it stabilizes.

- ☐ 33. Based on your observations, what effect does increasing the proportional gain have on the stabilization time and overshooting of the feedback voltage? Explain.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

- ☐ 34. Now experiment further with integral control. Remove the proportional amplifier from the circuit by removing the two leads which are connected at its terminals.

Connect the ERROR DETECTOR output to the integral amplifier input, and set the INTEGRAL GAIN at $\frac{1}{2}$ of MAX.

Alternately select SETPOINT potentiometers 1 and 2 and observe the response of the cylinder rod before it stabilizes to the position called by the 5-V setpoint.

- ☐ 35. Do your observations confirm the theoretical response shown in Figure 5-7?

☐ Yes ☐ No

- ☐ 36. Measure the voltage at the ERROR DETECTOR output. Is the voltage null, indicating that the cylinder rod position corresponds to the position called by the SETPOINT potentiometer 2?

☐ Yes ☐ No

- ☐ 37. On the Conditioning Unit, close the shutoff valves, and turn the regulator adjusting knob completely counterclockwise.

- ☐ 38. Turn off the PID Controller and the DC Power Supply.

- ☐ 39. Disconnect and store all leads and components.

CONCLUSION

In this exercise, you studied proportional-plus-integral control of cylinder rod position. You saw that unlike proportional control, proportional-plus-integral control automatically eliminates the error between the setpoint and feedback voltage (measured position) due to the integral action of the controller.

You observed the effect of increasing the integral gain and proportional gain on the response of the rod position (feedback voltage) to a sudden change in setpoint. You saw that as the integral or proportional gain is increased, the stabilization time decreases. At excessive integral or proportional gains, the system may even start to oscillate without being able to return to equilibrium.

Closed-Loop Position Control, Proportional-Plus-Integral Mode

REVIEW QUESTIONS

1. What does “integral gain” mean?

2. What are the advantages and disadvantages of integral control?

3. Briefly describe the operation of a controller in the proportional-plus-integral mode.

4. What effect does increasing the integral gain have on proportional-plus-integral position control?

5. What is the purpose of the anti-reset function?

Other Samples Extracted
from
Pneumatics Fundamentals

Unit Test

1. When calculating the total piston area for the rod end of a cylinder
 - a. the rod area must be added to the piston area.
 - b. the rod area must be subtracted from the piston area.
 - c. the piston area must be subtracted from the rod area.
 - d. the piston area must be added to the rod area.

2. A directional control valve with two flow path configurations and three fluid ports is called
 - a. 3-way, 2-position directional control valve.
 - b. 2-way, 3-position directional control valve.
 - c. 2-way, 2-position directional control valve.
 - d. 3-way, 3-position directional control valve.

3. If the same pressure is applied to both sides of the piston in a double-acting cylinder, the cylinder will
 - a. extend because the extension force is greater than the retraction force.
 - b. extend because the seals in the cylinder will allow fluid in the rod end to leak into the cap end.
 - c. retract because the pressure applied to the cylinder rod will create a retraction force greater than the extension force.
 - d. remain in its original position because pressure in each side will prevent the piston from moving.

4. The devices that convert fluid energy into mechanical energy are called
 - a. air bearings.
 - b. pneumatic motors.
 - c. cylinders.
 - d. actuators.

5. They are commonly used to control the speed of fluid actuators.
 - a. Directional control valves.
 - b. Check valves.
 - c. Flow control valves.
 - d. Shutoff valves.

6. The symbol for a directional control valve consists of a separate envelope for each
 - a. valve.
 - b. flow path.
 - c. way.
 - d. position.

Unit Test (cont'd)

7. They are commonly used to control the direction of fluid actuators.
 - a. Check valves.
 - b. Directional control valves.
 - c. Flow control valves.
 - d. Shutoff valves.

8. When the actuator does not constantly work against a load,
 - a. the meter-in configuration is commonly used to control the speed.
 - b. the meter-in and meter-out configuration is commonly used to control the speed.
 - c. the meter-out configuration is commonly used to control the speed.
 - d. the by-pass configuration is commonly used to control the speed.

9. When an intensifier is contained within an individual cylinder,
 - a. the rod end is used as the low-pressure side.
 - b. the rod end is used as the high-pressure side.
 - c. the cap end is used as the high-pressure side.
 - d. the rod end is used as the master cylinder.

10. If two cylinders connected in series are of the same size and stroke, the upstream cylinder will extend
 - a. faster.
 - b. slower.
 - c. at exactly the same speed.
 - d. after the downstream cylinder.

Instructor's Guide Sample
Extract from
Electrical Control
of Pneumatic Systems

Industrial Applications

EXERCISE 4-1 PNEUMATIC ACTUATOR DECELERATION CIRCUITS

ANSWERS TO PROCEDURE QUESTIONS

- ☐ 10. When the rod is in the fully retracted position, LS1 is actuated. NO contact LS1 and NC contact LS2 are closed. Pressing PB1 causes DV1-SOL-A to be energized and the cylinder rod extends.
- ☐ 11. No. Flow control valve FCV1 is fully open and does not restrict air flow to decelerate the cylinder rod.
- ☐ 14. Yes. The air forced out of the cylinder rod end is restricted by FCV1 and the extension speed is slowed down.
- ☐ 15. Because of the bypass check valve of the flow control valve FCV1.
- ☐ 16. The cylinder rod will not complete a full extension and the system will stop if the rod does not reach LS2.
- ☐ 25. When the START pushbutton PB1 is pressed, relay coil CR1 is energized. This causes NO contact CR1-B to go closed, DV1-SOL-A to be energized and the motor to start rotating.
- ☐ 26. No. The air flow is block by check valve CV1 in one direction.
- ☐ 27. When the BRAKE pushbutton PB3 is pressed, relay coil CR2 is energized. This causes CR1 to be de-energized. This also causes the spool of DV1 to shift and the motor to stop.
- ☐ 29. When the STOP pushbutton PB2 is pressed, relay coil CR1 is de-energized and the spool of DV1 returns to its center position. This causes the motor to stop rotating. The motor acts like a vacuum pump while decelerating.

Industrial Applications

ANSWERS TO REVIEW QUESTIONS

1. The check valve is used to allow the retraction of the cylinder rod at full speed.
2. The degree of cushioning can be adjusted with the needle valve.
3. The cylinder rod extends at full speed until the sensing device detects the presence of the rod. At this point, the air forced-out of the cylinder rod end is redirected through a flow control valve that restricts the flow.
4. A bi-directional pneumatic motor may be stopped without pulling a vacuum, using a particular center configuration of the directional valve as shown in Figure 4-5.
5. Because of the compressibility of air.

EXERCISE 4-2 COUNTING OF ACTUATOR CYCLES

ANSWERS TO PROCEDURE QUESTIONS

- ☐ 4. The display count should be 000.
- ☐ 5. The displayed count is incremented by one. Pressing PB1 momentarily switches the CONTROL input of the counter to common. This activates the CONTROL input and increments the counter value by one.
- ☐ 6. Pilot lamp L1 should turn on. When the counter reaches the preset value, the counter output contacts are shifted to their activate state. This causes CT1-A to close, energizing L1.
- ☐ 7. Yes.
- ☐ 8. The displayed count should return to zero and the pilot lamp L1 should turn off. Pressing the reset button momentarily switches the RESET input of the counter to common. This resets the count to zero and deactivates CT1-A, de-energizing L1.
- ☐ 9. The display count is incremented after PB1 is released.
- ☐ 10. Yes.

Industrial Applications

- ☐ 19. When the START pushbutton PB1 is pressed, the current is allowed to flow to energize relay coil CR1 and SOL-A of directional valve DV1. This causes the spool of DV1 to shift and the cylinder rod to extend.
- ☐ 20. Energizing relay coil CR1 causes NO contact CR1-C on rung 3 to go closed. The COMMON input of the counter is then connected to common and the count value increases by one.
- ☐ 21. Yes. This is because when the cylinder completes its fifth extension stroke, the count value of counter CT1 reaches the preset value of 5, which activates the counter relay contacts. This causes NO contact CT1-B on rung 3 to close, connecting the counter RESET (R) input to common and causing counter CT1 to reset its count to zero.
- ☐ 22. Yes.
- ☐ 23. Yes. Pressing the STOP pushbutton PB3 causes relay coil CR2 to de-energize. This causes holding contact CR2-A to go open. When the cylinder is created on rung 1 and the cylinder stops.
- ☐ 24. The cylinder rod does not extend. The START pushbutton PB1 creates an open-circuit condition on rung 1. This prevents DV1-SOL-A and CR1 from being energized to start the cylinder extension.
- ☐ 29. Yes.
- ☐ 30. Yes.
- ☐ 40. Motor speed: 2000 \pm 500 r/min
- ☐ 41. Yes.

ANSWERS TO REVIEW QUESTIONS

1. Electrical counters are used to count quantities produced during process and control operation. They are also used for machine maintenance scheduling by controlling the number of machine operations.
2. Each time a pulse is received at the control terminal, the counter count is incremented by one. When the preset count is reached, the counter activates its output contacts. Additional inputs continue to increment the count.

Industrial Applications

Momentary activation of the reset input deactivates the counter contacts and resets the count to zero.

3. The preset value is the count the counter must reach before activating its output contacts.
4. Yes.
5. The counter value can be returned to zero by momentarily activating the reset input of the counter.

EXERCISE 4-3 INDUSTRIAL DRILLING SYSTEM AND SAFETY CIRCUITS

ANSWERS TO PROCEDURE QUESTIONS

- ☐ 8. Yes.
- ☐ 10. When the START pushbutton PB1 is pressed, the current is allowed to flow through ladder rung 1 to energize relay coil CR1. DV1-SOL-A is energized. This shifts the valve causing the clamp cylinder to extend and the pneumatic drill unit to rotate.
- ☐ 11. When the clamp cylinder becomes fully extended, the pressure rises quickly behind its piston. When it reaches the actuation 600 kPa (80 psi), it activates pressure switch PS1, causing NO contact PS1 on rung 1 to go closed. This energizes DV2-SOL-A and shifts the spool of the valve and the drill cylinder extends.
- ☐ 12. When the drill cylinder becomes fully extended, it activates photoelectric switch PE1. This causes NC contact PE1 on rung 1 to go open, de-energizing relay coil CR1. This causes DV2-SOL-A to de-energize and the drill cylinder retracts. DV1-SOL-A is also de-energized but the spool of DV3 does not shift. So the pneumatic motor continues to rotate.
- ☐ 13. When the drill cylinder becomes fully retracted, it activates magnetic proximity switch PX2. This causes NC contact PX2 on rung 2 to go open. This de-energizes relay coil CR2 causing DV1-SOL-B to energize and the spool of DV1 to shift. This causes the pneumatic motor to stop and the clamp cylinder to retract at full speed.
- ☐ 20. No.

Industrial Applications

- ☐ 21. No.
- ☐ 22. The cylinder rod extends full stroke.
- ☐ 23. Yes.
- ☐ 24. The cylinder rod immediately retracts.
- ☐ 25. Yes. You would be able to operate the cylinder circuit simply by pressing the other pushbutton, PB2
- ☐ 31. Yes.
- ☐ 32. The cylinder rod does not extend. Pressing pushbutton PB1 causes relay coil CR1 to energize, opening contact CR1-B and closing contact CR1-A. Since contact CR2-B is closed, this also causes timer TD1 to start timing. 1 second later, relay contacts TD1-A and TD1-B open, de-energizing relay coil CR1 and preventing relay contacts CR1-A and CR1-B from closing to energize valve solenoid SOL-A.
- ☐ 33. If PB1 is pressed and then PB2 is pressed, the time which can elapse between the two events before the cylinder fails to operate is the time set on the time-delay relay. In this case, 1 s.
- ☐ 34. No. Tying down PB2 would cause timer TD1 to energize through NO contact PB2 and NC contact CR1-B in the closed condition. 1 second later, TD1 would shift its NC contacts TD1-A and TD1-B to the open condition. This would prevent relay coils CR1 and CR2 from being energized and keep relay contacts CR1-A and CR2-A in the open condition until both pushbuttons are released.

ANSWERS TO REVIEW QUESTIONS

1. The drill cylinder will not extend after extension of the clamp cylinder. The pressure developing at the pneumatic port of PS1 will be insufficient to activate PS1.
2. The pushbuttons have to be located far enough apart so that two hands are required for operating them.

Industrial Applications

3. No, because the operator would be unable to instantly retract the cylinder during its extension if a hazardous situation should occur.
4. A two-hand, non-tie-down safety circuit is a circuit that requires the use of both hands to start the circuit and that cannot be override by tying down one of the pushbuttons.
5. The cylinder rod does not extend.

Industrial Applications

EXERCISE 4-4 GARBAGE COMPACTOR SIMULATION CIRCUIT

ANSWERS TO PROCEDURE QUESTIONS

☐ 1.

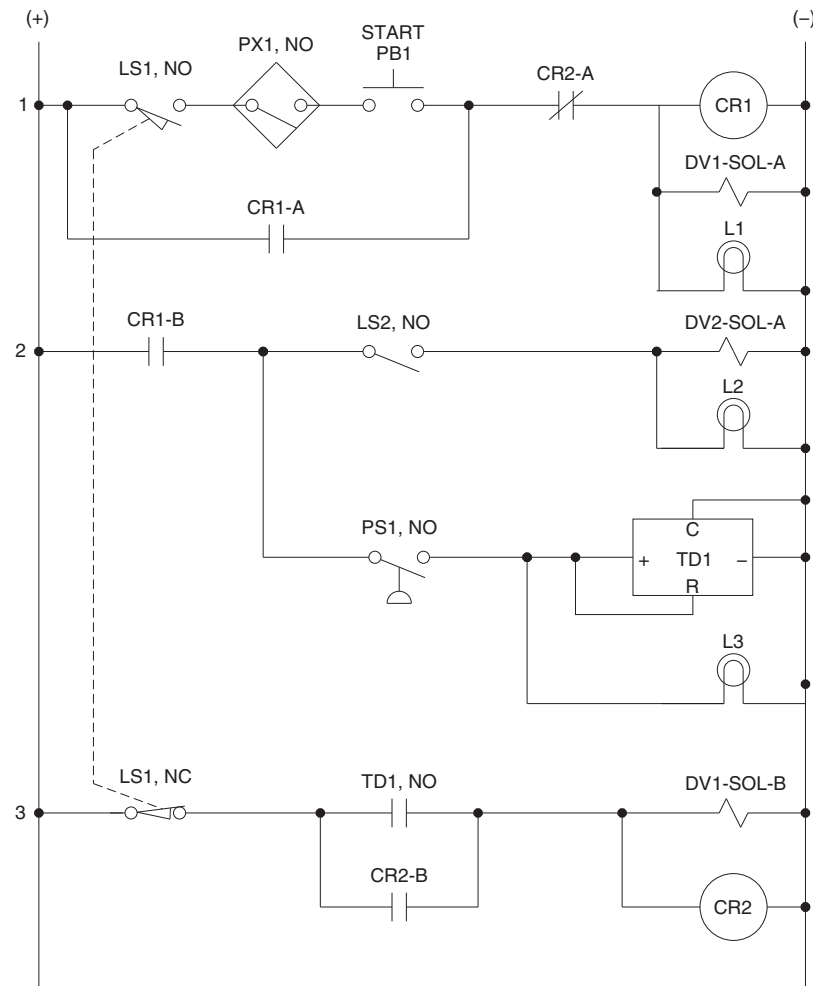


Figure 4-20.

☐ 9. Yes.

☐ 10. No. Depending on the garbage volume, the length of extension of the depress cylinder will vary.

Industrial Applications

- ☐ 11. The garbage will be less compacted.
- ☐ 12. To maintain pressure on the garbage a preset time to improve compaction.

ANSWERS TO REVIEW QUESTIONS

1. Magnetic proximity switch PX1 is used to confirm the retracted position of the depress cylinder.
2. The garbage would be more compacted.
3. A pressure regulator.
4. The circuit will not start. Limit switch LS1 must confirm the retracted position of the feed cylinder to operate the system.
5. LS2.

ANSWERS TO UNIT TEST

1. *b*; 2. *c*; 3. *a*; 4. *d*; 5. *b*; 6. *d*; 7. *a*; 8. *d*; 9. *c*; 10. *c*.

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Parker Hannifin Corporation. Industrial Pneumatic Technology. Bulletin 0275-B1