Unit 24: Applications of Pneumatics and Hydraulics

Unit code: J/601/1496   QCF level: 4   Credit value: 15

OUTCOME 2

TUTORIAL 2 – HYDRAULIC AND PNEUMATIC CYLINDERS

The material needed for outcome 2 is very extensive so there are ten tutorials in this outcome. You will also be completing the requirements for outcome 1 which is integrated into it. The series of tutorials provides an extensive overview of fluid power for students at all levels seeking a good knowledge of fluid power equipment.

2   **Understand the construction, function and operation of pneumatic and hydraulic components, equipment and plant**

Pneumatic equipment: types, construction, function and operation e.g. air compressors, coolers, dryers, receivers, distribution equipment, fluid plumbing and fittings, drain traps, FRL air service units, valves, actuators, seals

Hydraulic equipment: types, construction, function and operation e.g. fluids, pumps, motors, actuators, reservoirs, accumulators, fluid plumbing and fittings, valves, filters, seals, gauges

Performance characteristics: air compressors e.g. volumetric efficiency, compression ratio, isothermal efficiency; hydraulic pumps e.g. operating efficiency, losses, flow rate, operating pressure, shaft speed, torque and power

On completion of this tutorial you should be able to do the following.

- Revise the basic units and quantities.

- Explain the working principles of a range of hydraulic and pneumatic cylinders.

- Describe the construction of cylinders.

- Describe the seals used in cylinders.

- Describe the ways that cylinders are mounted.

- Explain the symbols for cylinders.

- Explain the relationships between pressure, speed, force and flow rate.

On completion of this tutorial you should attempt worksheet 3 obtainable from the home page for fluid power.
As circuit construction requires an understanding of other components, you may not be able to complete all the exercises at this stage in which case you should come back to them later.

1. **INTRODUCTION**

Cylinders are linear actuators which convert fluid power into mechanical power. They are also known as JACKS or RAMS.

Hydraulic cylinders are used at high pressures and produce large forces and precise movement. For this reason they are constructed of strong materials such as steel and designed to withstand large forces.

Because gas is an expansive substance, it is dangerous to use pneumatic cylinders at high pressures so they are limited to about 10 bar pressure. Consequently they are constructed from lighter materials such as aluminium and brass. Because gas is a compressible substance, the motion of a pneumatic cylinder is hard to control precisely. The basic theory for hydraulic and pneumatic cylinders is otherwise the same.

2. **THEORY**

2.1 **FORCE**

The fluid pushes against the face of the piston and produces a force. The force produced is given by the formula:

$$F = pA$$

p is the pressure in N/m^2 and A is the area the pressure acts on in m^2.

This assumes that the pressure on the other side of the piston is negligible. The diagram shows a double acting cylinder. In this case the pressure on the other side is usually atmospheric so if p is a gauge pressure we need not worry about the atmospheric pressure.
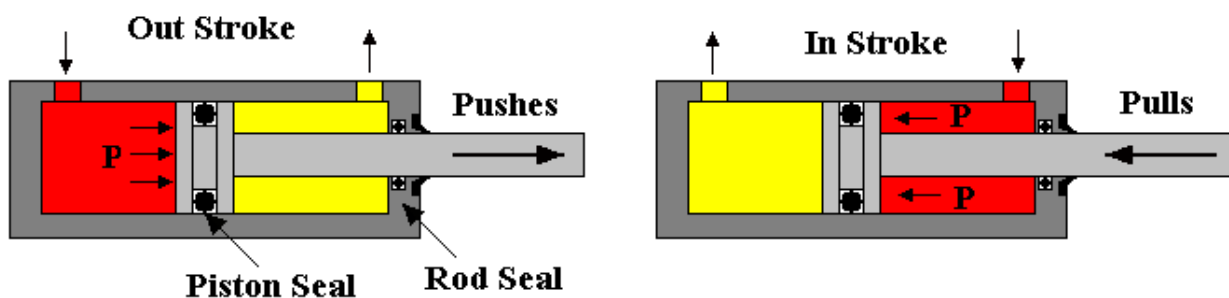
Figure 1

Let A be the full area of the piston and a be the cross sectional area of the rod. If the pressure is acting on the rod side, then the area on which the pressure acts is is (A - a).

$$F = pA \quad \text{on the full area of piston.}$$

$$F = p(A-a) \quad \text{on the rod side.}$$

This force acting on the load is often less because of friction between the seals and both the piston and piston rod.

2.2 SPEED

The speed of the piston and rod depends upon the flow rate of fluid. The volume per second entering the cylinder must be the change in volume per second inside. It follows then that:

$$Q \ m^3/s = \text{Area x distance moved per second}$$

$$Q \ m^3/s = A \times \text{velocity} \quad \text{(full side)}$$

$$Q \ m^3/s = (A\text{-}a) \times \text{velocity (rod side)}$$

Note in calculus form velocity is given by $v = A \ dx/dt$ and this is useful in control applications.

In the case of air cylinders, it must be remembered that Q is the volume of compressed air and this changes with pressure so any variation in pressure will cause a variation in the velocity.

2.3 POWER

Mechanical power is defined as Force x velocity. This makes it easy to calculate the power of a cylinder. The fluid power supplied is more than the mechanical power output because of friction between the sliding parts.

$$P = F \ v \quad \text{Watts}$$

2.4 SINGLE ACTING CYLINDERS

A simple single acting cylinder is shown below. The cylinder is only powered in one direction and needs another force to return it such as an external load (e.g. in a car hoist or jack) or a spring. No hydraulic fluid is present on the low pressure side.
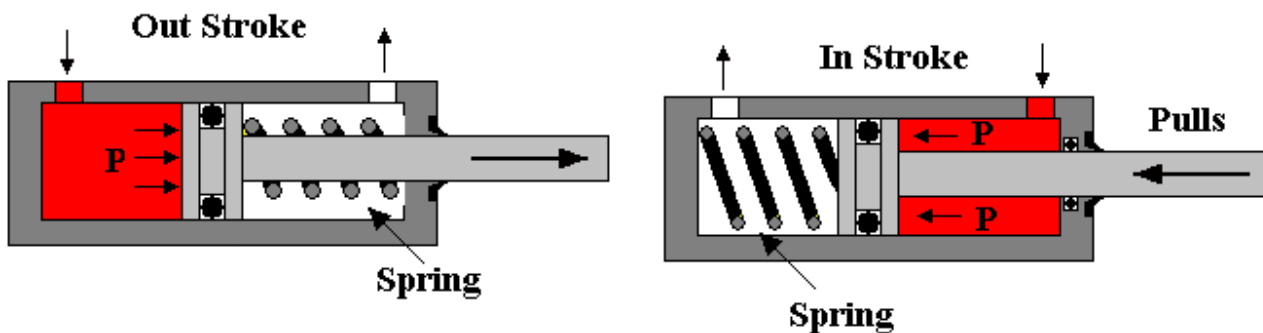
Single Acting Cylinder for Pushing   Single Acting Cylinder for Pulling
Figure 2

2.5 DOUBLE ROD CYLINDERS

The basic design of a double rod cylinder is shown below. The design allows equal force and speed in both directions. It is useful in robotic mechanisms were the rod is clamped at both ends and the body moves instead.
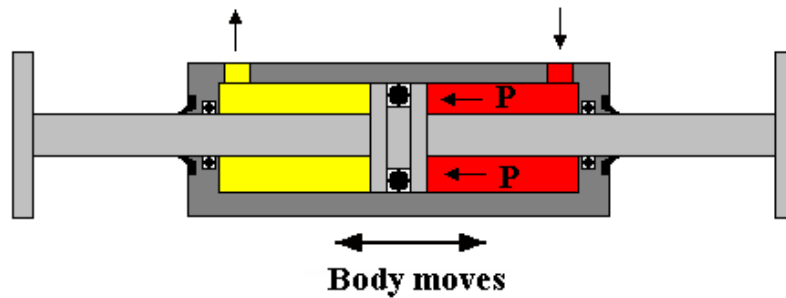
Figure 3

2.6 TELESCOPIC CYLINDERS

These cylinders produce long strokes from an initial short length. Each section slides inside a larger section.

These cylinders have from 2 to five stages. They are typically used in refuse lorries for ejecting the compacted refuse. They are also used for lifts, tipping platforms, lifting platforms and other commercial vehicle applications.
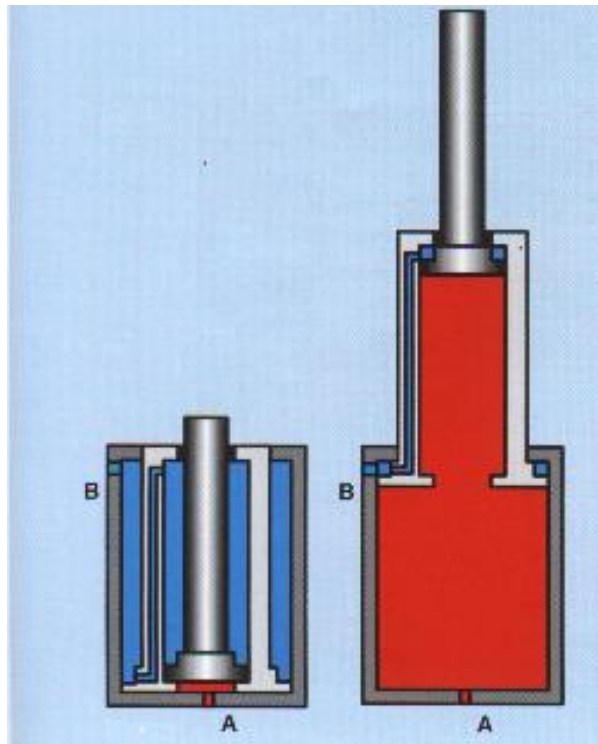
Figure 4

3. SEALS AND BEARINGS

The detailed diagram shows a double acting cylinder. The main seals used are

      1. Piston seals to prevent leakage from one side to the other.
      2. Rod seal to prevent leakage from the rod end.
      3. Static seals to prevent leakage from joints between the barrel and end caps.
      4. Wiper seal to stop dirt being drawn inside with the rod.

The bearings are

   1.   The rod end bearing made of brass or bronze. This takes the side loads on the rod and ensures lubrication and reduced wear. It also prevents the seal distorting and leaking.
   2.   The pistons bearing to take the sideways forces and reduce wear.
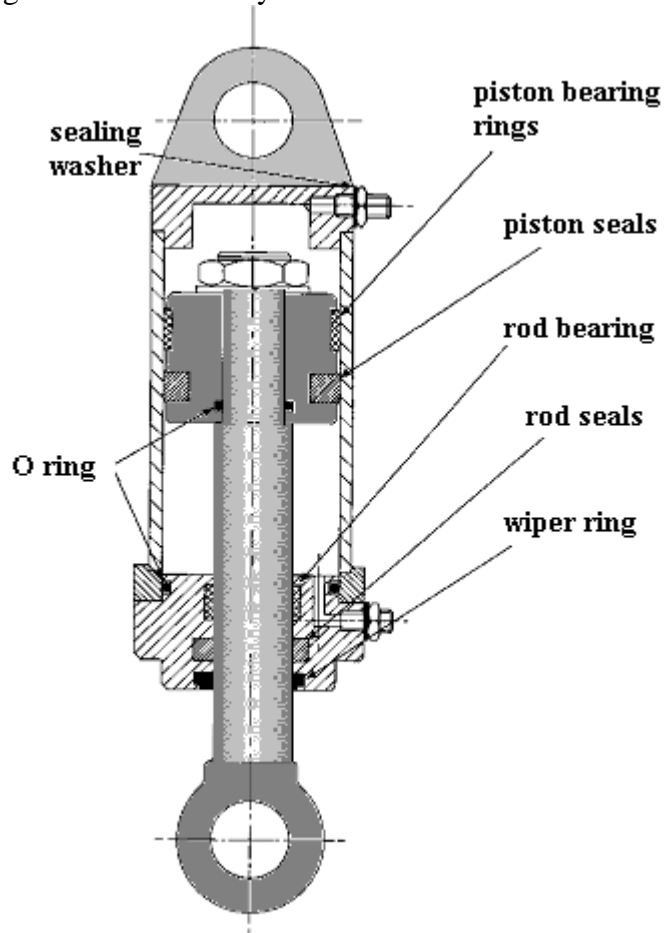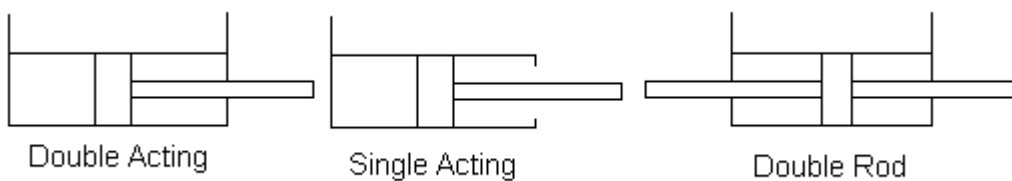
Figure 5

4. SYMBOLS

Figure 6

5. BUCKLING

Buckling occurs when the rod bends or bows out sideways under load. The longer and thinner the rod, the more likely it is for buckling to occur. When selecting a cylinder from a catalogue, the manufacturer will show information to enable you to determine the buckling load.

6. CONSTRUCTION

The detailed diagram shows the main construction details. Hydraulic cylinders are built to withstand substantial pressures and so are expensive compared to pneumatic cylinders. The body is a tube or barrel with a smooth finish to prevent seals wearing out. Steel is usually used for the strength required. The fluid ports are contained in the end caps. One end cap has a hole for the rod. The end caps must be sealed to the barrel. The picture shows cylinders with tie rods for holding the end caps in place.

Figure 7

The next picture shows cylinders with the end caps screwed onto the barrel.

Figure 8

Other methods of construction use welding and swaging techniques. These types cannot be disassembled for servicing.

In some applications no fasteners are needed and external restraints prevent the end caps blowing out.
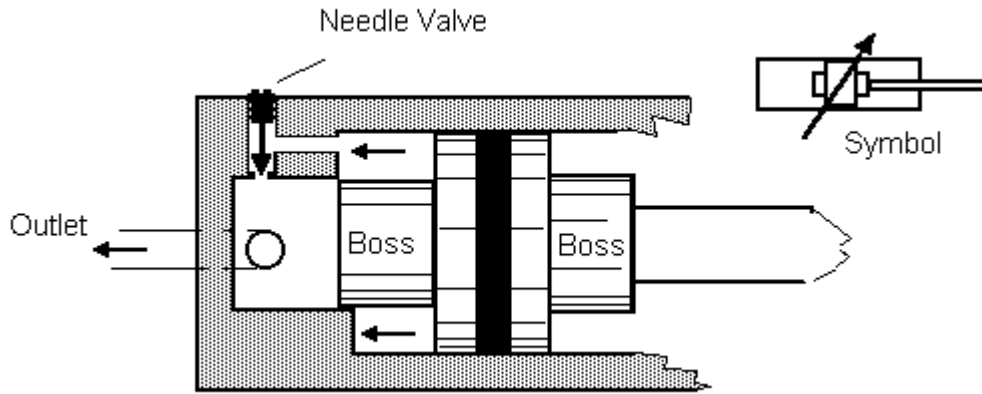
6. **CUSHIONING**

Figure 9

The fluid is normally expelled through the outlet port direct but when the cushioning boss enters the recess, the fluid around the piston is trapped. The only way the fluid can escape is through the secondary path, which is restricted by a needle valve. The needle valve is adjusted so that the piston is slowed up over the last part of its stroke by a pressure build up in the fluid escaping past the needle valve.

7. **QUICK START**

The problem with cushioning is that when you try to move the piston back the other way, fluid only has the cushioning boss to push on and because it is a small area the force may not be enough to move it or it may only move slowly until the boss clears the recess. To get around this a one way check valve is placed in parallel with the needle valve so that fluid can easily get into the space behind the piston and push on the full area.

8. **END FIXINGS**

The diagram shows typical ways of mounting cylinders and attaching them to machines.
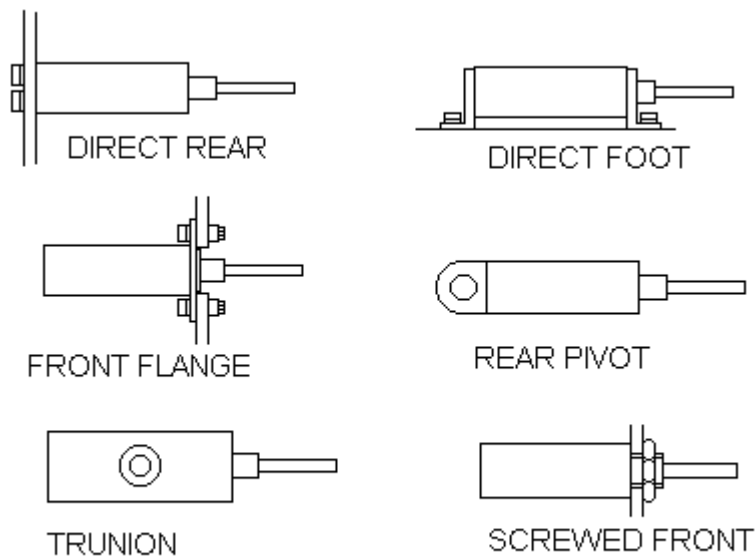

Figure 10

9. CYLINDER SPEED CONTROL

The basic method of controlling the speed is by controlling the flow in or out of the cylinder. The simplest way is to place a restrictor on the appropriate port but this reduces the thrust and wastes energy through friction.

One of the problems with pneumatics is the compressibility of the air which makes it unsuitable for precise movement control in applications such as machine tools and robots. This problem is overcome by the use of air/oil systems (covered later). The cylinder is filled with oil and both ports are connected to a storage vessel with oil in them. The oil in these vessels has air supplied to the top. When air pressure is supplied to one tank, the oil is forced into the cylinder. The pressures are low and the cylinders are often pneumatic cylinders. The speed is controlled by a one way variable restrictor on each port. This system has the cost benefit and flexibility of a pneumatic system but with the precise and steady motion of hydraulics.

WORKED EXAMPLE No.1

A double acting hydraulic cylinder has a bore of 100 mm. The rod is 40 mm diameter and the stroke is 120 mm. It must produce a pushing force of 12 kN. The flow rate available in both directions is 12 dm^3/min.

Calculate:
i.   The system pressure needed.
ii. The force with which it pulls given the same pressure.
iii. The speed on the outward stroke.
iv. The speed of retraction.
v.   The power used on the outstroke.

Assume ideal conditions throughout.

SOLUTION

$A = \pi D2/4 = \pi \times 0.1^2/4 = 7.854 \times 10^{-3}$ m^2

$p = F/A = 12000/ 7.854 \times 10^{-3} = 1.528 \times 10^6$ N/m^2 = or 1.528 MPa

$a = \pi d^2/4 = \pi \times 0.04^2/4 = 1.257 \times 10^{-3}$ m^2

Pulling force = $p(A-a) = 1.528 \times 10^6 \times (7.854 \times 10^{-3} - 1.257 \times 10^{-3}) = 10008$ N

Flow rate $Q = 0.012/60 = 20 \times 10^{-3}$ m^3/s

Speed on the outward stroke = $Q/A = 20 \times 10^{-3} / 7.854 \times 10^{-3} = 0.025$ m/s or 25 mm/s

Speed of retraction = $Q/(A-a) = 20 \times 10^{-3}/(7.854 \times 10^{-3} - 5.027 \times 10^{-3}) = 0.03$ m/s or 30 mm/s

Power = $pQ = 1.528 \times 10^6 \times 20 \times 10^{-3} = 305.6$ Watts

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1. A double acting hydraulic cylinder with a single rod must produce a thrust of 80 kN and move out with a velocity of 3 mm/s on the out stroke (positive stroke). The operating pressure is 100 bar gauge. Calculate the bore diameter required and the flow rate of the oil.

    (Answers 101 mm and 24 cm^3/s)

2. The cylinder in question has a rod diameter 25 mm. If the flow rate and pressure are the same on the retraction (negative) stroke, what would be the force and speed available?

    (Answers 75 kN and 3.2 mm/s)

3. A single acting hydraulic cylinder has a piston 75 mm diameter and is supplied with oil at 80 bar gauge and 0.265 dm^3/s. Calculate the thrust, velocity and power.

    (Answers 35.343 kN, 60 mm/s and 2.12 kW)

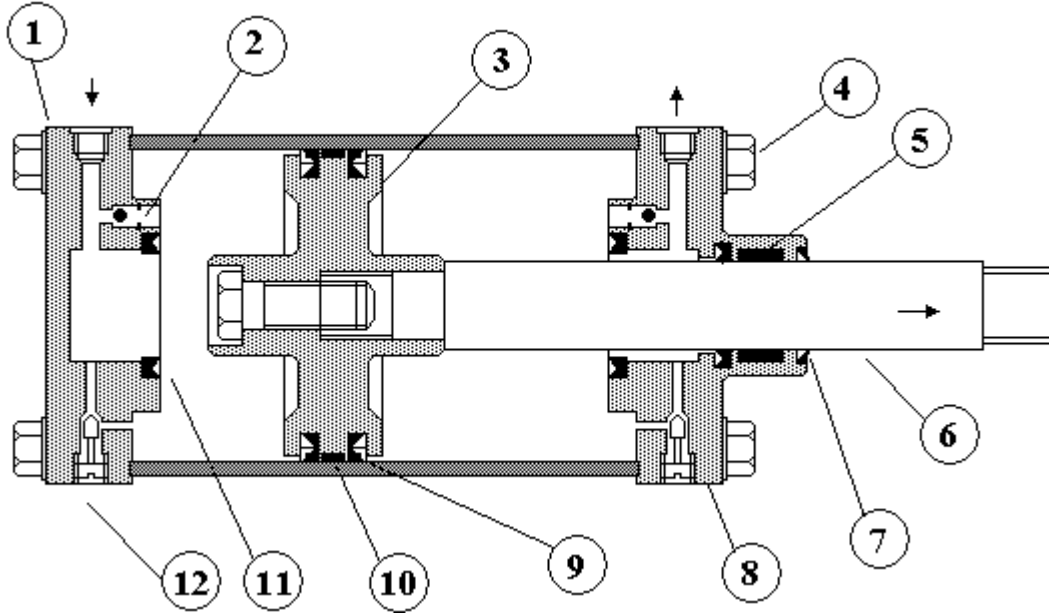**This is a good point to do Worksheet No. 5 as part of your assessment.**

WORK SHEET 5

CYLINDERS

This self assessment is in the form of a worksheet to be completed by the student.

PART 1   CONSTRUCTION OF A PNEUMATIC CYLINDER

Identify by name the parts of a typical pneumatic cylinder shown on the diagram.

1.   _____

2.   _____

3.   _____

4.   _____

5.   _____

6.   _____

7.   _____

8.   _____

9.   _____

10. _____

11. _____

PART 2   QUESTIONS

1.   Draw the symbol for a single acting cylinder.

2.   Draw the symbol for a double acting cylinder with cushioning.

3.   Explain in one sentence why pneumatic cylinders are used at low pressures and hydraulic cylinders at high pressures.

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_____

_____

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PART 3   HYDRAULIC CYLINDER CIRCUIT

If you have access to suitable test rig or simulation software, you should construct this circuit and try out the following demonstration.

A hydraulic cylinder is mounted vertically and has a large weight on the rod that is lifted when pressure is applied to the annular side of the piston.

This demonstration is to show that pressures higher than the operating pressure can be generated on a hydraulic cylinder with a restricted outlet.
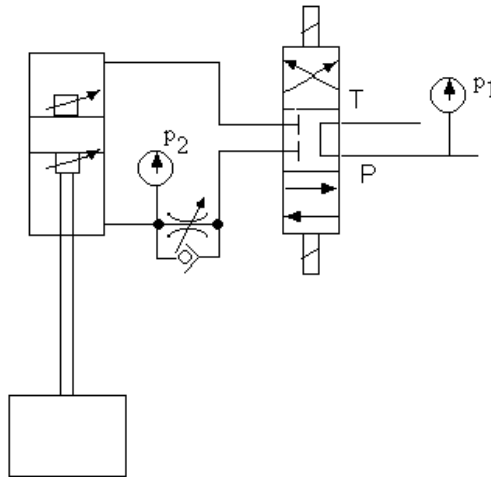
Operate the load up and down and adjust the restrictor to give slow descent.

Note the system pressure p_1._____   Note the pressure on the bottom p_2. _____

Explain why p_2 is larger than the system pressure.

_____

_____

_____

Demonstrate that you can stop the piston half way. Explain how the directional valve enables this to happen.

_____

_____

PART 4   CUSHIONING

Adjust the cushioning on the bottom of the cylinder and demonstrate various degrees of cushioning. Explain in a few words what the purpose of cushioning is.

_____

_____

_____