Design and Fabrication of Compressed Air Engine.

Final Year Project

For the award of

Bachelor of Technology (B. Tech.) in

Mechanical Engineering

Submitted By:

Manik Gupta	(2006EME21)
Vishavjeet Singh	(2006EME26)
Harish Gupta	(2006EME29)
Sudhanshu Rometra	(2006EME37)
Zorawar Singh	(2006EME49)

Under the Supervision of:

Mr. R.K. Shahu

(Lecturer)

School of Mechanical Engineering

Shri Mata Vaishno Devi University, Katra (J&K), India .

April, 2010.

CERTIFICATE

This is to certify that the thesis entitled " Design and Fabrication of Compressed Air Engine” is being submitted by Manik Gupta , Zorawar Singh, Sudhanshu Rometra, Harish Gupta, Vishavjeet Singh to School of Mechanical Engineering, College of Engineering, Shri Mata Vaishno Devi University, Katra (J&K), for the award of the Bachelor of Technology in Mechanical, is a bonafide work carried out by them under my supervision and guidance.

The results obtained by us have not been submitted to any other university or institute, either in part or in full, for the award of any other degree or diploma.

Guide:	Director:
Mr. R.K. Shahu	Dr. A.S.Sudan
(Lecturer)	School Of Mechnical Engineering
School of Mechanical Engineering	

ACKNOWLEDGEMENT

We are highly thankful to Mr. R.K. Shahu of Mechanical Engineering Department, S.M.V.D. University, Katra for his efficient guidance and support. He always encouraged and inspired us a lot to work hard and get through the problems. We extend our gratitude to him for being the guiding force. His ever increasing helping nature needs a special mention.

We would also like to thank all the faculty of School of Mechanincal Engineering, to provide us all the help that we required at different stages of completion of our project work.

Last, but not the least , we would like to thank our friends for their encouragement and help which they gave us to overcome the difficulties at various stages of our project work.

S.M.V.D. University

April, 2010

Contents: Page no.

Chapter 1: Introduction

- Compressed Air Engine Basics
- History
- Applications
- Advantages
- Disadvantages

1.1 Compressed Air Engine Basics:

A Compressed-air engine is a pneumatic actuator that creates useful work by expanding compressed air. A compressed-air vehicle is powered by an air engine, using compressed air, which is stored in a tank. Instead of mixing fuel with air and burning it in the engine to drive pistons with hot expanding gases, compressed air vehicles (CAV) use the expansion of compressed air to drive their pistons.

They have existed in many forms over the past two centuries, ranging in size from hand held turbines up to several hundred horsepower. For example, the first mechanically-powered submarine, the 1863 Plongeur, used a compressed-air engine.

The laws of physics dictate that uncontained gases will fill any given space. The easiest way to see this in action is to inflate a balloon. The elastic skin of the balloon holds the air tightly inside, but the moment you use a pin to create a hole in the balloon's surface, the air expands outward with so much energy that the balloon explodes. Compressing a gas into a small space is a way to store energy. When the gas expands again, that energy is released to do work. That's the basic principle behind what makes an air car go.

Some types rely on pistons and cylinders, others use turbines. Many compressed air engines improve their performance by heating the incoming air, or the engine itself. Some took this a stage further and burned fuel in the cylinder or turbine, forming a type of internal combustion engine.

One manufacturer claims to have designed an engine that is 90 percent efficient. Compressed air propulsion may also be incorporated in hybrid systems, e.g., battery electric propulsion and fuel tanks to recharge the batteries. This kind of system is called hybrid-pneumatic electric propulsion. Additionally, regenerative braking can also be used in conjunction with this system.

1.2 History:

a) The first compressed-air vehicle was devised by Bompas, a patent for a locomotive being taken out in England in 1828. There were two storage tanks between the frames, with conventional cylinders and cranks. It is not clear if it was actually built. (Knight, 1880)

b) The first recorded compressed-air vehicle in France was built by the Frenchmen Andraud and Tessie of Motay in 1838. A car ran on a test track at Chaillot on the 9th July 1840, and worked well, but the idea was not pursued further.

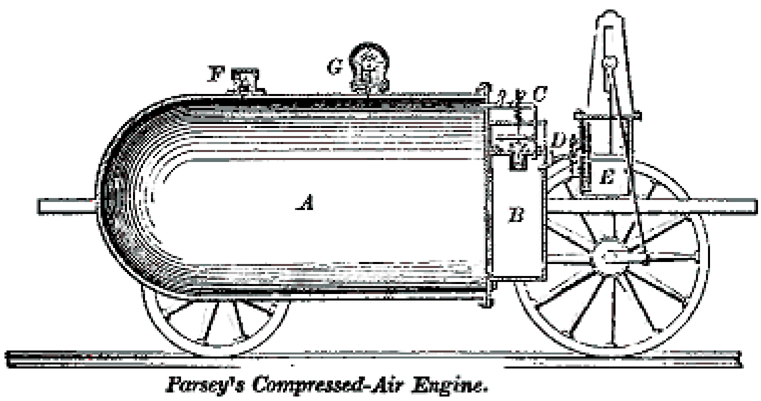


Fig: 1.1

c) In 1848 Barin von Rathlen constructed a vehicle which was reported to have been driven from Putney to Wandsworth (London) at an average speed of 10 to 12 mph.

d) At the end of 1855, a constructor called Julienne ran some sort of vehicle at Saint-Denis in France, driven by air at 25 atmospheres (350 psi), for it to be used in coal mines.

e) Compressed air locomotives were use for haulage in 1874 while the Simplon tunnel was being dug. An advantage was that the cold exhaust air aided the ventilation of the tunnel.

f) Louis Mékarski built a standard gauge self-contained tramcar which was tested in February 1876 on the Courbevoie-Etoile Line of the Paris Tramways Nord (TN), where it much impressed the current president and minister of transport Maréchal de MacMahon. The tramcar was also shown at the exhibition of 1878 as it seemed to be an ideal transport method, quiet, smooth, without smoke, fire or the possibility of boiler explosion.

g) The compressed-air locos were soon withdrawn due to a number of accidents, possibly caused by icing in the pipes of the brakes, which were also worked by compressed air.

h) In Louis Mékarski built a standard gauge self-contained tramcar which was tested in February 1876 on the Courbevoie-Etoile Line of the Paris Tramways Nord (TN), where it much impressed the current president and minister of transport Maréchal de MacMahon. The tramcar was also shown at the exhibition of 1878 as it seemed to be an ideal transport method, quiet, smooth, without smoke, fire or the possibility of boiler explosion.

1.3 Applications:

The compressed air engine can be used in many vehicles. Some of its applications to be used as engine for vehicles are:

a) Mopeds
   Jem Stansfield, an English inventor has been able to convert a regular scooter to a compressed air moped. This has been done by equipping the scooter with a compressed air engine and air tank.

b) Buses
MDI makes MultiCATs vehicle that can be used as buses or trucks. RATP has also already expressed an interest in the compressed-air pollution-free bus.

c) Locomotives
Compressed air locomotives have been historically used as mining locomotives and in various areas.

d) Trams
Various compressed-air-powered trams were trialed, starting in 1876 and has been successfully implemented in some cases.

e) Watercraft and aircraft
Currently, no water or air vehicles exist that make use of the air engine. Historically compressed air engines propelled certain torpedoes.

1.4 Advantages:

The advantages are well publicised since the developers need to make their machines attractive to investors. Compressed-air vehicles are comparable in many ways to electric vehicles, but use compressed air to store the energy instead of batteries. Their potential advantages over other vehicles include:

a) Much like electrical vehicles, air powered vehicles would ultimately be powered through the electrical grid, which makes it easier to focus on reducing pollution from one source, as opposed to the millions of vehicles on the road.

b) Transportation of the fuel would not be required due to drawing power off the electrical grid. This presents significant cost benefits. Pollution created during fuel transportation would be eliminated.

c) Compressed air technology reduces the cost of vehicle production by about 20%, because there is no need to build a cooling system, fuel tank, Ignition Systems or silencers.

d) Air, on its own, is non-flammable.

e) High torque for minimum volume.

f) The mechanical design of the engine is simple and robust.

g) Low manufacture and maintenance costs as well as easy maintenance.

h) Compressed-air tanks can be disposed of or recycled with less pollution than batteries.

i) Compressed-air vehicles are unconstrained by the degradation problems associated with current battery systems.

j) The tank may be able to be refilled more often and in less time than batteries can be recharged, with re-fuelling rates comparable to liquid fuels.

k) Lighter vehicles would mean less abuse on roads. Resulting in longer lasting roads.

l) The price of fuelling air-powered vehicles will be significantly cheaper than current fuels.

1.5 Disadvantages:

Like the modern car and most household appliances, the principal disadvantage is the indirect use of energy. Energy is used to compress air, which - in turn - provides the energy to run the motor. Any conversion of energy between forms results in loss. For conventional combustion motor cars, the energy is lost when oil is converted to usable fuel - including drilling, refinement, labour, storage, eventually transportation to the end-user. For compressed-air cars, energy is lost when electrical energy is converted to compressed air.

a) When air expands, as it would in the engine, it cools dramatically (Charles law) and must be heated to ambient temperature using a heat exchanger similar to the Intercooler used for internal combustion engines. The heating is necessary in order to obtain a significant fraction of the theoretical energy output. The heat exchanger can be problematic. While it performs a similar task to the Intercooler, the temperature difference between the incoming air and the working gas is smaller. In heating the stored air, the device gets very cold and may ice up in cool, moist climates.

b) Refuelling the compressed air container using a home or low-end conventional air compressor may take as long as 4 hours though the specialized equipment at service stations may fill the tanks in only 3 minutes.

c) Tanks get very hot when filled rapidly. SCUBA tanks are sometimes immersed in water to cool them down when they are being filled. That would not be possible with tanks in a car and thus it would either take a long time to fill the tanks, or they would have to take less than a full charge, since heat drives up the pressure.

d) Early tests have demonstrated the limited storage capacity of the tanks; the only published test of a vehicle running on compressed air alone was limited to a range of 7.22 km.

e) A 2005 study demonstrated that cars running on lithium-ion batteries out-perform both compressed air and fuel cell vehicles more than three-fold at same speeds. MDI has recently claimed that an air car will be able to travel 140km in urban driving, and have a range of 80 km with a top speed of 110km/h on highways, when operating on compressed air alone.

Chapter 2: Literature Review

- Description of Mechanical Components
- Description of Electronic Components
- Study of the Compressed Air Engine and its Working.

2. Description of Components of Compressed Air Engine:

Various Mechanical parts used in engine are:

1. Crank shaft
2. Connecting rod
3. Piston cylinder
4. Valves
5. Roller bearing

2.1 Description of Mechanical Parts:

2.1.1 Crank shaft:

The **crankshaft**, sometimes casually abbreviated to ***crank***, is the part of an **engine** which translates reciprocating motion into rotary motion or vice versa. Crank shaft consists of the shaft parts which revolve in the main bearing, the crank pins to which the big ends of the connecting rod are connected, the crank webs or cheeks which connect the crank pins and the shaft parts.

Fig 2.1

Crank shafts can be divided into two types:

1. Crank shaft with a side crank or overhung crank.
2. Crank shaft with a centre crank.

A crank shaft can be made with two side cranks on each end or with two or more centre cranks. A crank shaft with only one side crank is called a *single throw crank shaft* and the one with two side cranks or two centre cranks as a *multi throw crank shaft.*

The overhung crank shaft is used for medium size and large horizontal engines. Its main advantage is that only two bearings are needed, in either the single crank or two crank, crank shafts. Misalignment causes most crank shaft failures and this danger is less in shafts with two bearings than with three or more supports. Hence, the number of bearings is very important factor in design. To make the engine lighter and shorter, the number of bearings in automobiles should be reduced.

For the proper functioning, the crank shaft should fulfil the following conditions:

1. Enough strength to withstand the forces to which it is subjected i.e. the bending and twisting moments.
2. Enough rigidity to keep the distortion a minimum.
3. Stiffness to minimize. And strength to resist, the stresses due to torsional vibrations of the shaft.
4. Sufficient mass properly distributed to see that it does not vibrate critically at the speeds at which it is operated.
5. Sufficient projected areas of crank pins and journals to keep down the bearing pressure to a value dependent on the lubrication available.
6. Minimum weight, especially in aero engines.

The crank shafts are made much heavier and stronger than necessary from the strength point of view so as to meet the requirements of rigidity and vibrations. Therefore, the weight cannot be reduced appreciably by using a material with a very high strength. The material to be selected will always depend upon the method of manufacture i.e. cast, forged, or built up. Built up crank shafts are sometimes used in aero engines where light weight is very important.

In industrial engines, 0.35 carbon steel of ultimate tensile strength 500 to 525 MPa and 0.45 carbon steel of ultimate tensile strength of about 627 to 780 MPa are commonly used. In transport engines, alloy steel e.g. manganese steel having ultimate strength of about 784 to 940 MPa is generally used. In aero engines, nickel chromium steel having ultimate tensile strength of about 940 to 1100 MPa is generally used.

Failure of crank shaft may occur at the position of maximum bending; this may be at the centre of the crank or at either end. In such a condition the failure is due to bending and the pressure in the cylinder is maximal. Second, the crank may fail due to twisting, so the connecting rod needs to be checked for shear at the position of maximal twisting. The pressure at this position is the maximal pressure, but only a fraction of maximal pressure.

2.1.2. Connecting rod:

Connecting rod is a part of the engine which is used to transmit the push and pull from the piston pin to the crank pin. In many cases, its secondary function is to convey the lubricating oil from the bottom end to the top end i.e. from the crank pin to the piston pin and then for the splash of jet cooling of piston crown. The usual form of connecting rod used in engines has an eye at the small end for the piston pin bearing, a long shank, and a big end opening which is usually split to take the crankpin bearing shells.

The connecting rods of internal combustion engine are mostly manufactured by drop forging. The connecting rod should have adequate strength and stiffness with minimum weight. The materials for connecting rod range from mild or medium carbon steel to alloy steels.

In industrial engines, carbon steel with ultimate tensile strength ranging from 550 to 670 MPa is used. In transport engines, alloy steel having a strength of about 780 to 940 MPa is used e.g., manganese steel. In aero engines, nickel chrome steel having ultimate tensile strength of about 940 to 1350 MPa is most commonly used.

For connecting rod of low speed horizontal engines, the material may be sometimes steel castings. For high speed engines, connecting rod may also be made up of duralumin and aluminium alloys.

The usual shape of connecting rod is:

- Rectangular
- Circular
- Tubular
- I section
- H section

In low speed engines, the section is usually circular with flattened sides, or rectangular, the larger dimension being in the plane of rotation. In high speed engines, lightness of connecting rod is a major factor. Therefore tubular, I-section or H-section rods are used.

Fig 2.2

The length of the connecting rod depends upon the ratio of connecting rod length and stroke i.e. l/r ratio; on l/r ratio depends the angularity of the connecting rod with respect to the cylinder centre line. The shorter the length of the connecting rod l in respect to the crank radius r, the smaller the ratio l/r, and greater the angularity. This angularity also produces a side thrust of the piston against the liner. The side thrust and the resulting wear of the liner decreases with a decrease in the angularity. However, an increase of l/r ratio increases the overall height of the engine. Due to these factors, the common values of l/r ratio are 4 to 5.

The stresses in the connecting rod are set up by a combination of forces. The various forces acting on the connecting rod are:

1. The combined effect of gas pressure on the piston and the inertia of the reciprocating parts.
2. Friction of the piston rings and of the piston.
3. Inertia of the connecting rod.
4. The friction of the two end bearings i.e. of the piston pin bearing and the crank pin bearing.

2.1.3. Bearing:

The concept behind a bearing is very simple: Things roll better than they slide. The wheels on your car are like big bearings. If you had something like skis instead of wheels, your car would be a lot more difficult to push down the road. That is because when things slide, the **friction** between them causes a **force** that tends to slow them down. But if the two surfaces can roll over each other, the friction is greatly reduced.

Bearings reduce friction by providing smooth metal balls or rollers, and a smooth inner and outer metal surface for the balls to roll against. These balls or rollers "bear" the load, allowing the device to spin smoothly.

Working of a Bearing:

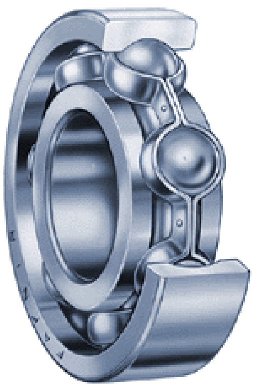
As one of the bearing races rotates it causes the balls to rotate as well. Because the balls are rolling they have a much lower coefficient of friction than if two flat surfaces were rotating on each other.

Ball bearings tend to have lower load capacity for their size than other kinds of rolling-element bearings due to the smaller contact area between the balls and races. However, they can tolerate some misalignment of the inner and outer races.

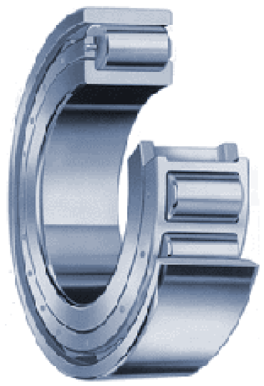
Compared to other rolling-element bearings, the ball bearing is the least expensive, primarily because of the low cost of producing the balls used in the bearing.

Types of Bearings:

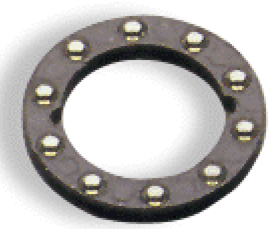
There are many types of bearings, each used for different purposes. These include ball bearings, roller bearings, ball thrust bearings, roller thrust bearings and tapered roller thrust bearings.



Cut away view of a ball bearing

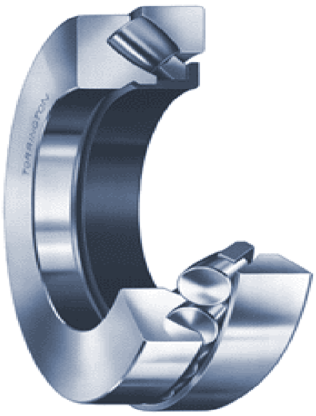


Cut away view of a roller bearing



Ball thrust bearing

Roller thrust bearing

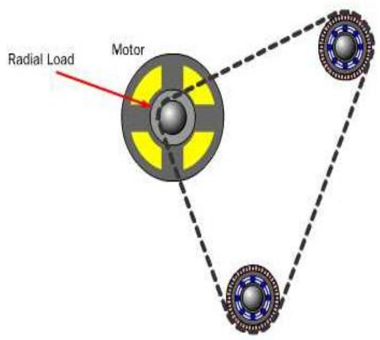


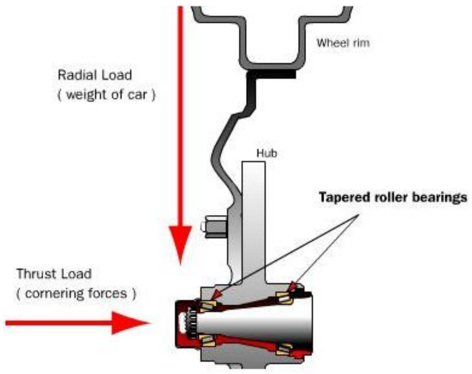
Cutaway view of (left) a spherical roller thrust bearing and (right) a radial tapered roller bearing

Fig 2.4

Bearing Loads:

Bearings typically have to deal with two kinds of loading, radial and thrust. Depending on where the bearing is being used, it may see all radial loading, all thrust loading or a combination of both.





The bearings that support the shafts of motors and pulleys are subject to a radial load.

Fig 2.5

Bearing Used:

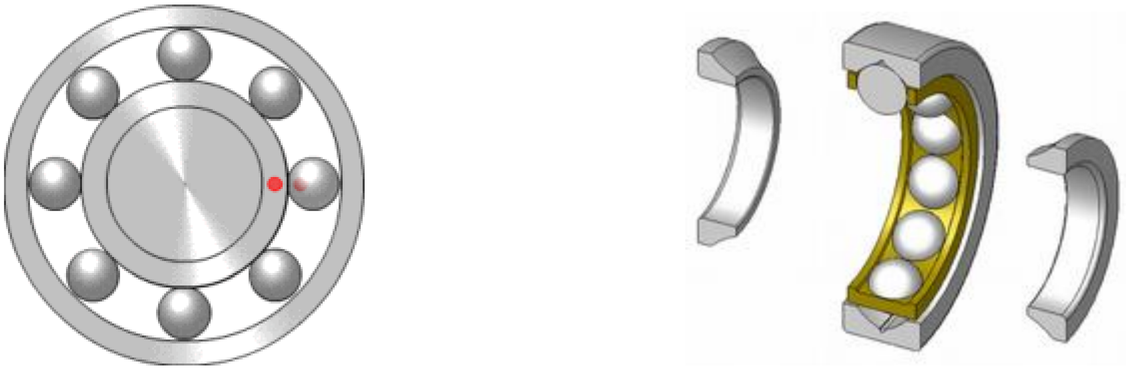


Fig: 2.6 - Ball bearings

A ball bearing is a type of rolling-element bearing which uses balls to maintain the separation between the moving parts of the bearing. The purpose of a ball bearing is to reduce rotational friction and support radial and axial loads. It achieves this by using at least two races to contain the balls and transmit the loads through the balls. Usually one of the races is held fixed.

2.2 Description of Electronic Parts:

Various electronic parts used are:

1. Resistance
2. Transformer
3. Diode
4. Relay
5. Capacitor
6. Transistor
7. Integrated Circuit

2.2.1 Resistance:

Resistance is the opposition of a material to the current. It is measured in Ohms (Ω). All conductors represent a certain amount of resistance, since no conductor is 100% efficient. To control the electron flow (current) in a predictable manner, we use resistors. Electronic circuits use calibrated lumped resistance to control the flow of current.

Broadly speaking, resistor can be divided into two groups viz.

1. Fixed Resistors.
2. Adjustable (Variable) Resistors.

In fixed resistors, the value is fixed & cannot be varied. It can be divided into

(a) Carbon composition (b) Wire wound (c) Special type.

The most common type of resistors used in our projects is carbon type. In this, resistance value is normally indicated by colour bands. Each resistance has four colours, one of the bands on either side will be gold or silver, this is called fourth band and indicates the tolerance, and others three band will give the value of resistance.

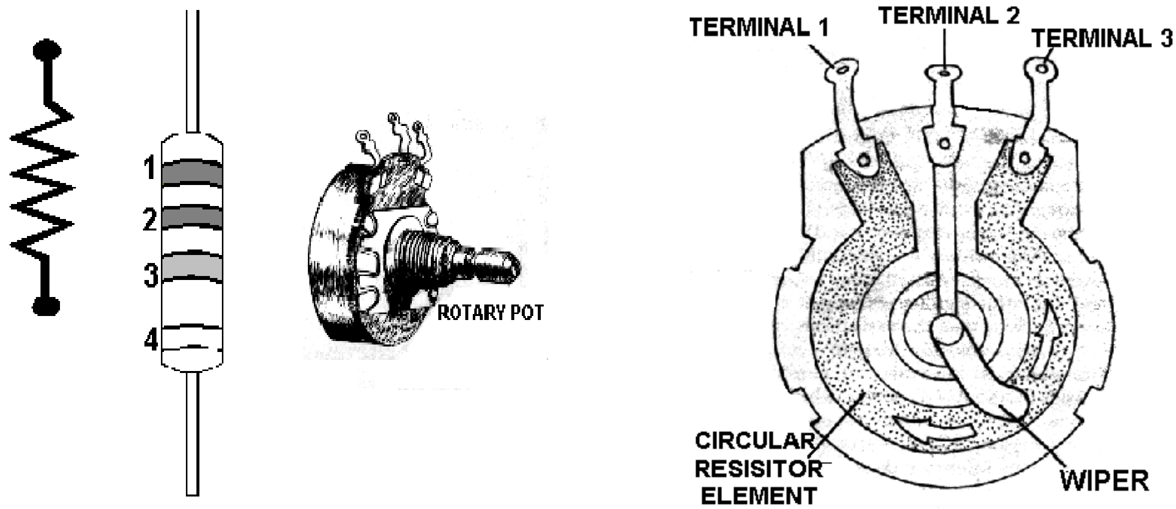


Fig 2.7

In variable resistors, the resistance value can be varied by an adjuster knob. In variable resistors, we have the dial type of resistance boxes. There is a knob with a metal pointer. This presses over brass pieces placed along a circle with some space b/w each of them.

Resistance coils of different values are connected b/w the gaps. When the knob is rotated, the pointer also moves over the brass pieces. If a gap is skipped over, its resistance is included in the circuit. If two gaps are skipped over, the resistances of both together are included in the circuit and so on.

The dial type of resistance boxes is better because the contact resistance in this case is small & constant.

2.2.2. Diode:

A diode is a simplest semiconductor device, made up of a sandwich of P-type semi conducting material, with contacts provided to connect the p-and n-type layers to an external circuit. This is a junction Diode. If the positive terminal of the battery is connected to the p-type material (cathode) and the negative terminal to the N-type material (anode), a large current will flow. This is called forward current or forward biased.

Fig 2.8

If the connections are reversed, a very little current will flow. This is because under this condition, the p-type material will accept the electrons from the negative terminal of the battery and the N-type material will give up its free electrons to the battery, resulting in the state of electrical equilibrium since the

N-type material has no more electrons. Thus there will be a small current to flow and the diode is called Reverse biased.

Thus the Diode allows direct current to pass only in one direction while blocking it in the other direction. Power diodes are used in converting AC into DC. In this, current will flow freely during the first half cycle (forward biased) and practically not at all during the other half cycle (reverse biased). This makes the diode an effective rectifier, which convert ac into pulsating dc. Signal diodes are used in radio circuits for detection. Zener diodes are used in the circuit to control the voltage.

Some common diodes are:

- Zener diode.
- Photo diode.
- Light Emitting diode.

1. <u>Zener Diode:</u>

   A Zener diode is specially designed junction diode, which can operate continuously without being damaged in the region of reverse break down voltage. One of the most important applications of zener diode is the design of constant voltage power supply. The zener diode is joined in reverse bias to d.c. through a resistance R of suitable value.

2. <u>Photo Diode:</u>

   A photo diode is a junction diode made from photo- sensitive semiconductor or material. In such a diode, there is a provision to allow the light of suitable frequency to fall on the p-n junction. It is reverse biased, but the voltage applied is less than the break down voltage. As the intensity of incident light is increased, current goes on increasing till it becomes maximum. The maximum current is called saturation current.

3. <u>Light Emitting Diode (LED):</u>

   When a junction diode is forward biased, energy is released at the junction diode is forward biased, energy is released at the junction due to recombination of electrons and holes. In case of silicon and germanium diodes, the energy released is in infrared region. In the junction diode made of gallium arsenate or indium phosphide, the energy is released in visible region. Such a junction diode is called a light emitting diode or LED.

2.2.3. Relay:

Relay is an electrically operated switch. Current flowing through the coil of the relay creates a magnetic field which attracts a lever and changes the switch contacts. The coil current can be on or off so relays have two switch positions and they are double throw (changeover) switches.

Relays allow one circuit to switch a second circuit which can be completely separate from the first. For example a low voltage battery circuit can use a relay to switch a 230V AC mains circuit. There is no electrical connection inside the relay between the two circuits; the link is magnetic and mechanical.

The coil of a relay passes a relatively large current, typically 30mA for a 12V relay, but it can be as much as 100mA for relays designed to operate from lower voltages. Most ICs (chips) cannot provide this current and a transistor is usually used to amplify the small IC current to the larger value required for the relay coil. The maximum output current for the popular 555 timer IC is 200mA so these devices can supply relay coils directly without amplification.

Relays are usually SPDT or DPDT but they can have many more sets of switch contacts, for example relays with 4 sets of changeover contacts are readily available. For further information about switch contacts and the terms used to describe them please see the page on switches.

Most relays are designed for PCB mounting but you can solder wires directly to the pins providing you take care to avoid melting the plastic case of the relay. The coil will be obvious and it may be connected either way round. Relay coils produce brief high voltage 'spikes' when they are switched off and this can destroy transistors and ICs in the circuit. To prevent damage you must connect a protection diode across the relay coil.

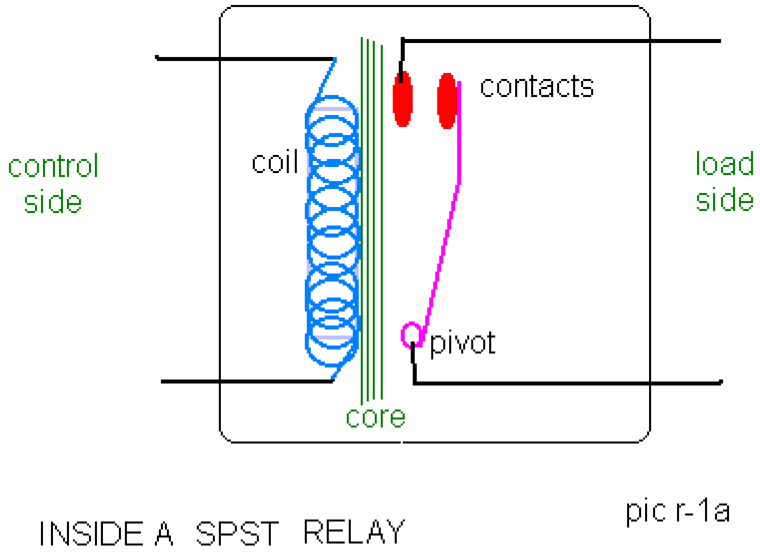


Fig 2.9

The relay's switch connections are usually labeled COM, NC and NO:

- **COM** = Common, always connect to this; it is the moving part of the switch.
- **NC** = Normally Closed, COM is connected to this when the relay coil is **off**.
- **NO** = Normally Open, COM is connected to this when the relay coil is **on**.
- Connect to COM and NO if you want the switched circuit to be **on when the relay coil is on**.
- Connect to COM and NC if you want the switched circuit to be **on when the relay coil is off**.

2.2.4. Capacitor:

It is an electronic component whose function is to accumulate charges and then release it.

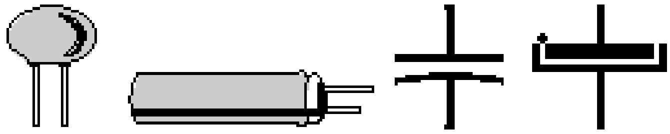


Fig 2.10

To understand the concept of capacitance, consider a pair of metal plates which all are placed near to each other without touching. If a battery is connected to these plates the positive pole to one and the negative pole to the other, electrons from the battery will be attracted from the plate connected to the positive terminal of the battery. If the battery is then disconnected, one plate will be left with an excess of electrons, the other with a shortage, and a potential or voltage difference will exists between them. These plates will be acting as capacitors. Capacitors are of two types: -

- **Fixed type** like ceramic, polyester, electrolytic capacitors-these names refer to the material they are made of aluminium foil.
- **Variable type** like gang condenser in radio or trimmer. In fixed type capacitors, it has two leads and its value is written over its body and variable type has three leads.

Unit of measurement of a capacitor is 'farad' denoted by the symbol 'F'. It is a very big unit of capacitance. Small unit capacitor are pico-farad denoted by 'pF' (I pF=1/1000,000,000,000 F).

2.2.5. Transistor:

The name is transistor derived from 'transfer resistors' indicating a solid state Semiconductor device. In addition to conductor and insulators, there is a third class of material that exhibits proportion of both. Under some conditions, it acts as an insulator, and under other conditions it's a conductor. This phenomenon is called Semi-conducting and allows a variable control over electron flow.

So, the transistor is semi conductor device used in electronics for amplitude. Transistor has three terminals, one is the collector, one is the base and other is the emitter, (each lead must be connected in the circuit correctly and only then the transistor will function). Electrons are emitted via one terminal and collected on another terminal, while the third terminal acts as a control element.

Each transistor has a number marked on its body. Every number has its own specifications. There are mainly two types of transistor:

(i) NPN (ii) PNP

NPN Transistors:

When a positive voltage is applied to the base, the transistor begins to conduct by allowing current to flow through the collector to emitter circuit. The relatively small current flowing through the base circuit causes a much greater current to pass through the emitter / collector circuit. The phenomenon is called current gain and it is measure in beta.

PNP Transistor:

It also does exactly same thing as above except that it has a negative voltage on its collector and a positive voltage on its emitter.

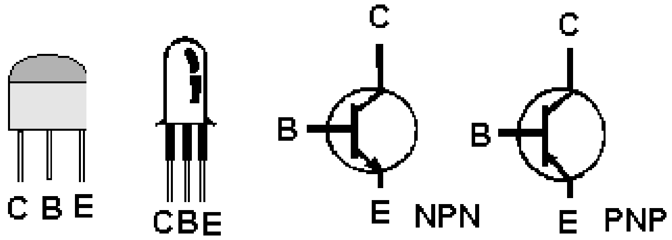


Fig 2.11

Transistor is a combination of semi-conductor elements allowing a controlled current flow. Germanium and Silicon is the two semi-conductor elements used for making it. There are two types of transistors such as “Point Contact and Junction Transistors”. Point contact construction is defective so is now out of use. Junction triode transistors are in many respects analogous to triode electron tube.

A junction transistor can function as an amplifier or oscillator as can a triode tube, but has the additional advantage of long life, small size, ruggedness and absence of cathode heating power.

2.2.6 Transformer:

A transformer is an electrical device that transfers energy from one circuit to another by magnetic coupling with no moving parts. A transformer comprises two or more coupled windings, or a single tapped winding and, in most cases, a magnetic core to concentrate magnetic flux. A changing current in one winding creates a time-varying magnetic flux in the core, which induces a voltage in the other windings. Michael faraday built the first transformer, although he used it only to demonstrate the principle of electromagnetic induction and did not foresee the use to which it would eventually be put.

2.3. Study of the Compressed Air Engine and its Working:

The laws of physics dictate that uncontained gases will fill any given space. The easiest way to see this in action is to inflate a balloon. The elastic skin of the balloon holds the air tightly inside, but the moment you use a pin to create a hole in the balloon's surface, the air expands outward with so much energy that the balloon explodes. Compressing a gas into a small space is a way to store energy. When the gas expands again, that energy is released to do work. That's the basic principle behind what makes an air car go.

The first air cars will have air compressors built into them. After a brisk drive, you'll be able to take the car home, put it into the garage and plug in the compressor. The compressor will use air from around the car to refill the compressed air tank**.** Unfortunately, this is a rather slow method of refueling and will probably take up to two hours for a complete refill. If the idea of an air car catches on, air refueling stations will become available at ordinary gas stations, where the tank can be refilled much more rapidly with air that's already been compressed. Filling your tank at the pump will probably take about three minutes.

The first air cars will almost certainly use the Compressed Air Engine (CAE) developed by the French company, Motor Development International (MDI). Air cars using this engine will have tanks that will probably hold about 3,200 cubic feet (90.6 kiloliters) of compressed air. The vehicle's accelerator operates a valve on its tank that allows air to be released into a pipe and then into the engine, where the pressure of the air's expansion will push against the pistons and turn the crankshaft. This will produce enough power for speeds of about 35 miles (56 kilometers) per hour. When the air car surpasses that speed, a motor will kick in to operate the in-car air compressor so it can compress more air on the fly and provide extra power to the engine. The air is also heated as it hits the engine, increasing its volume to allow the car to move faster.

India's Tata Motors will likely produce the first air car in the marketplace in the next few years. Tata Motors' air car will also use the CAE engine. Although Tata announced in August 2008 that they aren't quite ready to roll out their air cars for mass production, Zero Pollution Motors still plans to produce a similar vehicle in the United States. Known collectively as the FlowAIR, these cars will cost about $17,800. The company, based in New Paltz, N.Y., says that it will start taking reservations in mid-2009 for vehicle deliveries in 2010. The company plans to roll out 10,000 air cars in the first year of production. MDI also recently unveiled the joystick-driven AirPod, the newest addition to its air car arsenal. Although the AirPod generates a top speed of only 43 mph, it's also extremely light and generates zero emissions.

Major automobile makers are watching the air car market with interest. If the first models catch on with consumers, they'll likely develop their own air car models. At present, a few smaller companies are planning to bring air cars to the market in the wake of the MDI-based vehicles. These include:

- **K'Airmobiles** -- French company K'Air Energy has built prototypes of an air-fuelled bicycle and light road vehicle based on the K'air air compression engine
- **Air Car Factories SA** -- This Spanish company has an air car engine currently in development. The company's owner is currently involved in a dispute with former employer MDI over the rights to the technology.

Chapter 3: Design and Fabrication

- Design of Mechanical Components
- Design of Electric Circuit
- Fabrication & Assembly
- Problems faced during Designing
- Solutions Adapted

3.1. Design of Mechanical Components:

3.1.1. Design of Piston Cylinder:

Designing a piston cylinder for the following requirements:

Power: 100 W

Working Pressure: 5 Bar = 50 N/cm^2

Step 1: Finding the appropriate Length of Stroke

Case I

Bore Dia:	10 mm (Assumed)	= 1 cm
Speed of Engine:	180 rpm (Assumed)	= 3 rps

Length of Stroke:

Power (P)	=	Pressure (p) x Volume x Speed of Engine
100	=	50 x 3.14/4 x 1^2 x Ls x3/100
Ls	=	84.92 cm

Case II

Bore Dia:	50 mm (Assumed)	= 5 cm
Speed of Engine:	180 rpm (Assumed)	= 3 rps

Length of Stroke:

Power (P)	=	Pressure (p) x Volume x Speed of Engine
100 x 100	=	50 x 3.14/4 x 5^2 x Ls x 3
Ls	=	3.39 cm

Case III

Bore Dia:	25 mm (Assumed)	= 2.5 cm
Speed of Engine:	180 rpm (Assumed)	= 3 rps

Length of Stroke:

Power (P)	=	Pressure (p) x Volume x Speed of Engine
100 x 100	=	50 x 3.14/4 x 2.5^2 x Ls x 3
Ls	=	13.58 cm

Considering the values, the most appropriate value seems to be in the Case III, when the bore dia was taken as 2.5 cm and length of stroke comes out to be “**13.58 cm”.**

Step 2: To select the material of the cylinder

For thick cylinder t/d ratio should be greater than 1/15

i.e. $t/d > 1/15$

where, t : Thickness of cylinder wall

d: Bore Dia

In case of the bore dia being 2.5 cm, the thickness of the cylinder wall to be taken as thick cylinder should be greater than 0.16 cm. We consider the thickness to be **0.2 cm**.

Therefore,

Outer Diameter (d_o) = 2.5 + 2 x 0.2 = 2.9 cm

So by Lame's Equation,

$$\sigma_t = \left[\frac{P_i \times {d_i}^2}{4r^2}\right] \times \left[\frac{(4r^2 + {d_o}^2)}{{d_o}^2 - {d_i}^2}\right]$$

where,	σ_t	:	Tangential Stress of the material
	P_i	:	Internal Pressure
	d_i	:	Bore Dia
	d_o	:	Outer dia of the cylinder
	r	:	Radius at which the stress needs to be find

$$\sigma_t\,(\text{max}) = \left[\frac{50\times 2.5^2}{4\times1.25^2}\right] \times \left[\frac{(4\times1.25^2 + 2.9^2)}{2.9^2 - 2.5^2}\right]$$

$$= 107.04 \text{ N/cm}^2$$

So, the tangential stress faced at the internal walls of the cylinder is around **107.04 N/cm²**.

By the relation,

$$\sigma_{ut} = 8 \text{ x } \sigma_t$$

$$= 8 \text{ x } 107.04$$

$$= 856.32 \text{ N/cm}^2$$

$$= 8.56 \text{MN/m}^2$$

On the basis of the ultimate stress value, the material selected is "Grey Cast Iron" whose ultimate stress value is **166 MN/m²**, which is more than enough to bear the stress produced.

Step 3: To calculate radial stress and shear stress

Max Radial Stress is given by,

$$\sigma_r (max) = - P_i$$

where, P_i : Internal Pressure

$$\sigma_r (max) = - 50 \text{ N/cm}^2$$

Max Shear Stress at internal walls of the cylinder

$$\tau_{max} = \left[\frac{P_i \times d_o{}^2}{d_0{}^2 - d_i{}^2}\right]$$

$$= \left[\frac{50 \times 2.9^2}{2.9^2 - 2.5^2}\right]$$

$$= 194.67 \text{ N/cm}^2$$

Step 4: Thickness of Cylinder Head:

The thickness of the cylinder cap or cylinder head secured firmly to the cylinder is given by,

$$t' = d_i \times \left[\frac{P_i}{6\sigma_t}\right]^{\frac{1}{2}}$$

Where, σ_t : Allowable working stress on the cover plate

For Cast Iron, $\sigma_t = 20.6 \text{ MN/m}^2$

$$= 2060 \text{ N/cm}^2$$

And, t' = $2.5 \times \left[\frac{50}{6 \times 2060}\right]^{\frac{1}{2}}$

= 0.159 cm

= 1.59 mm

Step 5: Design of Piston and Piston Rod

As the cylinder is to be used as pneumatic cylinder, there should be negligible clearance between the cylinder and the piston as this could lead to leakage of air. So the dia of piston is taken to be same as that of the bore dia of the cylinder.

So, Dia of piston = 2.5 cm

= 25 mm

And, Dia of piston rod is given as

$$d_{pr} = d_i \times \left[\frac{P_i}{\sigma_t^*}\right]^{\frac{1}{2}}$$

Now, For σ_t*

Using Gray Cast Iron as the material for piston rod

σ_{ut} = 166 MN/m^2

σ_t = 1/8 x 166 = 20.75 MN/m^2

And, For double acting cylinder, the factor of safety is taken as 10.

So, Actual working tensile stress in piston rod,

$$\sigma_t^* = \sigma_t / 10$$

$$= 20.75 / 10$$

$$= 2.075 \text{ MN/m}^2$$

$$= 207.5 \text{ N/cm}^2$$

Therefore, $d_{pr} = 2.5 \times \left[\frac{50}{207.5}\right]^{\frac{1}{2}}$

$$= 1.225 \text{ cm}$$

Thickness of piston head, $t_{ph} = 0.43 \text{ x } d_i \text{ x } (P_i / \sigma_t)^{1/2}$

For piston head the allowable tensile stress for gray cast iron,

$$\sigma_t = 2.075 \text{ MN/m}^2$$

$$= 207.5 \text{ N/cm2}$$

Therefore, $t_{ph} = 0.43 \text{ x } 2.5 \text{ x } (50/207.5)0.5$

$$= 0.53 \text{ cm}$$

3.1.2 Design of Connecting Rod:

Section of Rod:

In the plane of motion, the ends of the rod are direction free and so freely hinged at the piston pin and crank pin. Hence for buckling about the neutral axis xx, the strut is freely hinged. In the plane, perpendicular to the plane of motion, for buckling about the axis yy , the strut is fixed ended due to the constraining effect of the bearings at piston and crank pins, therefore , for buckling about axis yy, the rod is four times as strong as for buckling about axis xx. But the rod should be equally strong in both the planes,

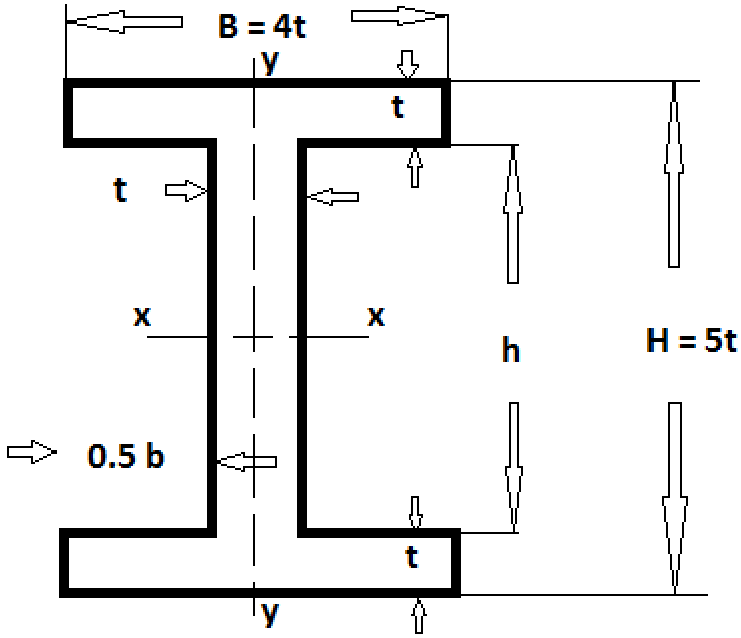


Fig 3.1

Now, $4I_{yy} = I_{xx}$

Therefore, $k^2_{yy} = 1/4\ k^2_{xx}$

Let the flange and web thickness of section = t

So, Depth of section = 5t

Width of section = 4t

Therefore, Area of the section, $A = 11t^2$

And,

$$I_{xx} = 1/12(BH^3 - bh^3)$$

$$= 1/12 \times [4t \times (5t)^3 – 3t \times (3t)^3]$$

$$= 419/12\ t^4$$

$$I_{yy} = (2tB^3 + ht^3)$$

$$= 1/12 \times [2t \times (4t)^3 + 3t \times t^3]$$

$$= 131/12\ t^4$$

$$k^2_{xx} = I_{xx}/A$$

$$= 419t^4 / (12 \times 11t^2)$$

$$= 3.18t^2$$

$$k^2_{yy} = I_{yy}/A$$

$$= 131t^4 / (12 \times 11t^2)$$

$$= 0.995t^2$$

Therefore, $\frac{k_{xx}{}^2}{k_{yy}{}^2} = 1/3.2,$

which is slightly higher than 1/4, therefore, the proportion of the section are satisfactory.

Now a section of the rod can be determined by considering the buckling about axis xx by the Ranking formulae,

Buckling load = $\dfrac{f_{cu} \times A}{1 + a \times (\frac{l}{k})^2}$

Also, Buckling load = Maximum explosion load * F.O.S.

Let, F.O.S. = 5

Buckling Load = $\pi/4 \text{ x } d_i^2 \text{ x } P_i \text{ x F.O.S.}$

= $\pi/4 \text{ x } (2.51 \text{ x } 0^{-2})^2 \text{ x } 5 \text{ x} 10^5 \text{ x } 5$

= 1.2265 KN

Now, Ultimate Crushing Stress, f_{cu} = 166 MPa (For Grey Cast Iron)

And, $A = 11t^2$; $a = 1/1600$; $l = 0.15$ m (assumed),

For hinged ends, $k = k_{xx}$

Therefore, $1226.5 = \dfrac{[166 \text{ x } 10^6 \text{ x } 11t^2]}{[1 + (1/1600) \text{ x } (0.15^2/3.18t^2)]}$

$9290688 \text{ x } 10^6 t^4 - 6240432\, t^2 - 27.59625 = 0$

Solving, **t = 1.78 mm**

So, Depth = 5t = 8.90 mm

Width = 4t = 7.12 mm

And, Depth at crank end = 1.25 x 0.8 = 1 cm

Depth at piston end = 0.72 cm

Length of crank rod, l = 0.15 m

Taking, $l/r = 3.5$

Therefore, $r = 0.15/3.5 = 0.042$ m $= 4.2$ cm

Transverse Inertia Bending Stress

Centripetal force per unit connecting rod, C $= \rho A \omega^2 r$

$A = 11t^2$

$= 11(1.78 \times 10^{-3})^2 = 3.48524 \times 10^{-5}\ m^2$

$\rho = 7200\ kg/m^3$

$\omega = 2\pi N/60$

$= 2\pi \times 180 / 60 = 18.84$ rad/sec

$C = 7200 \times 3.49 \times 10^{-5} \times 18.84^2 \times 4.2 \times 10^{-2}$

$= 37460106.75 \times 10^{-7}$

$= 3.75$ N/m

Now, Maximum Bending Moment $= 0.128\ F_n \times l$

And, $F_n = 1/2\ C \times l$

Maximum B.M. $= 0.128\ C\ l^2/2$

$= 0.128 \times 3.75 \times 0.15^2 /2$

$= 5.4 \times 10^{-3}$ N-m

Now,	Bending Load, f_b	=	$(B.M.)_{max}/Z$
Where,	Z	=	$I_{xx}/ (Depth/2)$
	I_{xx}	=	$419/12 \times t^4$
		=	$419/12 \times (1.78 \times 10^{-3})$
		=	$3.505 \times 10^{-2}\ m^4$
So,	Z	=	$3.505 \times 10^{-10} / (0.445 \times 10^{-2})$
		=	$7.876 \times 10^{-8}\ m^3$
Therefore,	f_b	=	$5.4 \times 10^{-3} / 7.876 \times 10^{-8}$
		=	0.685×10^5
		=	0.06 MPa

As the components of the above designed specification were not available in the market, so we chose the components of the following specifications after doing a market survey.

3.1.3. Specifications:

Cylinder:

Body make	Type 304 stainless steel body
Internal Dia	1.75 cm
Outer Dia	3 cm
Operating Temp.	-28 to 90 °C
Pressure Range	1.5 to 8 bar
Length	12.9 cm
Head	Aluminium alloy
No. of Ports/cylinder	2

Piston:

Body make	Type 303 stainless steel piston rods
Length	12.7 cm
Rod dia	0.8 cm

According to above specifications, after doing market survey, we chose the connecting rod and crankshaft of the auto-loader with the following specifications:

Length of the connecting rod	12.7 cm
Crank radius	3.6 cm
Length of crank rod	16.6 cm

By Lame's Equation,

Tangential Stress in Cylinder,

$$\sigma_t = \left[\frac{P_i \times {d_i}^2}{4r^2}\right] \times \left[\frac{\left(4r^2 + {d_0}^2\right)}{{d_0}^2 - {d_i}^2}\right]$$

Where,

σ_t	:	Tangential Stress of the material
P_i	:	Internal Pressure (5 Bar)
d_i	:	Bore Dia
d_o	:	Outer dia of the cylinder
r	:	Radius at which the stress needs to be find

$\sigma_t\,(max) \quad = \quad \left[\frac{50\times 1.75^2}{4\times 0.875^2}\right] \times \left[\frac{(4\times 0.875^2 + 3^2)}{3^2 - 1.75^2}\right]$

$= \quad 101.58\ N/cm^2$

Now, Max Radial Stress is given by,

$\sigma_r\,(max) \quad = \quad -\,P_i$

where, P_i : Internal Pressure

$\sigma_r\,(max) \quad = \quad -\,50\ N/cm^2$

And, Max Shear Stress at internal walls of the cylinder

$\tau_{max} \quad = \quad \left|\frac{P_i \times d_o{}^2}{d_0{}^2 - d_i{}^2}\right|$

$= \quad \left|\frac{50\times 3^2}{3^2 - 1.75^2}\right|$

$= \quad 75.79\ N/cm^2$

Now, Inertial Force on the moving parts,

$F \quad = \quad 0.004032\ r\ n^2\ x\ W_R\ x\ [\cos\theta \pm \frac{\cos 2\theta}{n_1}]$

Where, θ : crank angle from the dead centre, positive sign is to be taken from the inner dead centre while the negative sign from outer dead centre

$\cos\theta \pm \frac{\cos 2\theta}{n_1}$: Inertial factor

Crank radius, r = 42mm

Length of connecting rod, L = 150 mm

Now, W_r = 0.5 kg

Crank angle	Inertial Force on the piston (Newton)
0^o	8.29
30^o	6.54
60^o	2.40
90^o	-1.75
120^o	-4.14
150^o	-4.79
180^o	-4.79

So, The indicated power per cylinder of the model is calculated by the following relation:

$$
\begin{aligned}
I.P &= (Pr \times Vol \times rpm)/60 \\
&= [5 \times 10^5 \times \pi/4 \times (1.75 \times 10^{-2})^2 \times (12.9 \times 10^{-2}) \times 180] / 60 \\
&= 46.5 \text{ Watts}
\end{aligned}
$$

As the model have two cylinders,

Therefore, Total Indicated Power = 46.5 x 2

= 93 W

3.2. Design of Electric Circuit:

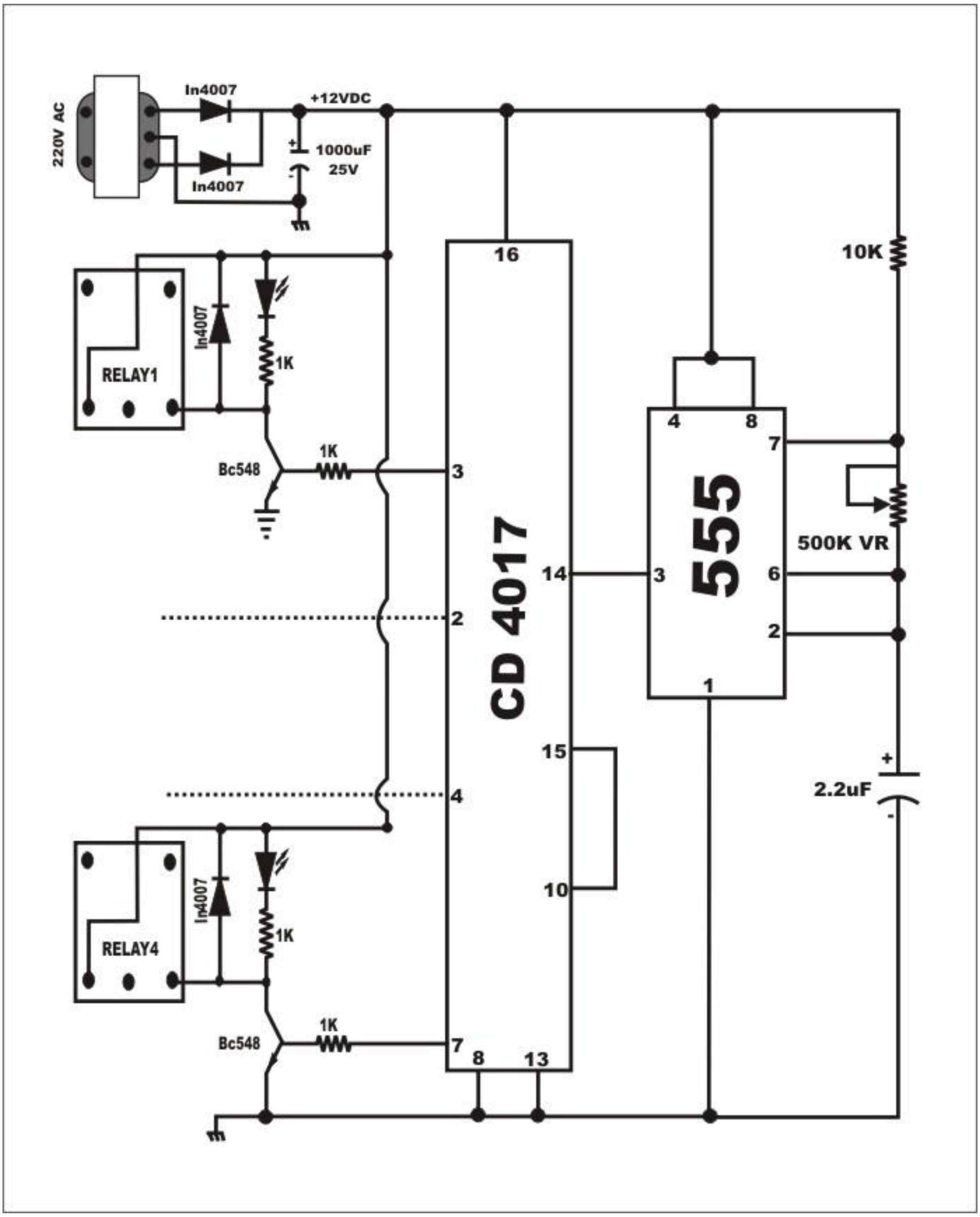
The electronic consist of step down transformer which step down 220 V to 12V which is the voltage required by the diodes, capacitor, ICs operating, 4 relay switches and the solenoid pneumatic valves. There are two diodes acting as full ac wave rectifier and a capacitor for filtering the rectified wave. The two ICs, one of which act as pulse generator and other act as pulse counter, work as controlling device of relay switches.

The pulse generator generates pulses which act as on-off signal for the relay switches. After the pulse is generator it is fed to counter IC which counts it 0 to 3 such that the pulses are send in a cycle of 4 signals. The pulses are then sent to relay switches to turn them on, one by one. Each one pulse operates one relay switch at one time which in turn put on the solenoid valve on.

As there are 4 solenoid valves are used so 4 relay switches have to be used to operate each valve individually. These valves in turn on flow of air to the pneumatic cylinder, thus making piston work. As there is fixed timing of the switching ON of the relay switches so there is fixed working speed of the engine.

There is no feedback mechanism (sensors) used so that the speed of the piston-cylinder arrangement can be varied according to the pressure supplied because of high cost of sensor involved and more electronic circuit complex.

As there are four pneumatic valves which are used to carry out operation for each 90° of 360° of cycle. Since the cylinder double acting with two piston-cylinder arrangements , so, the cycle is divided into four parts; push-pull motions of each of two piston - cylinder arrangements in such a way that cycle run in push-pull-push-pull arrangement 90° each, there by providing power stroke for each 90° of cycle.


220V AC
In4007
In4007
+12VDC
1000uF
25V
In4007
RELAY1
1K
1K
Bc548
16
CD 4017
3
14
2
4
15
10
7
8
13
In4007
RELAY4
1K
1K
Bc548
555
4
8
7
3
6
2
1
10K
500K VR
2.2uF

3.3. Fabrication and Assembly:

As per the design, following mechanical parts were used to fabricate the working model:

1. Crank shaft - 2
2. Pneumatic cylinder - 2
3. Solenoid valve - 4
4. Roller Bearings - 2
5. Tyre - 2
6. Bearing stand
7. Compressor
8. Pneumatic pipe
9. Body base
10. Connecting screws

And following electronic parts are used:

1. Resistance
2. Diode
3. Relay
4. Capacitor
5. Transistor
6. Transformer
7. IC CD 4017
8. IC NE 555

Fabrication of the model involves the following steps:

1. Procurement of crank from the market

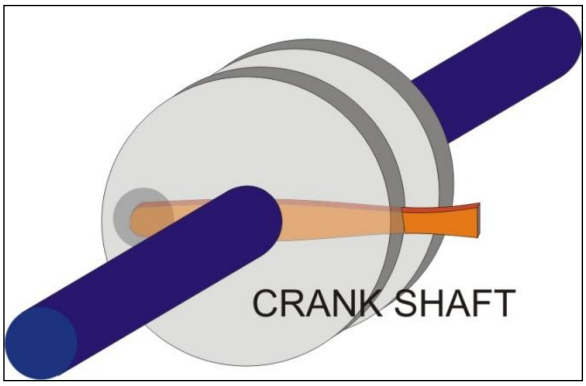


Fig 3.2

2. Fitting of bearing on the crank assembly.

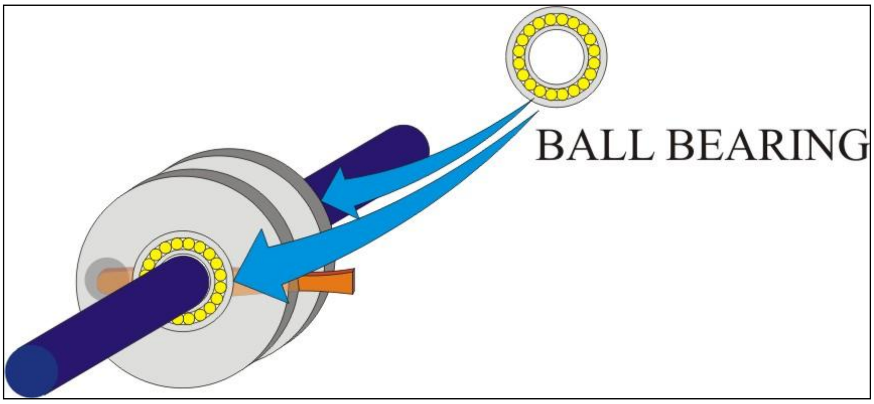


Fig 3.3

3. Fixing of Bearing stand on the crank assembly.

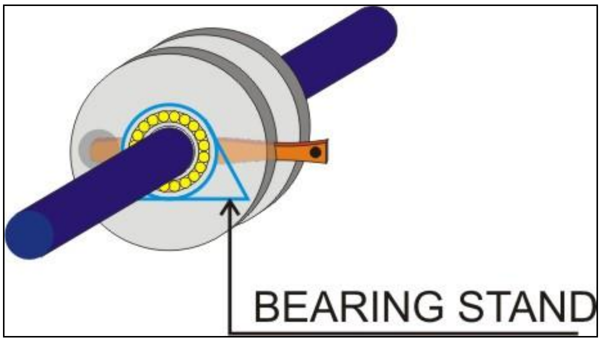


Fig 3.4

4. Welding of two crank shafts

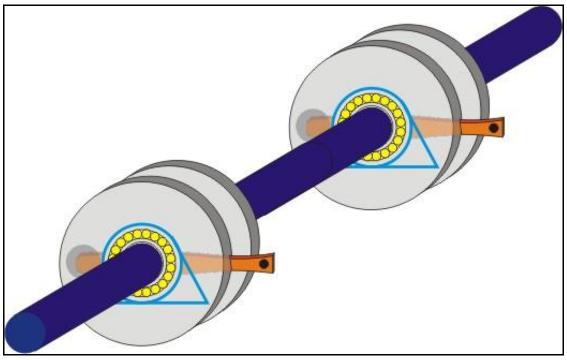


Fig 3.5

5. Fixing the crank assembly frame on the wooden board.

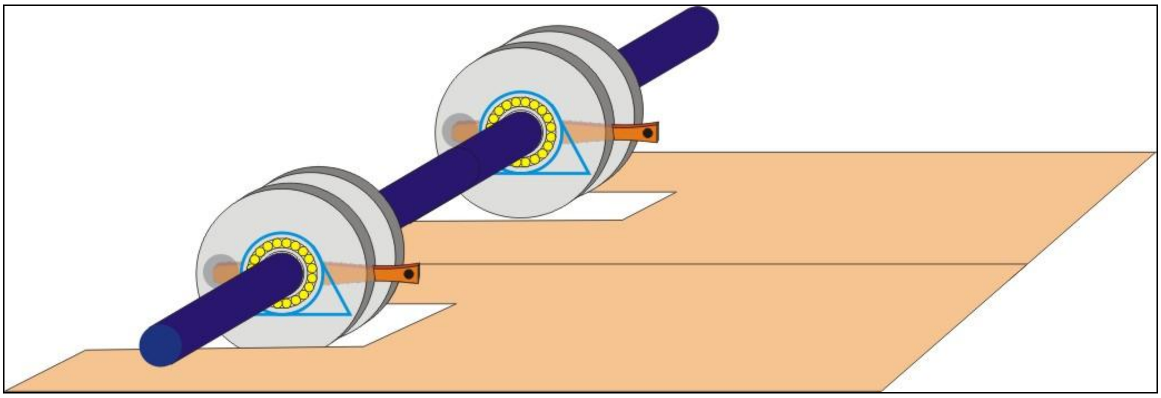


Fig 3.6

6. Fixing of solenoid valves with pneumatic cylinder.

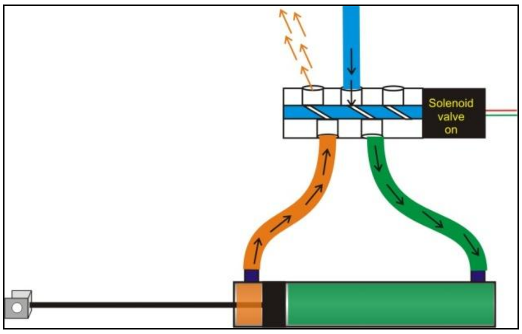


Fig 3.7

7. Welding of piston cylinder arrangement to crank assembly.

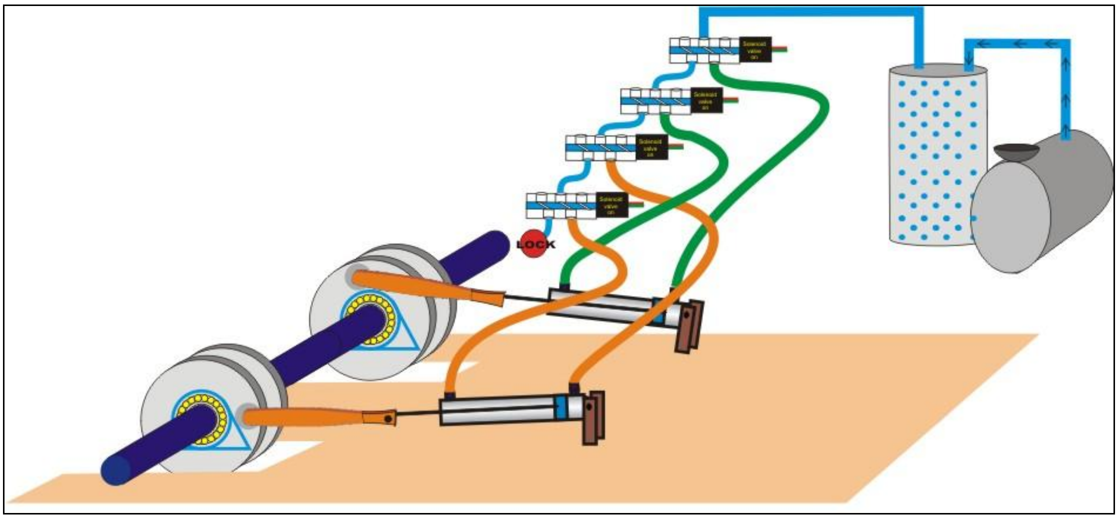


Fig 3.8

8. Powering the assembly with the electronic circuit and thus having the complete model.

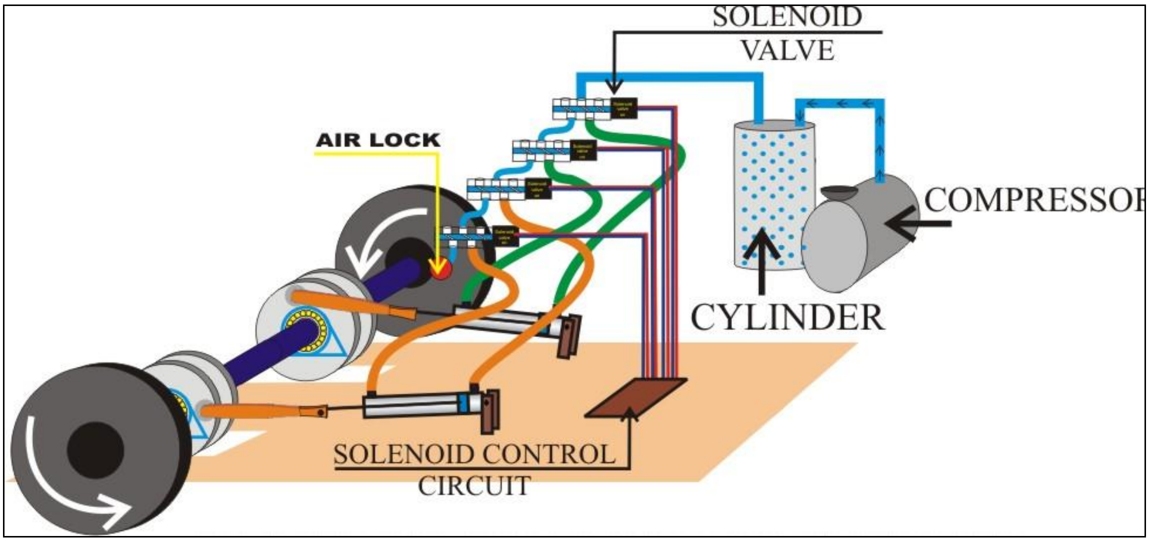


Fig 3.9

3.4. Problems faced during designing:

1. Availability of components of desired specification in market as per the design.
2. To vary the output speed and torque of the engine.
3. To prevent the air leakage.

3.5. Solutions Adapted:

1. As per market survey conducted by us we have selected the components with nearest possible specifications as per our design to get the desired power.
2. To get a variable output speed we have to use a feed back mechanism in the electronic circuit which will sense the pressure variation and therefore varies the timing of solenoid valve with pressure. But the use of feed back mechanism increases the complexity as well as cost of the model. So we dropped out the idea of using circuit with feedback mechanism.
3. With the use of air tight joints formed by the connectors we prevent the leakage of air.

Chapter 4: Conclusion

The model designed by us is a small scale working model of the compressed air engine. When scaled to higher level it can be used for driving automobiles independently or combined (hybrid) with other engines like I.C. engines.

Main advantages of Compressed Air Engine (C.A.E.) are:

1. Zero emission.
2. Use of renewable fuel.
3. Zero fuel cost (the cost is involved only in the compression of air).

But the Compressed Air Engine (C.A.E.) has some disadvantages, which are:

1. Less power output
2. High pressure of compressed air may lead to bursting of storage tank.
3. Probability of air leakage.

References:

- Sharma P.C. & Aggarwal D.K., Machine Design, S.K. Kataria & Sons, Ed. 11th Reprint.
- Mahadevan & Reddy, Design Data Handbook, CBS Publishers, Ed. 3rd.
- Mechanical Engineering and Design, Tata McGraw Hill, Ed. 3rd.
- Wiki Foundation Wikipedia Website.
- How Stuff Works Website.
- Engineering Hobbyist Website.