LOW PRESSURE PNEUMATICS SYSTEM

VERSION 1

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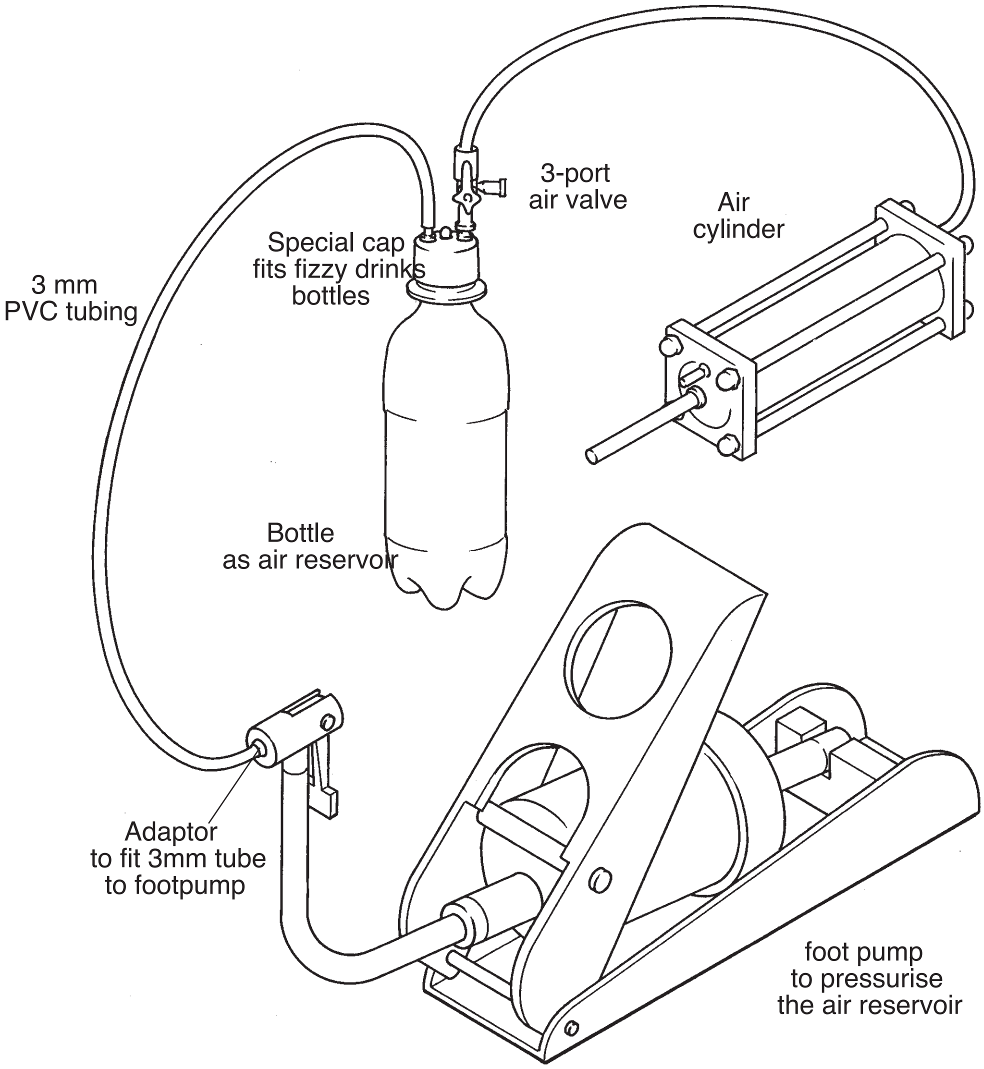
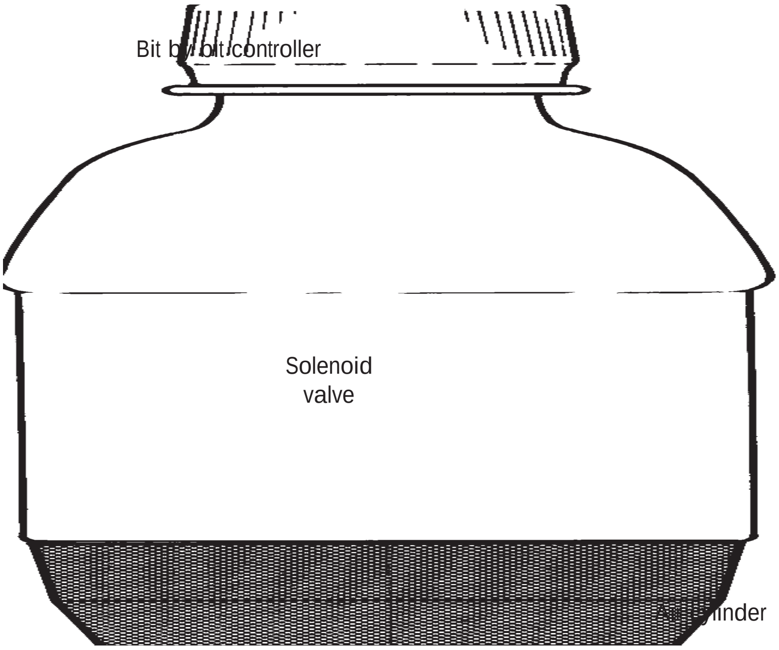
Introduction

The TEP low-pressure pneumatics system provides a comprehensive teaching resource made up of low-cost components connected by standard PVC tubing. The system offers excellence performance at pressures as low as 0.5 bar for a fraction of the price of commercial equipment and enables otherwise expensive components such as air cylinders to be treated as consumable items. It also provides important practical insights into the way air cylinders are designed and built.



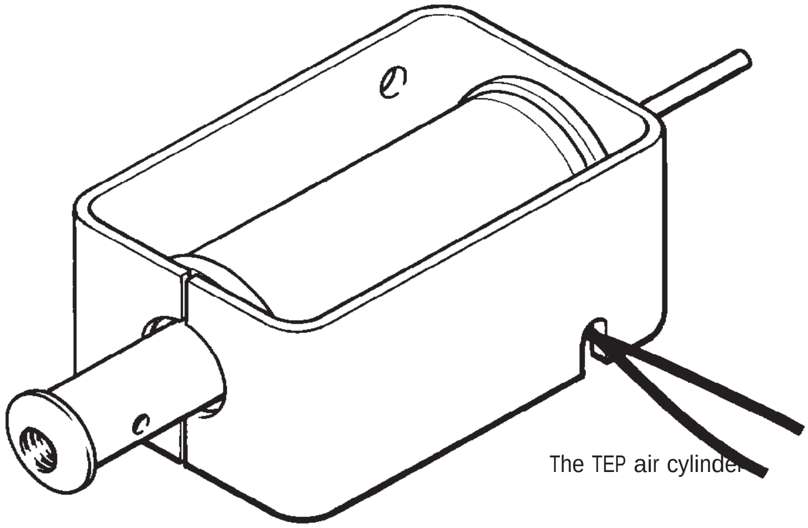
Since the early days of pneumatics work in schools and colleges, there has been a quiet revolution in the way commercial air systems are designed and built. It is now commonplace to use programmable electronic devices, including PLCs, to provide the control function - with air for primary power only. The TEP system makes it possible to emulate this concept through the use of either one of its two PLC-type controllers. These provide “intelligent” air control via the use of a unique mainly-plastic solenoid valve.



This handbook describes the parts of the low pressure system and provides a simple applications example. The TEP low-pressure system is readily available in the form of comprehensive packs or as individual components. See page 26 for product details and ordering information.

AIR CYLINDERS

The basic TEP air cylinder has a traditional construction and appearance. It uses high density polyethylene end caps which plug into a length of butyrate tubing - cut and finished to any required cylinder length. All other components, with the exception of the piston are of steel.



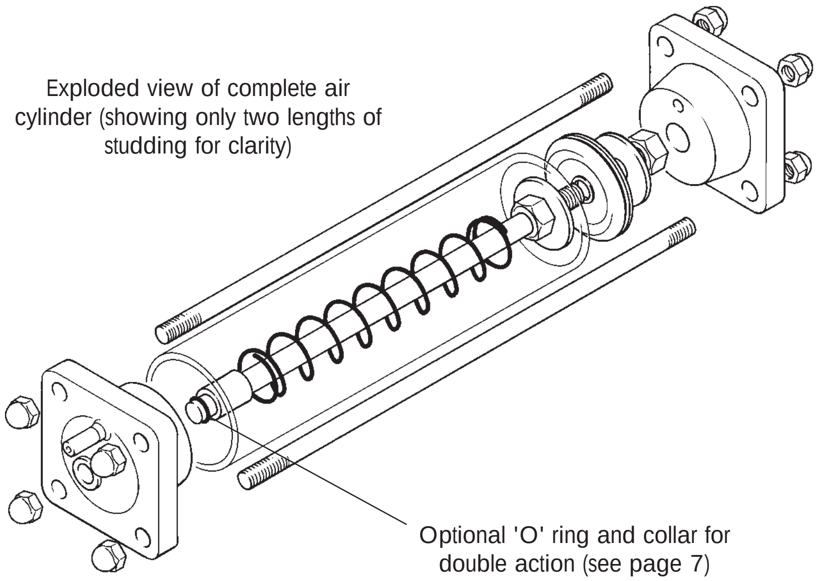
The TEP air cylinder

Each cylinder can be configured as either a spring-return or double-acting type. For the latter option, an “0” ring seal and retaining ring is inserted in the front end-cap before assembly. It is important that the cylinder is coated with a *viscous* lubricant such as petroleum jelly or grease - rather than oil or silicon spray. Petroleum jelly - e.g. “Vaseline” - is the preferred option for school use.

Safety note:
This type of air cylinder should not be subjected to air pressures in excess of 2 bar. For most project applications it will work perfectly satisfactorily at 1 bar maximum

Assembling a TEP Air Cylinder

A TEP air cylinder can be any length between 50 mm and 760 mm. The stroke is ultimately limited by the butyrate tube length available and the required stiffness of the 6mm diameter steel cylinder rod. (In TEP packs, part-made rods are supplied in standard lengths of 120mm with a single threaded end to accommodate the piston parts.)



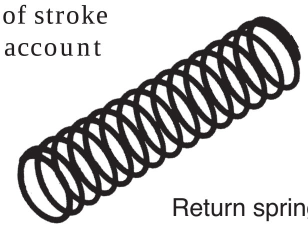
To determine the length of the *cylinder barrel*, you should first of all decide on the length of stroke required. If the cylinder is double acting, the length is given by:

- **required stroke length + allowance for internal plugs of end caps and piston (40mm)**

For spring return cylinders the length is given by:

- **required stroke length + above allowance + length of return spring fully compressed**

In practice, for the springs supplied in the TEP packs, allow 1.5 mm for every 1 cm of stroke required. (This allowance takes into account that the spring will be in slight compression even when the ram is fully retracted.)

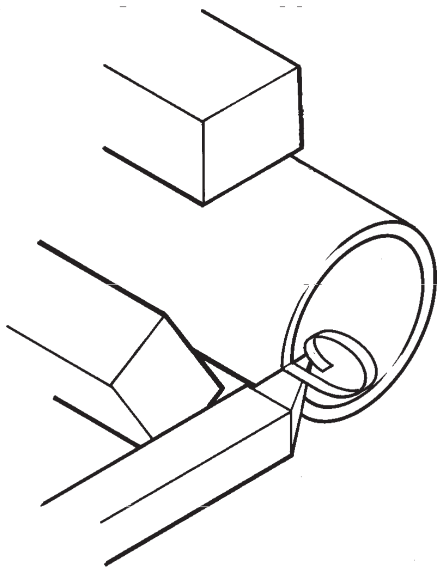


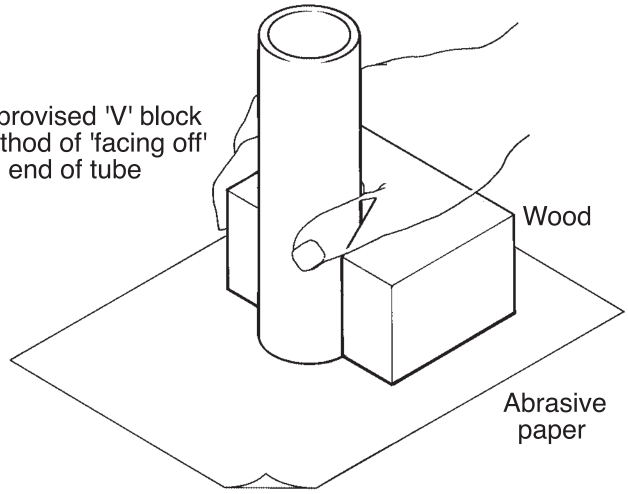
For example, for a required stroke of 50mm from a spring return cylinder, the barrel length is

50mm + 40mm allowance + (5 × 1.5) = 97.5mm

Stages in Construction of Cylinder

The barrel tube is cut with a hacksaw or parted off on a lathe. Ideally the ends should be faced off, but if a lathe is not available, the ends can be finished by holding the tube vertically in an improvised “V” block of wood and rubbing in a circular motion on abrasive paper.

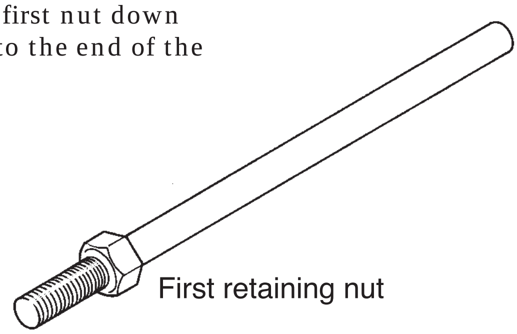




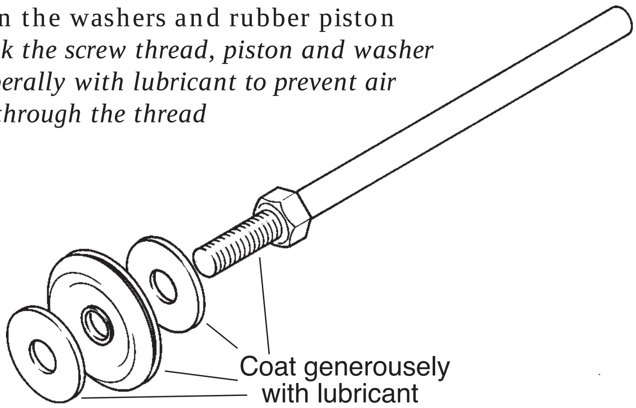
The studding is cut to the length of the barrel + 6mm x 2 for the two end caps plus an allowance for the retaining nuts. The studding may, of course, be extended for fastening the cylinder to something else.

If a screw thread (or other feature) is required on the end of the rod, this is done prior to assembling the piston. The piston is then assembled as shown in the exploded diagram following these steps:

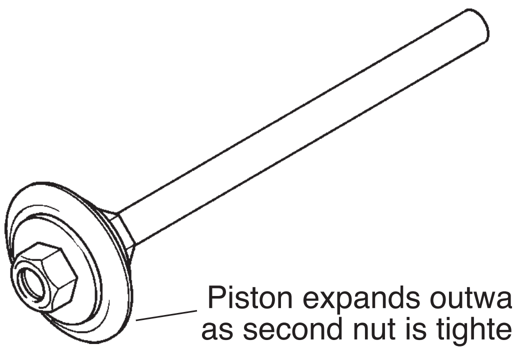
- screw the first nut down tightly onto the end of the rod thread



- slide on the washers and rubber piston *but pack the screw thread, piston and washer faces liberally with lubricant to prevent air ingress through the thread*



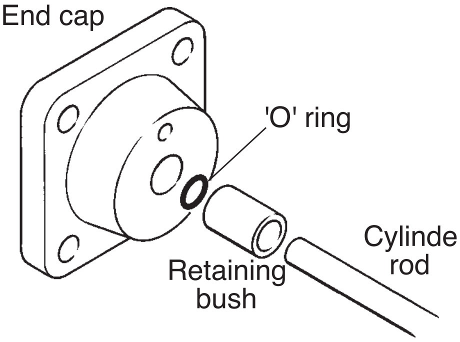
- tighten the second nut to squeeze the rubber piston between the washers. This increases its overall diameter and the nut should be tightened with pliers until the rubber piston is a good fit in the barrel. *If there is air leakage past the piston after the cylinder is assembled, the second nut will need to be tightened further.*



(Note: failing to pack around the piston with lubricant or not tightening the second nut to expand the piston are the two causes of possible leakage.)

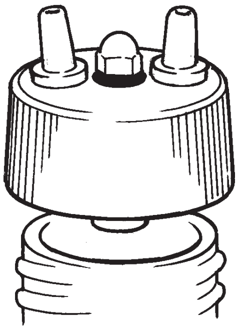
To complete the cylinder, the piston is placed in the barrel together with a spring of suitable length. As a rule of thumb, the free length of the spring should be the barrel length plus 5% - 10%. This ensures that the piston fully retracts to the end of its stroke. One or more of the springs supplied in the pneumatics pack can be used or a suitable spring can be wound from 1mm gauge piano wire. Finally, the end caps are added and secured with studding. *However, is important not to overtighten the nuts and distort the caps.*

To make up a double-acting cylinder, the above procedure is followed but in addition an “0” ring seal is placed in the internal recess of the front end cap and held in place there by pushing home a retaining bush. This is cut from 9.5mm outside diameter butyrate tubing to a length of approximately 15mm. Ideally, it should be faced off at both ends.

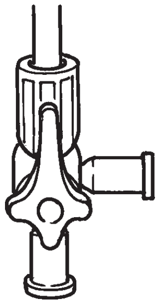


Low Pressure Air Supply System

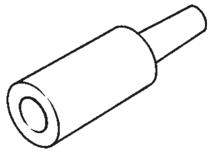
The TEP low pressure air supply exploits the remarkable pressure containment characteristics of PET fizzy drinks bottles. (See study file 1.) A special moulded top which seals onto any PET bottle enables connection both to a pump and a miniature three-port valve controlling the outlet. Any standard footpump can be used for pressurising the container using the special adaptor and 3mm bore PVC airline. A non-return valve is built into almost all footpumps and so the bottle can be pressurised simply by pumping with the outlet valve closed.



Bottle top

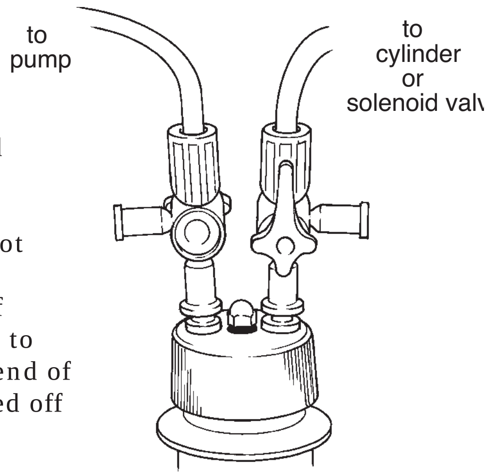


3-port valve

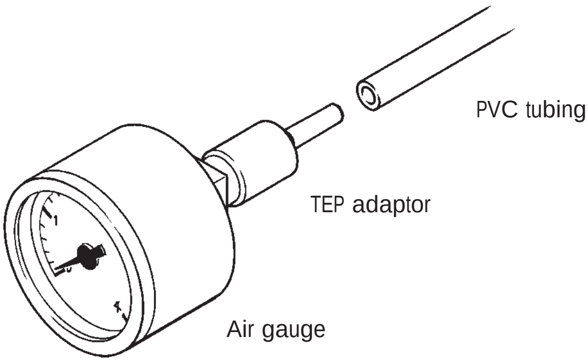


Foot-pump adaptor

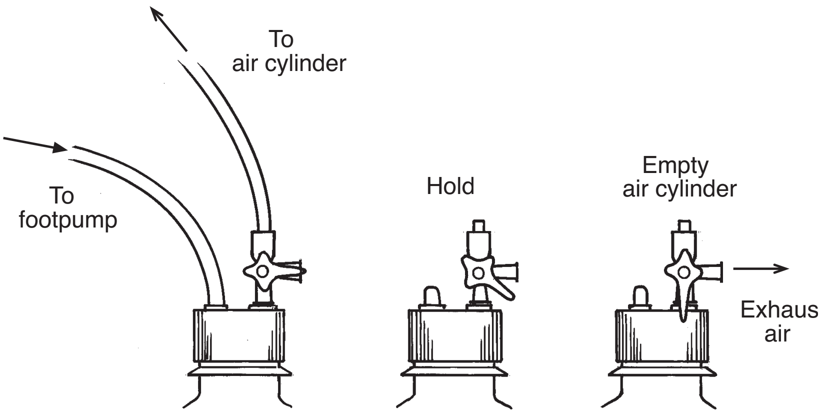
If the pump is to be removed when the bottle is pressurised, a second valve can be added to the inlet port and closed before the pump is disconnected.
It is preferable, however, not to attempt to remove the airline from the valve itself because it adheres strongly to the valve stem. The other end of the airline should be slipped off the pump adaptor.



If two or more bottles are pressurised for greater capacity, they are simply connected using PVC airline.
A standard pressure gauge can also be inserted in the system using the special TEP adaptor. This accommodates an external 1/8” BSP thread - which is standard on the rear of most smaller gauges.



The control positions of the miniature air valve are shown. Two of these valves can be synchronised manually to control a double acting cylinder but this is extremely awkward to manage. The valves are best used only with single-acting cylinders.



1. air flows to cylinder

2. air shut off to cylinder

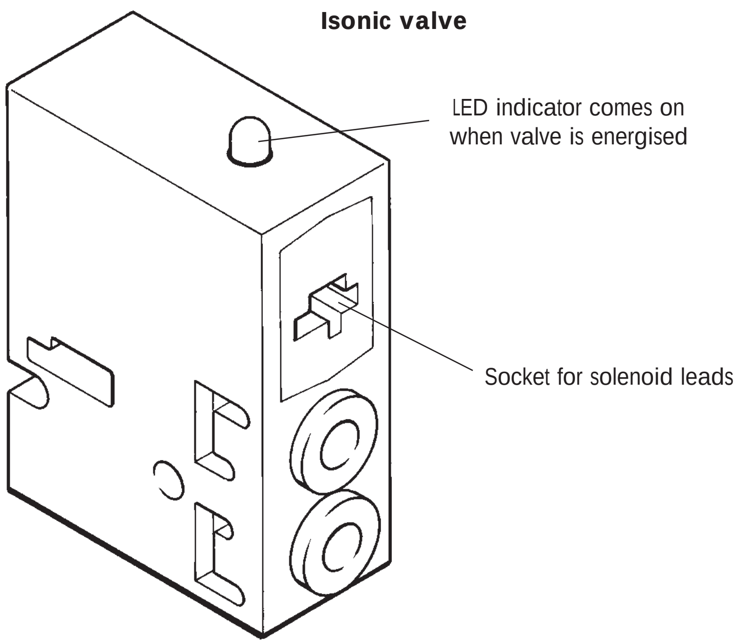
3. air shut off to cylinder and any air in cylinder exhausts

Air Safety note: The specially moulded bottle top incorporates a conventional pressure relief valve. The top's annular seal will also fail at higher pressures. All mouldings in the system are of polyethelyne from which PVC tubing will tend to slip at pressures in excess of 2 bar. **Under no circumstances should the system by operated at pressures higher than 2 bar and the system should never by connected to a conventional compressor.**

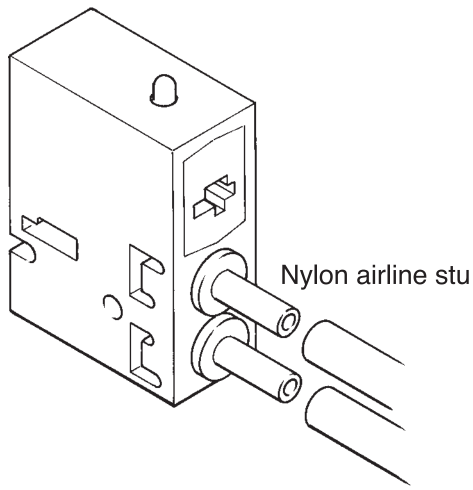
Solenoid Valves

In principle, any solenoid actuated air valve can be used within the TEP low pressure system - providing that the 3mm PVC airline can be connected. (This is not normally a problem since it can be slipped over a stub of conventional 4mm nylon airline.) The main problems are usually high cost and the standard working voltages or either 12v or 24v.

Because the complete TEP low pressure system uses either the “Bit by Bit” controller or PLC chip for sequential switching, the solenoid needs to be 6v working (or less) and with a low current requirement when energised. A device which fits both these requirements is Mead Fluid Dynamics' *Isonic* valve. (See study file 2). This unique valve is precision injection moulded in two parts welded together ultrasonically. This avoids a number of expensive machining operations and results in a very compact unit - supplied to TEP with integral electronic buffer and LED indicator.



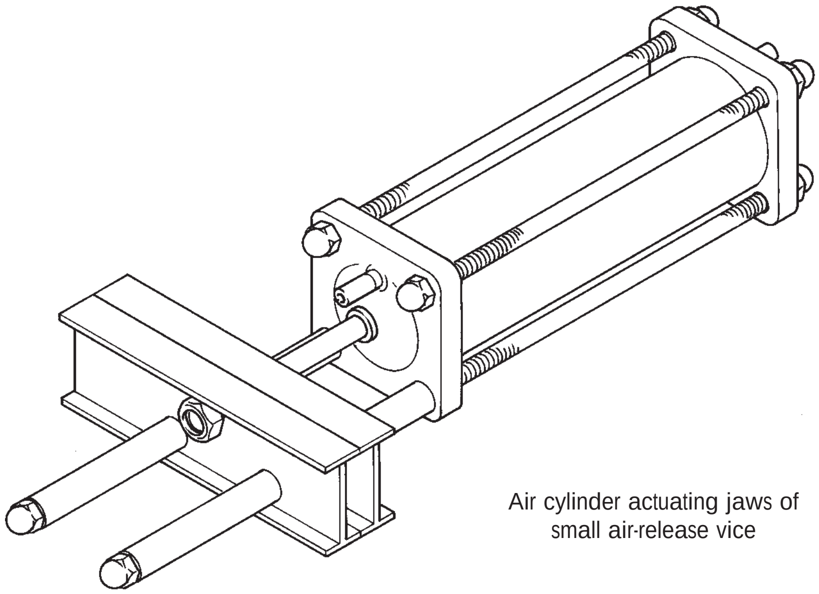
The valve is easily connected to 3mm PVC airline by inserting stubs of nylon airline into the quick-fit retaining collets and then sleeving these with the 3mm PVC.
Note: To release the nylon stubs from the valve, pull the nylon tube outwards and at the same time push down the collet towards the valve .



The *isonic* valve is designed for 5v working but will tolerate a supply of between 4.5v to 6v. The low working voltage and power requirement means that the valve will interface easily with most battery-powered control circuits. A valve can be tried out in a simple system using a push-button switch and a 4.5v battery pack.

A pair of *isonic* valves will substitute for a standard 5 port valve to drive a double-acting cylinder. This requires the use of a double throw switch or equivalent so that when one valve is energised the other is “off” - and vice versa.

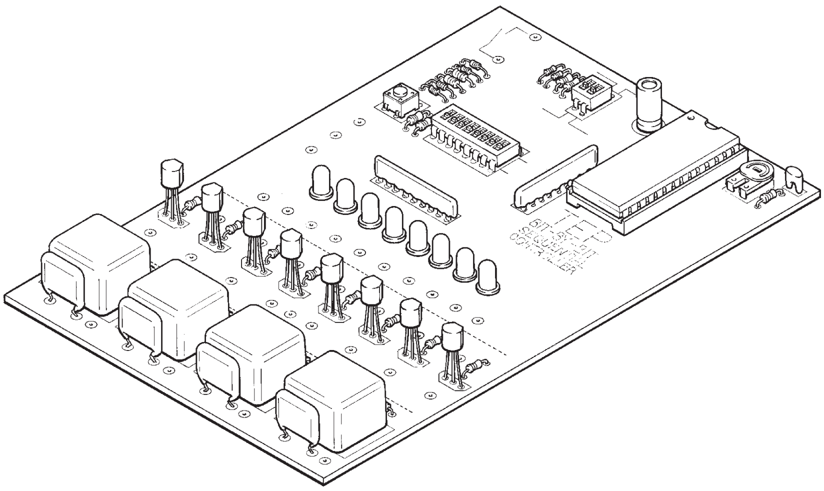
A possible application for a TEP air cylinder with solenoid valve control is shown. The cylinder has been converted into a small vice whose jaws are held closed by the cylinder’s return spring. When the solenoid valve controlling the cylinder’s air supply is energised, the vice jaws open. This enables the operator, for example, to control the vice from a foot switch.



Air cylinder actuating jaws of small air-release vice

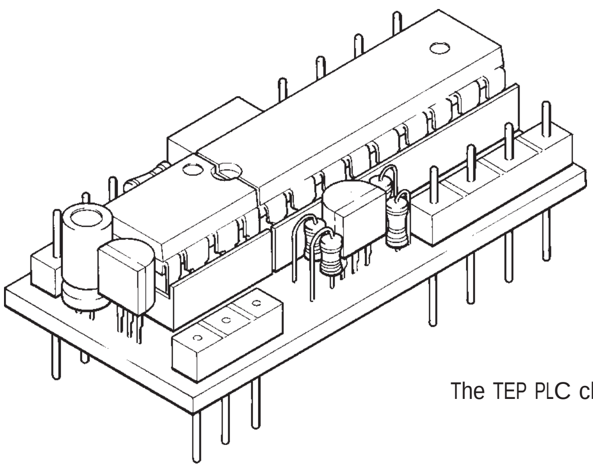
"BIT BY BIT" CONTROL

TEP's "Bit by Bit" controller is ideally suited to sequential control of air cylinders via solenoid valves. The controller is an 8 output device with a 64 line program capacity. Programs can be run at different speeds and interrupted or looped via external switches or logic signals. Each Isonic valve is connected to the controller board as shown. The valves have an internal buffer with back-EMF clamping and so no diode protection is needed. (See Study File 2 for basic programming procedures. A comprehensive handbook is available; see page 26)



PLC CHIP CONTROL

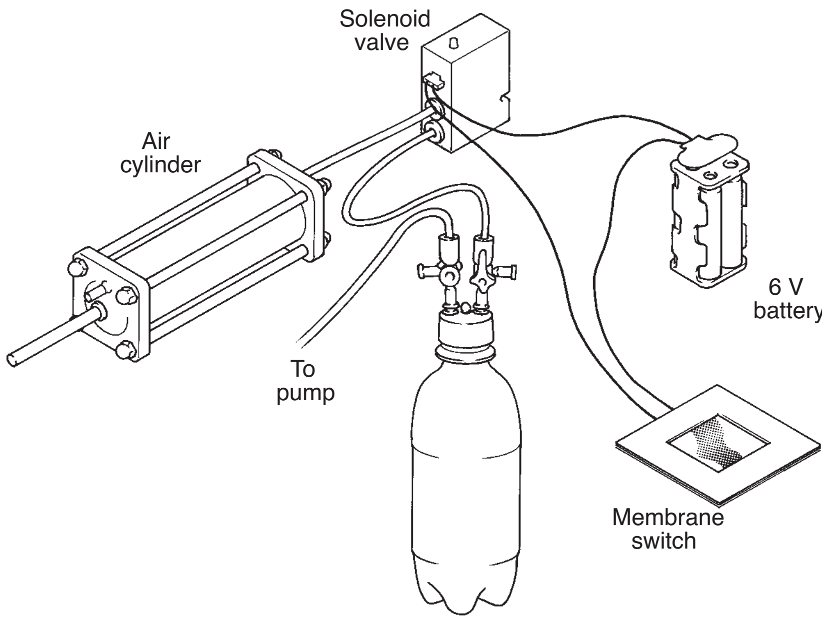
TEP's PLC chip can be programmed from a PC to provide a wide range of control functions. The chip has 8 outputs (each with input facility) and offers commercial performance as a systems controller. The versatility and power of the PLC chip precludes a brief description here. However, a comprehensive handbook is available (see page 26).



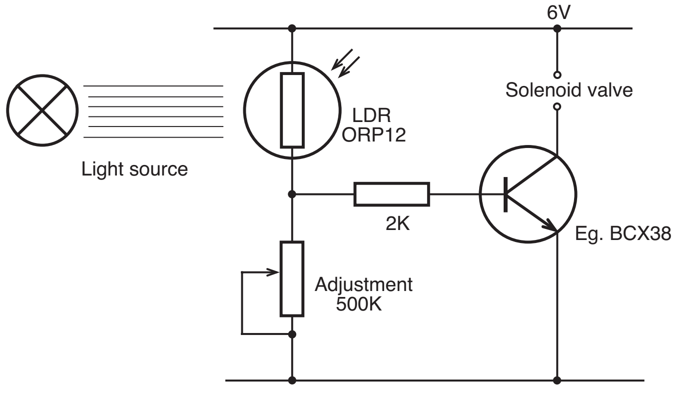
The TEP PLC chip

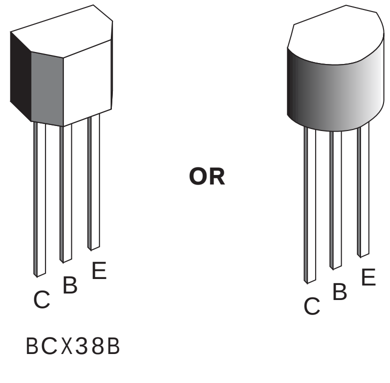
Dedicated Electronic Control

The *isonic* solenoid valve can be energised by any control circuit with an output voltage in the range of 4.5v-6v and capable of sourcing up to 100 mA. The most basic circuit is a switch - e.g. a membrane panel type - and a local battery to energise the valve.

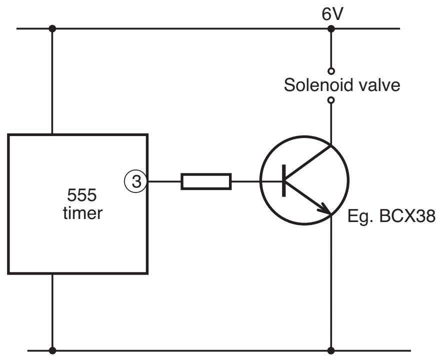


A simple circuit consisting of a potential divider and single transistor may be used to demonstrate sensing and control principles. In the example shown, a valve is energised when a beam of light falls on an LDR - so that an air cylinder - say - lifts a barrier, gate or guard. However, this circuit raises two connected problems. If the condition being sensed is changing gradually, the transistor will not switch the solenoid on cleanly. Secondly **there is always an inherent danger when a primary power source - even a low pressure one - is not controlled precisely enough**. In the example given, the immediate solution is to incorporate a shmitt trigger within the circuit to sharpen up its response. In relation to safety, it is always necessary to incorporate one or more failsafe “mechanisms” to protect an operator or user.



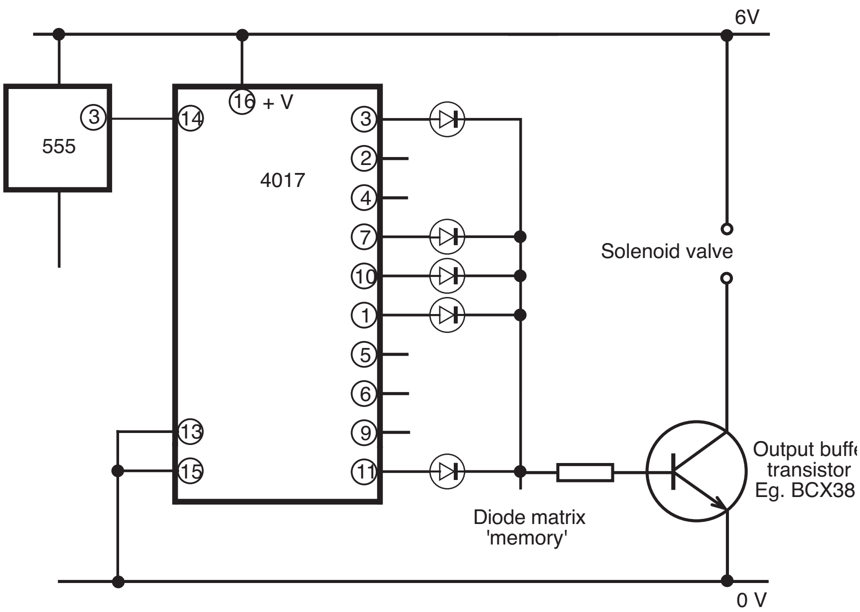


A 555 timer with a transistor output buffer could, for example, be used to keep a cylinder energised for a set period - following a signal from a sensor or from a switch momentarily closing. Even so - depending on the application - there would need to be a means of ensuring that an operator or user was not at risk following expiry of the timed interval.



Sequential Control

A dedicated controller, capable of “hard wired” programming can be constructed using a decade counter such as CMOS 4017 regulated by a “clock” - e.g. a 555 timer in its astable mode. The basic circuit is shown, but omitting all the clock details. For each clock pulse, each of the 4017 outputs goes to logic 1 in turn. The other 9 outputs remain at logic 0.



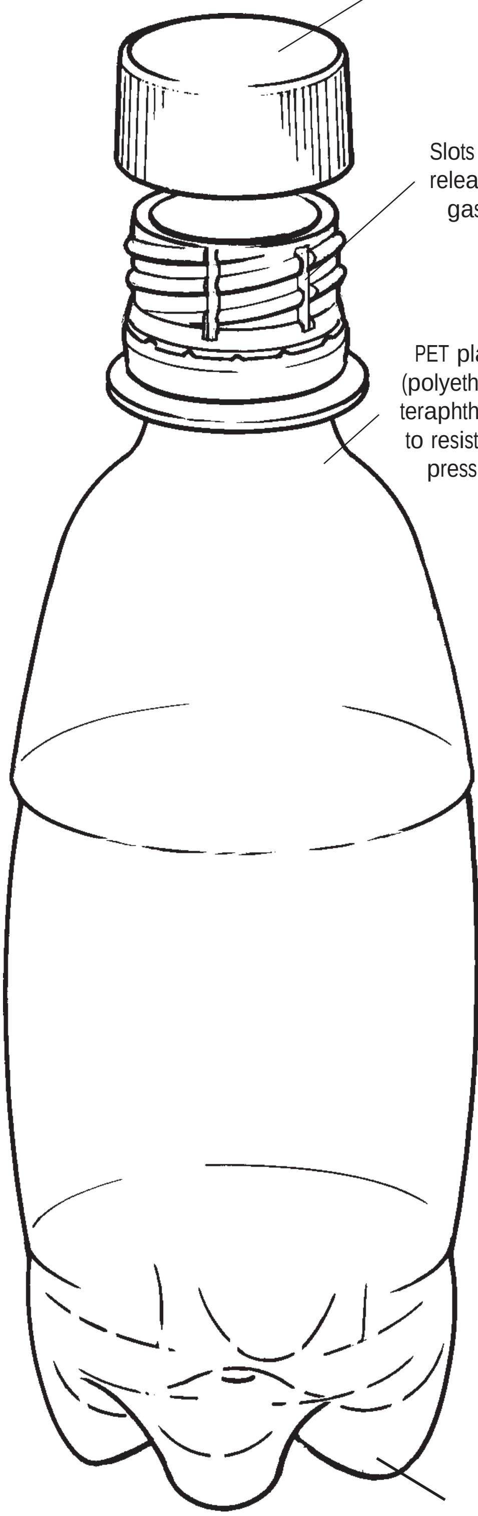
To program the controller the outputs are connected (or not connected) to a common rail via diodes. In the example shown, if the clock is running a speed of 1Hz, the solenoid valve will be energised for the first second as the first output goes to logic 1, off for the next two seconds because there is no connection to outputs, on for three seconds, off for three seconds - and so on.

STUDY FILE 1 - THE PET BOTTLE

1. The PET Fizzy Drinks Bottle

Some PET bottle facts:

- a typical 330 ml PET fizzy drinks bottle weighs only 10 grams,
- a typical PET bottle has a wall thickness of 0.2 mm which is made up of three separate layers or *laminates*,
- when a fizzy drinks bottle is shaken, it has to stand up safely to a pressure of approximately 4 bar - twice the pressure in a typical car tyre. If you work out the number of square inches on a 330 ml bottle's surface, **the total pressure loading on the bottle is approximately 1.5 tons** when the internal pressure is 4 bar,
- in tests, a typical PET bottle can withstand pressures of up to 10 bar,
- PET bottles have reduced accidents due to the fact that they are virtually impossible to break,
- it is estimated that **1.5 billion** PET bottles are sold and thrown away in the UK each year.



A Note on Pressure

$$\text{Pressure} = \frac{\text{force (in Newtons)}}{\text{area (in square metres)}}$$

The unit of pressure is the Pascal (pa for short). 1 pa = 1 Newton per square metre.

The pressure exerted by the atmosphere (atmospheric pressure) is approximately 100,000 pa. Atmospheric pressure is also used as a basis for measuring pressure in units called bars.

1 bar = atmospheric pressure = 10^5 N/m^2
2 bars = twice atmospheric pressure, etc.

Nb. Some people still use older imperial units and talk about pounds per square inch (p.s.i.) rather than newtons per square metre. Approximately 14.5 p.s.i. = 1 bar.

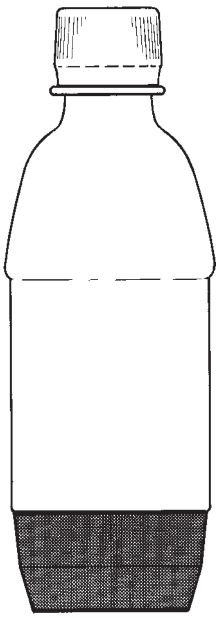
BOTTLE DESIGN & PET

Almost all plastic fizzy drinks bottles are made from a relatively new plastics material called PET. This stands for *polyethylene teraphthalate* which is a mixture (*co-polymer*) of plastics which gives very special properties. These properties include:

- **very high *tensile strength*** - resistance to stretching
- **high *impact resistance*** - the ability to withstand sudden knocks
- ***non-permeability*** - resistance to gas under pressure 'leaking' through the material

Most people take PET bottles for granted and throw them away without much thought. However, an enormous amount of thought has gone into their design to make them both cheap and safe.

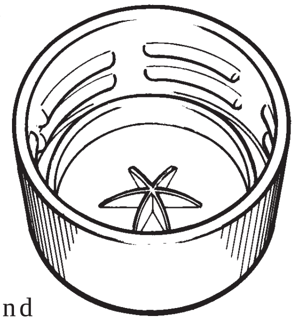
To withstand high pressures, the shape of a fizzy drinks bottle is very important. A good shape is a sphere which is sometimes used for natural gas containers. It is not a very practical shape for bottles because spheres take up a lot of space in boxes or on shelves. The next best shape is cylindrical, but this presents a problem because of the base. A thin flat base would 'balloon' outwards under pressure and cause the bottle to fall over. Some PET bottles do have a *balloon* base but these bottles also have a plastic ring at the bottom to stand on. A majority of PET bottles now have either a *champagne* base or a *petaloid* base to overcome the problem of containing pressure and at the same time enabling them to stand upright.



PET bottle with plastic ring on base for stability

The champagne base gets its name from glass champagne bottles that have an inverted dome at the bottom. The petaloid base shown in the drawing is so named because it resembles petals on a plant. It is really a number of balloon bases clustered together and because there are several of them the bottle stands up. You may think this is an obvious solution to the problem, but it took several years of development work to arrive at.

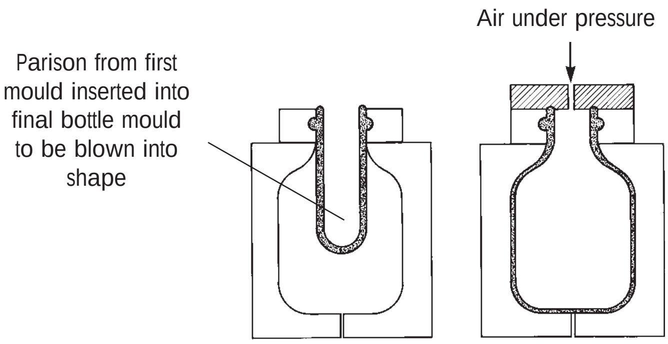
The screw cap and bottle top are also a very special designs. The cap has a built-in (*integral*) seal which gets tighter as it is twisted onto the bottle. Inside the cap star shaped *ribbing* helps to keep its top flat under pressure (see right). Without this, the cap tends to balloon out under pressure and cause the seal to break down.

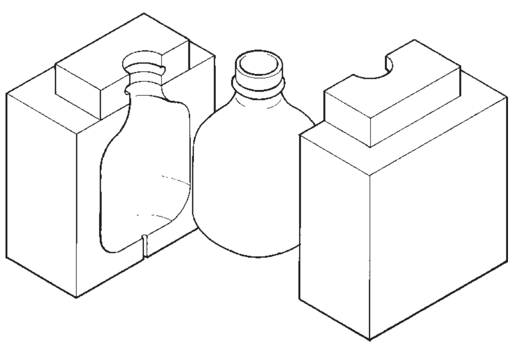


The screw threads on both the bottle top and the screw cap are slotted down their length. This is very important because when you unscrew a bottle top, it is important that any gas pressure build-up is released before the top has been fully unscrewed. Without these slots to release gas, the top could fly off under pressure and cause injury.

HOW THEY ARE MADE

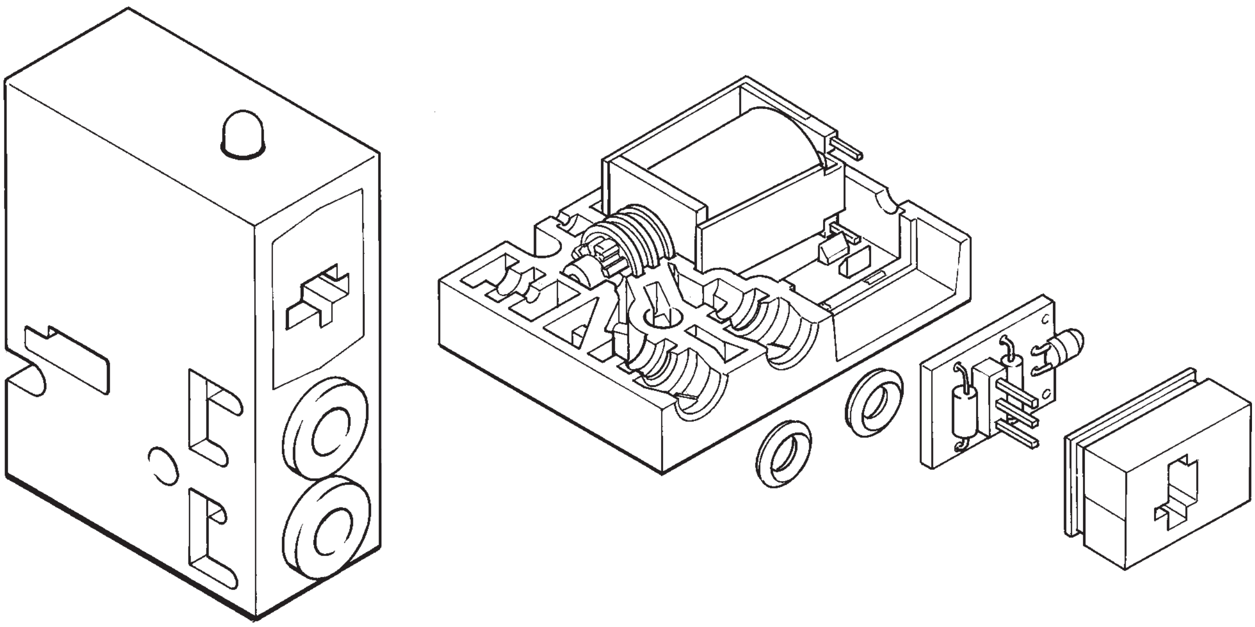
PET bottles are made by a process called *injection blow moulding*. In the first stage of this process, hot fused PET material is injected into a small mould and blown into a shape called a *parison* by the injection of air. This moulding is then transferred to a larger mould and blown into the final shape of the bottle.





STUDY FILE 2 - THE ISONIC SOLENOID VALVE

The Isonic valve is unique. Mead Fluid Dynamics has revolutionized the valve manufacturing process to optimize valve performance and reduce cost. By combining bisectional "half-shell" design with computer controlled ultrasonic welding and high quality moulded parts, the need for drilling and machining of internal flow channels has been eliminated.



Furthermore, ultrasonic welding has totally eliminated the need for fasteners, gaskets and inserts. The valves have excellent heat, chemical and impact resistance and at the same time are extremely compact.

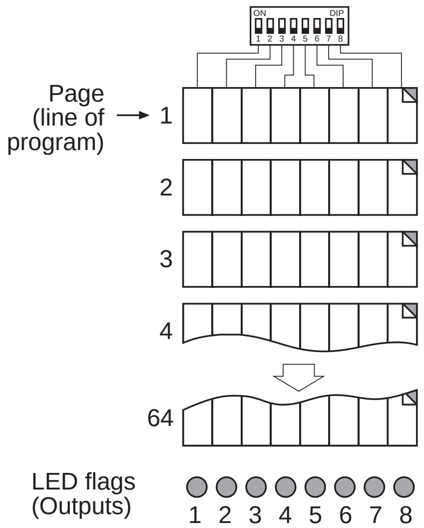
MAIN SPECIFICATIONS OF SELECTED TEP VALVE

Media	Air or inert gas
Lubrication	None required
Pressure range	1.0 bar to 6.0 bar
Temp. range	10°C - 50°C
Voltage	5 volts
Power consumption	1.3 watts continuous (at 5v)
Response time	10 milliseconds

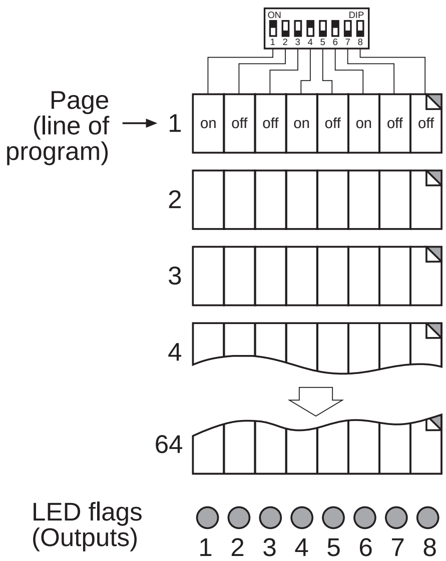
STUDY FILE 3 - TEP BIT BY BIT CONTROLLER

Basic Principles

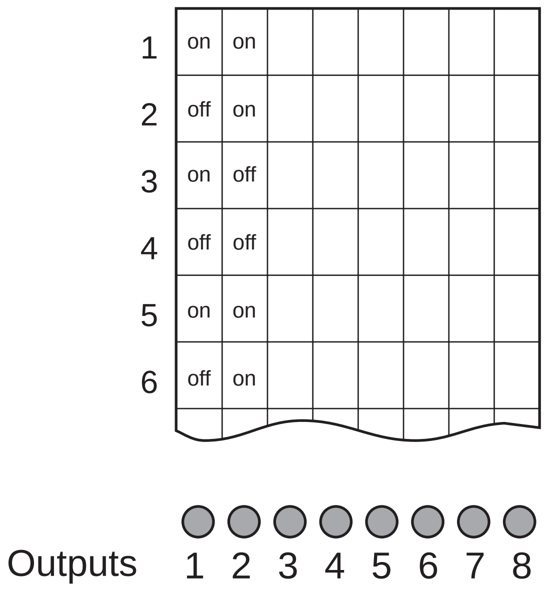
The TEP controller uses a single IC (integrated circuit) containing a memory where information can be stored in electronic form. It is useful to think of this memory as a book having a stack of pages. Every page represents a line of control programming and has 8 blank spaces - each one waiting to be filled with a bit of information. Each *vertical* column of blanks will contain the remembered instructions for a control output. Each control output is connected to an LED 'flag'.



The memory locations are filled with individual *bits* of information - of which there are only two types: logic 1 or logic 0. In the controller's memory these are really instructions which mean either turn ON an output (logic 1) or turn OFF an output (logic 0).



The information is written onto each 'page' of memory by setting the 8 DIP switches to either 'ON' or 'OFF' and then pressing the 'MEMORY' press-button switch . Pressing this button 'writes' the PROGRAM DATA switch settings into memory and automatically turns over to the next 'page'. This procedure can be repeated up to 64 times - the maximum number of pages or locations in the controller's memory.

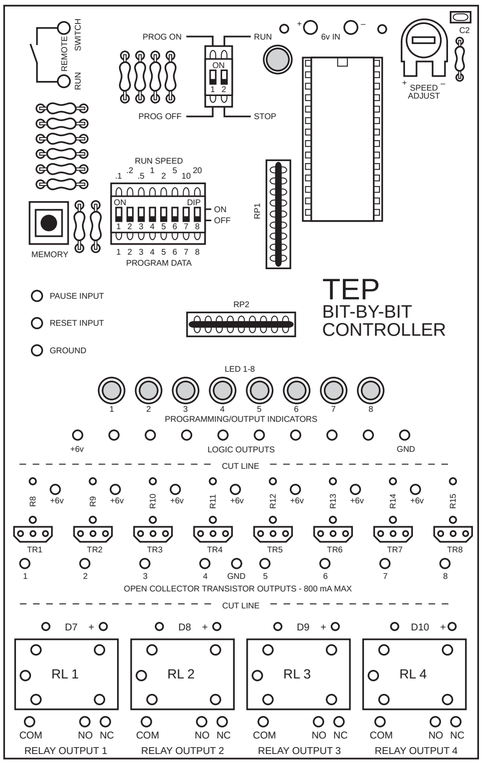


The illustration shows a sample 6-line program for the two left hand outputs. When the controller is instructed to read this program, it turns over the 'pages' at a set speed. An 'ON' bit of information lights up an output LED and an 'OFF' bit turns it off. If, for example, the controller is set to read each page for a second at a time, the LED on the far left hand side will turn on for one second off for the next and so on. LED number 2 will turn on for two seconds and then stay off for two seconds. When the program has been run - i.e., all the 'pages' turned over - the controller will automatically start again at the first line of the program. Unless it is stopped, the program will run over and over again.

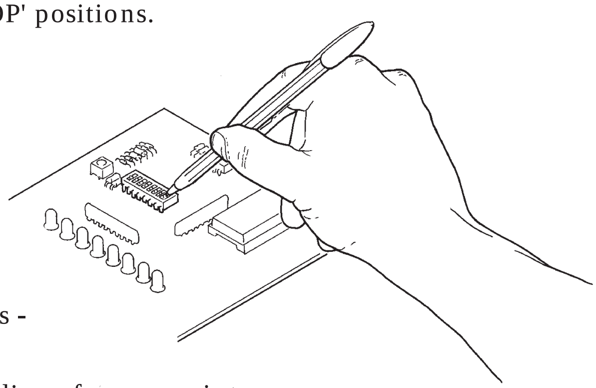
Please note: the remainder of this text will refer to **lines** of program and not pages.

Programming the Bit by Bit Controller

Using the whole-board diagram as a guide, you should now be able follow these instructions for programming the controller.



1. Make sure the RUN and PROGRAM switches at the top of the board are set at the 'PROG OFF' and 'STOP' positions.
2. Connect the battery or power supply.
3. Set the program switch to 'PROG ON'.
4. Write a line of program by setting each 'PROGRAM DATA' switch to either 'ON' or 'OFF'. This will turn the LED outputs on of off. Because the program switches are small, it is more convenient to operate them with a stylus - e.g., the tip of an empty pen.



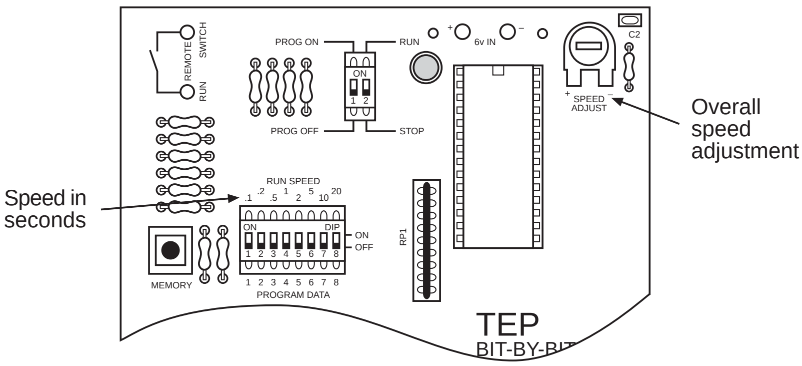
5. Press the 'MEMORY' switch to write this line of program into memory. When you do so, <u>all of the LEDs</u> will flash on briefly to confirm this has happened.
6. Repeat steps 4 and 5 above up to 64 times - once for each line of memory. If you try to go beyond 64 lines of programming, the extreme left hand LED will flash continuously.

   There is no problem if you write a program less than 64 lines. When the program is run, it will loop back to the beginning after the final line.

Running the Program

1. Switch the programming switch to 'PROG OFF'.
2. Set all the 'PROGRAM DATA' switches to the 'OFF' position.
3. The 'PROGRAM DATA' switches *will now control the program run speed*. As an example, set the fourth switch from the left to 'ON'.
4. Set the program run switch to 'RUN'. The program will now run at approximately 1 line per second. (Setting one of the other 'PROGRAM DATA' switches will run the program at a different speed - see below.) The LEDs will turn on and off according to the stored program in memory.

The speed of execution of the program depends on which 'PROGRAM DATA' switch is set to the 'ON' position and also on the setting of the 'SPEED ADJUST' resistor at the top of the board. The 'PROGRAM DATA' switches provide speed adjustment in fixed steps or ratios. The 'SPEED ADJUST' resistor provides *overall* continuous adjustment - faster or slower. To calibrate the controller to run at the speeds printed above the 'PROGRAM DATA' switches, create a simple program that turns LED 4 on for one program line, off for the next - and so on (keeping all the other LEDs off). Run this program, and time the result against a watch - altering the 'SPEED ADJUST' so that eventually the LED turns on and off at one second intervals.



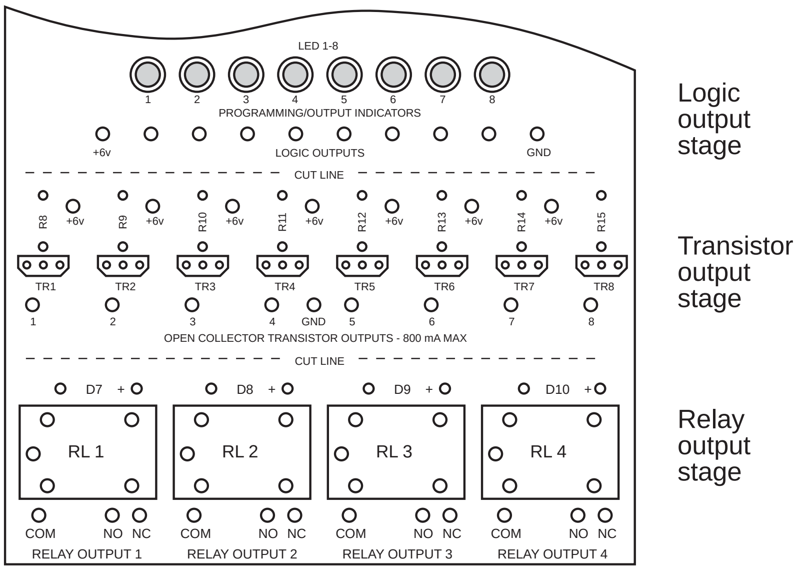
Technical note: *capacitor C2, together with the two resistors at the top right hand corner of the board, controls the chip's clock speed. This is 390 pF. If it is replaced with a lower value (no lower than 50 pF) the top run speed can be considerably increased. However, it will also have the effect of flashing the LEDs more rapidly when the memory button is pressed and the standby current consumption will increase slightly.*

If setting switch 4 provides a run speed of one program line per second, the switch on the far right will give program steps of 20 seconds duration. This adds up to a maximum 64 line program run time of 20 seconds × 64 lines = 1,280 seconds OR approximately 21 minutes. This run time can be extended further by adjusting the resistor. Remember, though, this also affects timings provided by the other 'PROGRAM DATA' switches.

Important note: The TEP controller has a volatile memory. This means that a program is lost when the power supply is disconnected although the larger capacitor at the top centre of the board will keep it energised for about 20 seconds. However, the Standby Current Consumption of the controller's chip is so low it can be left connected for most practical purposes.

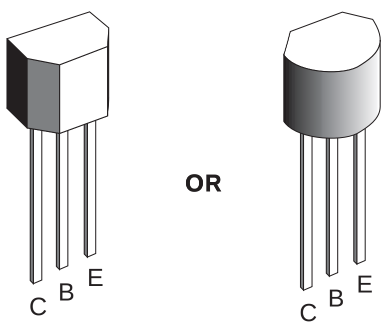
Using the Controller's Outputs

The bit by bit controller has 8 LED *flags* to show the status of each output. This enables you to create programs and run them but not to actually control anything! To switch a *load* such as a motor on or off a *buffer* stage has to be added to each output in use. For convenience, the controller board has additional printed tracks and locations for transistor buffers on all the outputs and transistor-plus-relay buffers on four of them. (Note: the board has only enough room physically for relays on the four left hand outputs.)



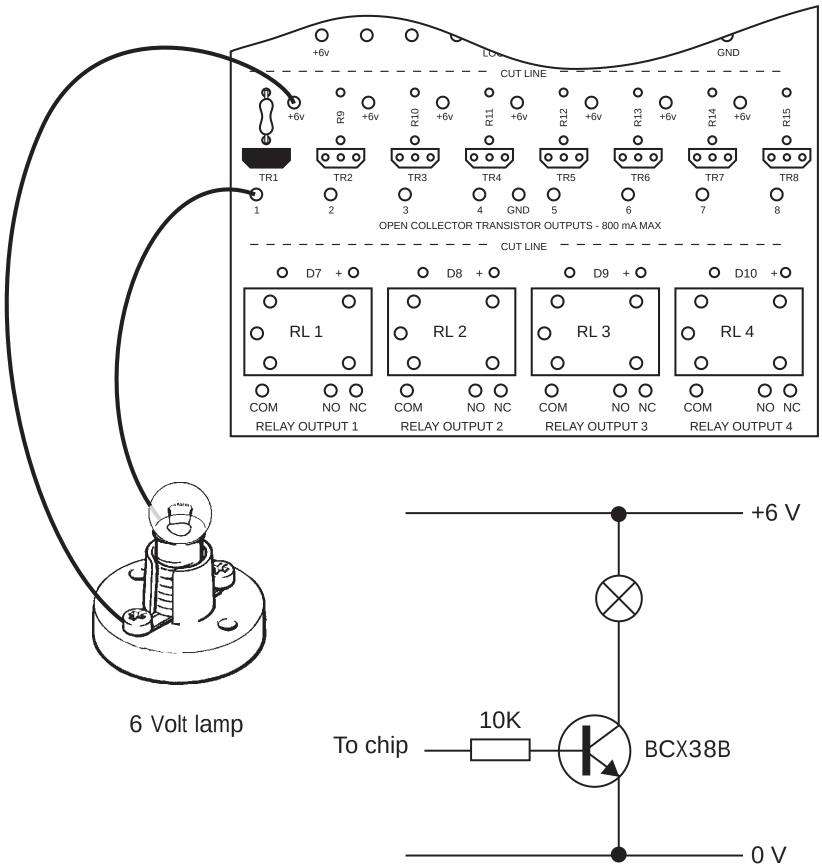
Using the Transistor Outputs

The recommended output transistor for which the board has been designed is the inexpensive BCX38B. This is a Darlington pair device and will switch on a load of nearly 1 amp (800 milliamps maximum). This is quite sufficient for most filament bulbs, buzzers and a solar motor.



BCX38B

To add a transistor to any required output, fix and solder in position a 10 K resistor and BCX38B transistor - for example, at the positions marked R8 and TR1. Make sure the transistor is the correct way around by matching the case outline with the outline on the board. Flying leads to the load are soldered to the +6 V point and open collector output for each transistor. The diagram shows a lightbulb connected to output 1. A circuit diagram for this output is also shown.



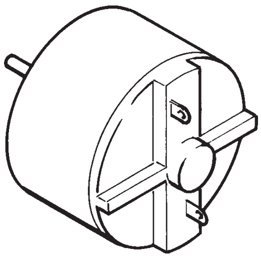
REMEMBER that when several transistors are used, the total load current - which can be quite high if all outputs are used - comes from the battery powering the controller. This could be depleted very quickly. Always work out the total load current (or an average for outputs switching on and off) and think carefully about the type of battery needed.

It is possible, for example, to run the following devices directly from the transistor outputs:

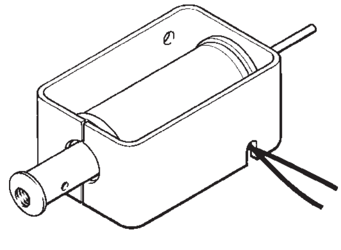
filament bulb	*buzzer*	*solar motor*
miniature solenoid	*stepper motor*	

Any motors other than the more expensive solar motor should be run from a relay. This is because they produce a high degree of electrical noise which may interfere with the operation of the chip.

A motor, solenoid or any other device with a coil is an *inductive* load and can produce a high voltage momentarily when switched off (back EMF).

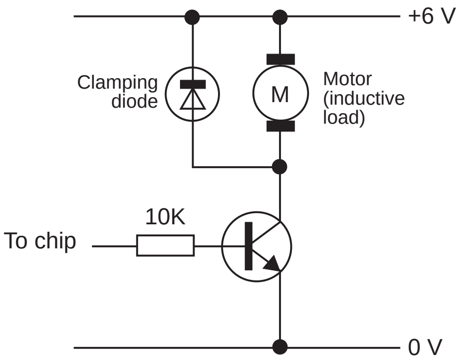


Solar motor

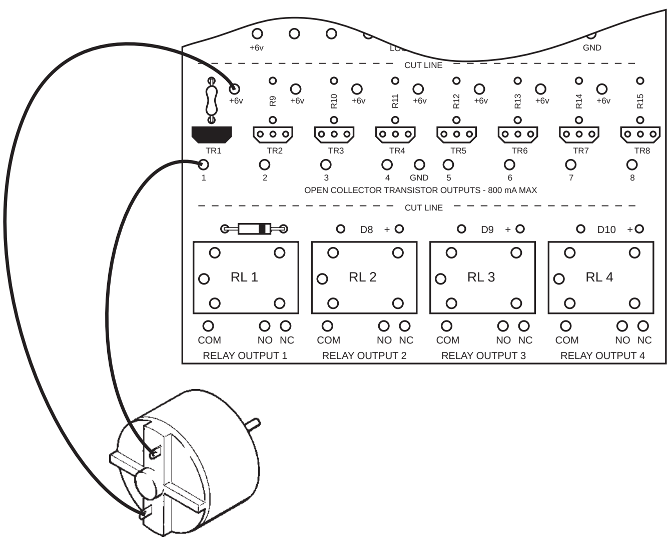


Miniature solenoid

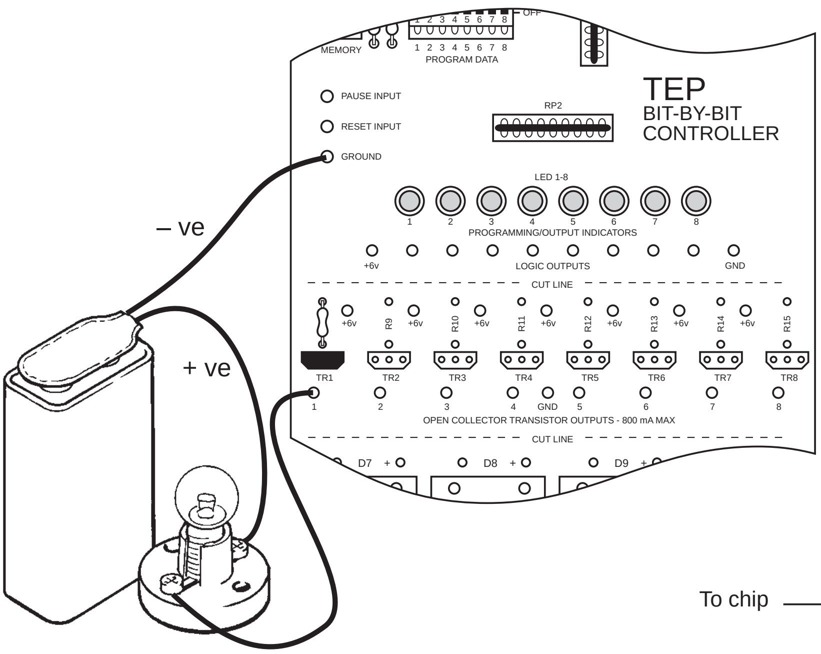
To prevent this damaging the transistor, a clamping diode should be added as shown in the diagram. This can be a general purpose type such as IN4001.

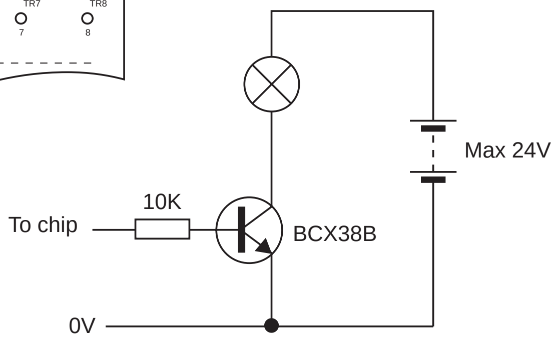


The most convenient way of connecting a clamping diode to an inductive load is to use one of the first four left hand outputs and simply solder in a diode *as if you were using a relay*. It is IMPORTANT to ensure that the diode is soldered in the correct way round - with the marked end facing towards the right.



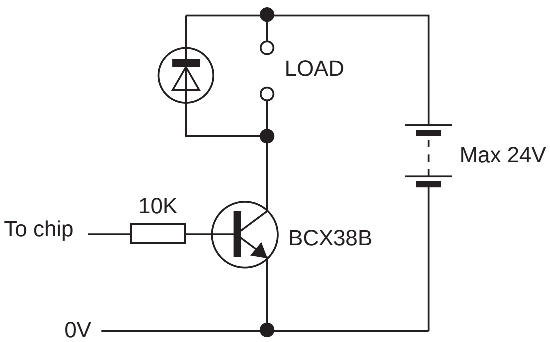
Using a transistor output with an external power supply
To avoid draining the battery powering the board itself, a load can be connected to a separate power supply, ideally a battery, up to 24V. The diagram shows a lightbulb thus connected to output 1. A circuit diagram for this output is also shown.





Remember that if a separate battery is used, the total load current should not exceed 800 mA otherwise the transistor will be damaged.

Please remember that if an inductive load, such as a motor, is connected, a clamping diode should be added as shown in the diagram below.



The easiest way to add this might be to connect it directly across the load itself; i.e. across the connecting legs of a motor in parallel with the suppression capacitors.

Component Supply

Low Pressure Pneumatics: Starter Pack
The TEP low pressure pneumatics system enables pupils to make and apply near-commercial performance air cylinders at very low cost. The starter pack provides parts for up to *seven cylinders* and comes complete with 30 metres of airline, TEP's air reservoir and three port valve. All that is needed to assemble a working system is a car footpump.
An unbound handbook is included with this pack.

Price: £23.00 Code: PAC 1112

Low Pressure Pneumatics: Comprehensive pack
This pack contains double the quantity of cylinder components of the starter pack and in addition contains a pressure gauge and two of the unique *isonic* solenoid valves which can be operated from a 4.5v to 6v battery - or direct from the "bit by bit" controller. If used with the controller, this pack provides a facility identical in principle to modern air systems where a Programmable controller controls one or more cylinders.
An unbound handbook is included with this pack.

Price: £69.00 Code: PAC 1110

Low pressure pneumatics spares pack
This provides enough components to make up 5 cylinders and includes end caps, piston parts and steel cylinder rods (threaded one end), springs, and '0' rings.
Price: £4.50 Code: PAC 1113

Low pressure pneumatics cylinder tube (1" inside diameter × 30" lengths)
Price: £3.10 each Code: CP9 004

Low pressure pneumatics end caps (pair).
Price: £0.45 per pair Code: CP9 004A

The above pneumatics systems packs, individual components and relevant publications are available from:

Teaching Resources
"E" Block
Middlesex University
Trent Park
Bramley Road
Oakwood, London N14 4XS

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