Design and Fabrication of Pneumatic-Compressed Air Vehicle

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Abstract— Compressed air as a source of energy in different uses in general and as a nonpolluting fuel in compressed air vehicles has attracted scientists and engineers for centuries. Efforts are being made by many developers and manufacturers to master the compressed air vehicle technology in all respects for its earliest use by the mankind. The present paper gives a brief description of how a compressed air vehicle using this technology was made. While developing of this vehicle, control of compressed air parameters like temperature, energy density, requirement of input power, energy release and emission control have to be mastered for the development of a safe, light and cost effective compressed air vehicle in near future.

Index Terms— compressed air, non-polluting fuel, input power, emission control.

I. INTRODUCTION

We are living in a very mobile society. So light utility vehicles(LUV) like bikes and cars are becoming very popular means of independent transportation for short distances. Petrol and diesel which have been the main sources of fuel in the history of transportation are becoming more expensive and impractical (especially from an environmental standpoint). Such factors are leading vehicle manufacturers to develop vehicles fuelled by alternative energies. When at present level of technological development fuel-less flying (like birds) i.e., flying based on the use of bio-energy and air power in the atmosphere seems to be almost impossible for human beings then engineers are fascinated at least with the enormous power associated with the human friendly as well as tested source of energy (i.e., air) to make air-powered vehicles as one possible alternative. Engineers are directing their sincere efforts to make use of air as an energy source to run the LUVs which will make future bikes and light/small cars running with air power for daily routine distances and the travel will be free from pollution and cost effective.

The air powered car is a type of vehicle designed to run on fuels that are different than the standard fuel used in most vehicles today. It runs on 'air,' which is good for the environment, renewable and absolutely free. Compared to regular fuel like gasoline which pollutes the air, is on short supply and is doubling in price in recent years, air powered solutions seems a dream come true.

Sadly, air by itself cannot be the only thing to fuel a car, as energy will need to be used as well to man mechanical air compressors. However, once the compressed air is released, the air will expand and can be used to move the pistons, power the engine or a host of other functions.

II. BACKGROUND

The society of today relies to a great extent on different means of transportation. Never before have people travelled to different parts of the world, far away from their own, as today. This massive travelling is a heavy load on our nature.

The cars that increase in numbers every day emit toxic emissions on the highways and the airplanes consume huge amounts of fossil fuels. In recent years the awareness of the effect of pollution on the environment and climate has increased. People are more conscious of the situation and are looking for alternative means of transportation with less impact on the environment. The exhaust emission standards are getting more and more stringent and there now exists a discussion about the introduction of a mandatory emissions standard for CO_2 a green house gas that contributes to the climate change which is an issue of growing international concern. This demand for lower exhaust emission levels together with increasing fuel prices leads to the demand of combustion engines with better fuel economy, which forces engine developers to find and investigate more efficient alternative engine management.

Today there exist several solutions to achieve lower exhaust emissions and better fuel economy. Some of them are well known while others are still in development. Some examples of such solutions are VVA (Variable Valve Actuation), EGR (Exhaust Gas Recirculation), direct injection, hybridization of vehicles, just to mention a few. In this work the emphasis has been put on vehicle hybridization. Vehicle hybridization can be done in various ways. The maybe best known example of vehicle hybridization is the electric hybrid. However other hybrids like hydraulic, fuel cell, flywheel and pneumatic hybrids are currently being investigated.

The main idea with electric hybridization is to reduce the fuel consumption by taking advantage of the otherwise lost brake energy. Hybrid operation also allows the combustion engine to operate at its most optimal operating point in terms of load and speed. Today, almost every car manufacturer is working on an electric hybrid prototype and a few already have a product on the market. Electric hybrids offer impressive reductions in fuel consumption. According to Fontaras et al. electric hybrids offer up to 60% lower fuel consumption compared to conventional gasoline fueled vehicles. Folkesson et al. have shown a reduction of over 40% in fuel consumption for a hybrid PEM (Proton Exchange Membrane) fuel cell bus compared to a conventional diesel engine operated bus.

The main disadvantage with electric hybrids is that they require an extra propulsion system and large heavy batteries with a limited life time. This introduces extra manufacturing costs which are compensated by a higher end-product price comparable to the price of high end vehicles. For instance, the purchase cost for a new electric hybrid bus is almost $200 000 higher compared to conventional bus. However, it should be remembered that the high cost will decrease as the sales volume of hybrid vehicles increase.

One way of keeping the extra cost as low as possible and thereby increase customer attractiveness, is the introduction of the pneumatic hybrid. It does not require an expensive extra propulsion source and it works in a way similar to the electric hybrid. During deceleration of the vehicle, the engine is used as a compressor that converts the kinetic energy contained in the moving vehicle into energy in the form of compressed air which is stored in a pressure tank. After a standstill the engine is used as an air-motor that utilizes the pressurized

air from the pressure tank in order to accelerate the vehicle. The system supports stop/start functionality, which means that the engine can be shut off during a full stop and thus the idle losses can be eliminated. The pneumatic hybrid concept also offers elimination of the "turbo-lag" associated with turbocharged engines by supercharging the engine with pressurized air.

Numerous research teams worldwide have demonstrated the potential of the pneumatic hybrid vehicle over the last decade. Tai et al. describes simulations of a pneumatic hybrid with a so called regenerative efficiency of 36% and an improvement by 64% of the fuel economy in city driving. Simulations made by Andersson et al. show simulations where a regenerative efficiency as high as 55% for a dual pressure tank system for heavy duty vehicles was achieved. The fuel consumption reduction for the pneumatic hybrid city bus was in the range of 23%. Trajkovic et al. presented a regenerative efficiency of 48% obtained from engine experiments. The same research team presented a vehicle model with an engine model based on experimental data. The model was tested over 10 different drive cycles and the fuel consumption reduction varied between 8 and 58%, depending on drive cycle. All the presented features of the pneumatic hybrid contribute to lower fuel consumption and in combination with the simplicity of the system, the pneumatic hybrid can be a promising alternative to the traditional vehicles of today and a serious contender to the better known electric hybrid.

HOW AIR POWERED VEHICLES WORK

The Science behind It All

If you have ever taken physics, you may know that one of its laws states that gases that are not contained will be able to fill any given space. A physical project you can do to demonstrate this law is to blow up a balloon. As the material of the balloon will contain the air inside, you can "see" trapped air. If you break the balloon's surface with a pin, the air will decompress quickly and expand, completely exploding the balloon. In the same way, the makers of the air powered car uses this science in compressing air or gas into a small area to store energy, and when that air expand, the energy will be able to power the vehicle.

Filling Up Car

The first air cars that are being made have air compressors in them which you will be able to fill with air around your car one it has been plugged in a compressor. The compressor will fill the air tanks, much like gas in used to fill conventional vehicles. At this time, filling your air car will take several hours for a total refill, but in the future it may be possible to fill these cars in a matter of minutes at a local "gas" station.

The Engine

The first air compressor engines are developed by the French company, Motor Development International (MDI). Any air vehicle with one of these engines will be able to hold approximately 3,200 cubic feet of compressed air which will be released slowly as the vehicle's accelerator will operate a valve on the tank that will let air slowly be released through a pipe into the engine. In the engine, the air will power the pistons and crankshaft which will create enough power to run the vehicle 30-35 miles per hour. If the vehicle goes faster than those speeds, a motor will start and operate an additional air compressor to compress air as your travel to give extra power to the engine.

Though the air car is still in its creation phase, it could end up being a mode of transformation that will help reduce pollution and save money on gas.

Garage Outlet Accessibility for Electric Car

As the electric car becomes increasingly popular, there is a clear necessity for an outlet accessible from the **garage**. Adding an outlet to your garage is not the only solution, but if you are intending to replace your gas-guzzling vehicle with an electric version, then you will need to have somewhere to recharge. Some car makers consider the best solution to the outsourced car charging areas, while most private car owners think that an addition to the garage would be best.

Battery Swapping

A more convenient method of powering your car in the long term is the battery swap method. In this system, the electronic outlet in your garage powers up a battery which is charged during the day. You have a pair of batteries, one in the car, and one being charged, so you are never without power.

Maintain an Electric Car without a Garage

The **air powered car** is a type of vehicle designed to run on fuels that are different than the standard fuel used in most vehicles today. It runs on 'air,' which is good for the environment, renewable and absolutely free. Compared to regular fuel like gasoline—which pollutes the air, is on short supply and is doubling in price in recent years—air powered solutions seems a dream come true.

Sadly, air by itself can't be the only thing to fuel a car, as energy will need to be used as well to man mechanical air compressors. However, once the compressed air is released, the air will expand and can be used to move the pistons, power the engine or a host of other functions. Though the idea isn't new, its popularity is growing and soon air powered vehicles may be available to purchase in the United States.

Inductive Charging

This method is being used with the new electric car models and utilizes a wide paddle that fits into a slot near the battery. This technique is being employed to reduce electrical shocks as well as extending the battery life.

Charging Your Electric Car in Your Garage

Although owning an electric car is environmentally friendly, the most important question to ask is whether you can charge your car directly from your own **garage** or not. An electric outlet in your garage is a necessity if you own an electric car because it's not always possible to go to a gas station to recharge your car. There is an interesting debate going on between car makers and private owners who are challenging the fact that the best solution, according to the car makers, is to have various outsourced car charging stations.

Having a Second Battery

The simplest of solutions is to have a second battery for your car. You could have the first battery in your car and the second battery charging in your garage by an electric outlet. Once your present battery runs out of power all you have to do is to insert the second battery and leave the first one to charge in your garage. This battery swap method is the only available option for today.

Legal and Electrical Situations

Having an electric car outlet into your garage requires some sort of permits because of the various tweaks you may need to perform onto your electric system, which may not be very cheap to make. As you may anticipate, this has to be done by a professional and Nissan, amongst other, is already making an agreement with a contractor that eventually will provide the equipment and installation. As you may know, there are different types of electric cars, that is, level one and level two. A level one electric car is charged by 120 volts and requires

from 8 to 12 hours of charging. A level two electric car requires 240 volts to charge and 4 to 6 hours to fully charge. The latter type is more suitable for a commercial and private purpose because normally you cannot afford a waiting time of 8 to 12 hours in order for your electric car to charge properly.

COMPRESSED AIR

Compressed air has a low energy density. In 300 bar containers, about 0.1 MJ/L and 0.1 MJ/kg is achievable, comparable to the values of electrochemical lead-acid batteries. While batteries can somewhat maintain their voltage throughout their discharge and chemical fuel tanks provide the same power densities from the first to the last litre, the pressure of compressed air tanks falls as air is drawn off. A consumer-automobile of conventional size and shape typically consumes 0.3–0.5 kWh (1.1–1.8 MJ) at the drive shaft per mile of use, though unconventional sizes may perform with significantly less.

A compressed-air vehicle (CAV) 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 use the expansion of compressed air to drive the pistons. One manufacturer claims to have designed an engine that is 90 % efficient.

Compressed-air propulsion may also be incorporated in hybrid systems, such as with battery electric propulsion. This kind of system is called a hybrid-pneumatic electric propulsion. Additionally, regenerative braking can also be used in conjunction with this system. Compressed air has been in use since the 19th century to power mine locomotives and trams in cities such as Paris (via a central, city-level, compressed air energy distribution system), and was previously the basis of naval torpedo propulsion.

During the construction of the Gotthardbahn from 1872 to 1882, pneumatic locomotives were used in the construction of the Gotthard Rail Tunnel and other tunnels of the Gotthardbahn.

In 1903, the Liquid Air Company located in London England manufactured a number of compressed-air and liquified-air cars. The major problem with these cars and all compressed-air cars is the lack of torque produced by the "engines" and the cost of compressing the air.

Since 2010 several companies have started to develop compressed air cars including hybrid types that also include a petrol driven engine; none has been released to the public, or have been tested by third parties.

CARS IN PRODUCTION

Several companies are investigating and producing prototypes including hybrid compressed-air/gasoline-combustion vehicles. As of August 2017 none of the developers have yet gone into production, although Tata has indicated they will begin selling vehicles from 2020 and MDI's US distributor Zero Pollution Motors says production of the AIRPod will commence in Europe in 2018.

Experimental cars and bikes

In 2008 a compressed air powered vehicle designed by engineering students at Deakin University in Australia was joint winner of the Ford Motor Company T2 competition to produce a car with a 200 km range and a cost of less than $7,000.

A compressed-air powered motorcycle, called the Green Speed Air Powered Motorcycle was made by Edwin Yi Yuan, based on the Suzuki GP100 and using the Angelo Di Pietro compressed-air engine.

Three mechanical engineering students from San Jose State University; Daniel Mekis, Dennis Schaaf and Andrew Merovich, designed and built a bike that runs on compressed air. The total cost of the prototype was under $1000 and was sponsored by Sunshops (on the Boardwalk in Santa Cruz, California) and NO DIG NO RIDE (from Aptos, California.). The top speed of the maiden voyage in May 2009 was 23 mph While their design was simple, these three pioneers of compressed air powered vehicles helped pave the way for French automaker Peugeot Citreon to invent a brand new air-powered hybrid. The 'Hybrid Air' system uses compressed air to move the car's wheels when driving under 43 mph. Peugeot says the new hybrid system should get up to 141 miles per gallon of gas. Models should roll out as early as 2016.

"Ku:Rin" named air-compressed three-wheeler vehicle was created by Toyota in 2011. The speciality about this vehicle is it has registered a record-breaking highest speed 129.2 km/h (80 mph) even if it has engine which uses only compressed air. This car was developed by the companies "Dream car workshop". This car is nicknamed as "sleek rocket", or "pencil shaped rocket".

As part of the TV-show Planet Mechanics, Jem Stansfield and Dick Straw Bridge converted a regular scooter to a compressed air moped. This has been done by equipping the scooter with a compressed-air engine and air tank.

In 2010, Honda presented the Honda Air concept car at the LA Auto Show.

III. OBJECTIVE

This thesis is based on a research project started in the beginning of 2006. The research in this work was conducted in close cooperation with Cargine AB, the company developing the pneumatic valve actuating system used in the project. The objective of the project is to study the new pneumatic hybrid concept and its different modes of engine operation. During the first two years of the project fundamental engine experiments were conducted in order to increase the understanding of the operating principle of the different engine modes associated with pneumatic hybridization and the parameters affecting their performance. It was soon realized that an engine model was necessary in order to understand the phenomena that control the pneumatic hybrid. The last couple of years of the project were mainly devoted to modeling of both a pneumatic hybrid engine and a pneumatic hybrid vehicle. The objective was to more thoroughly investigate the different parameters affecting the pneumatic hybrid engine performance and to examine the potential of reduction in fuel consumption for a pneumatic hybrid vehicle.

IV. METHODOLOGY

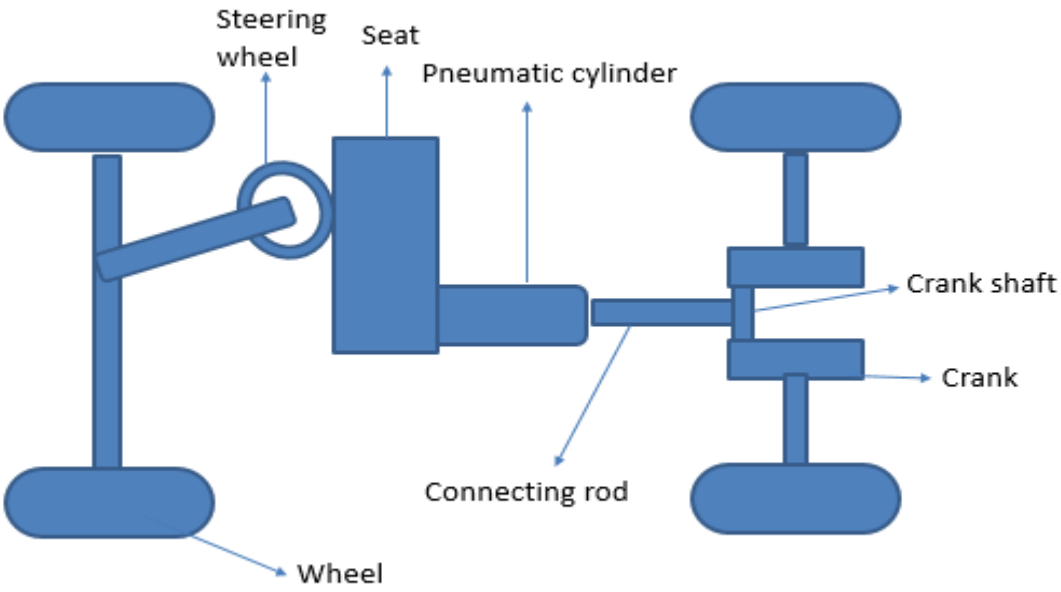


Figure 4.1 Block Diagram

Today fossil fuels are widely used as a source of energy in various different fields like power plants, internal & external combustion engines, as heat source in manufacturing industries, etc. But its stock is very limited and due to this tremendous use, fossil fuels are depleting at faster rate. So, in this world of energy crisis, it is inevitable to develop alternative technologies to use renewable energy sources, so that fossil fuels can be conserved. One of the major fields in which fossil fuels are used is Internal Combustion Engine. An alternative of IC Engine is "AIR POWERED ENGINE". It is an engine which will use compressed air to run the engine. It is cheap as it uses air as fuel, which is available abundantly in atmosphere. There are several technical benefits of using this engine, like as no combustion takes place inside the cylinder, working temperature of engine is very close to ambient temperature. This helps in reducing wear and tear of the engine components. Also there is no possibility of knocking. This in turn results in smooth working of engine.

One more technical benefit is that there will not be any need for installing cooling system or complex fuel injection systems. This makes the design simpler. Here air is compressed using compressor which in turn uses electricity, to run, which is cheaper and widely used. This adds value to its economic benefits. Also, as discussed earlier, as no combustion takes place which results in smooth working of the engine with minimum wear and tear, this will require less maintenance. So these are some of its economic benefits. One more interesting thing is that the exhaust temperature of this engine will be slightly less than the atmospheric temperature. So this will help in cooling the environment and if this technology is widely used than it will help in controlling global warming. These are some green bytes associated with this technology. Exhaust gases leaving the engine will be only air having low temperature. So this will eliminate the problem of harmful emissions, in conventional engines. This gives us environmental benefit of using this engine. Also as there will be no thermal radiations produced, radar can't detect these vehicles. So this will help our army too. Also the components used in this are: conventional SI engine, air vessel to store compressed air, and timing circuit are economical. These economical and readily available components make the technology easily adaptable.

WORKING PRINCIPLES

The pneumatic air vehicle consists of an air storage tank, pneumatic cylinder, connecting rod, crankshaft. The principle working of pneumatic air vehicle is to supply the air from air storage tank under controlled flow to the pneumatic cylinder. The shaft coming out of the cylinder is connected to crank shaft which converts the linear motion of cylinder to rotary motion of the crankshaft which in turn gives power to wheel.

The principle of compressed-air propulsion is to pressurize the storage tank and then connect it to something very like a reciprocating steam engine of the vehicle. 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. Thus, making the technology free from difficulties, both technical and medical, of using ammonia, petrol, or carbon disulphide as the working fluid. Manufacturers claim to have designed engine that is 90 percent efficient. The air is compressed at pressure about 150 times the rate the air is pressurized into car tyres or bicycle. The tanks must be designed to safety standards appropriate for a pressure vessel. The storage tank may be made of steel, aluminum, carbon fiber, kevlar or other materials, or combinations of the above.

The fiber materials are considerably lighter than metals but generally more expensive. Metal tanks can withstand a large number of pressure cycles, but must be checked for corrosion periodically. A company has stated to store air in tanks at 4,500 pounds per square inch (about 30 MPa) and hold nearly 3,200 cubic feet (around 90 cubic meters) of air. The tanks may be refilled at a service station equipped with heat exchangers, or in a few hours at home or in parking lots, plugging the vehicle into an on-board compressor.

ENGINE WORKING

To convert a conventional IC engine into an Air Powered one, few components are to be replaced. First of all replace the spark plug with a pulsed pressure control valve which can create required pressure. Now the pulsed air firing in this valve is controlled by controlling the supply of electrical signal to the plunger. For this we require an electronic timing circuit which can control the flow of electrical supply to

the plunger of this valve. This can be achieved by using PLC circuit. Now speed of the engine will be controlled by controlling this input signal.

Now fuel tank is to be replaced with air vessel, as it requires pressurized air as input. And two things are to be taken care while designing air vessel:

1) First is its strength to withstand high internal pressure, which exists due to compressed air. For this outer body of it should be made of a material, having high strength, like carbon fiber.
2) Second is its capacity to store air and its weight.

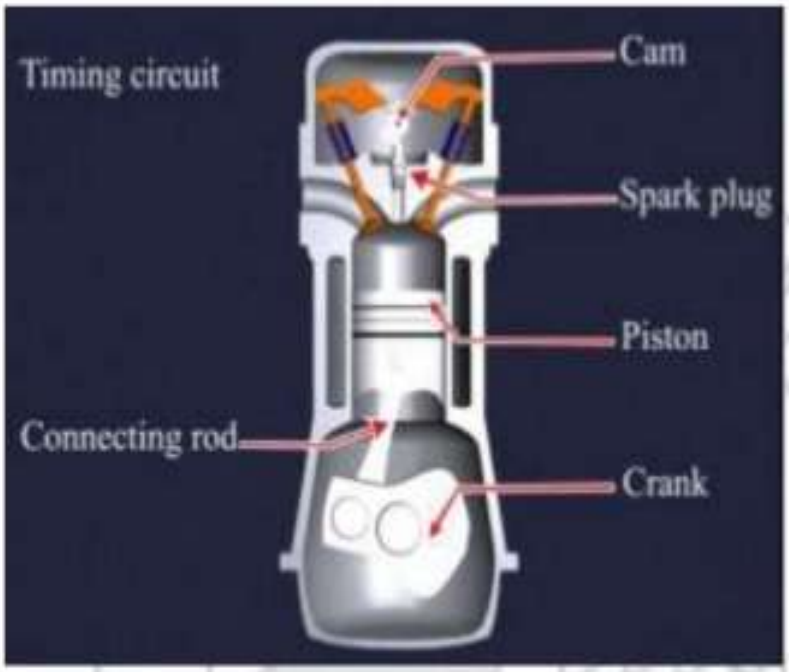
Now replace cam with a modified cam. This is to be done, so that both the inlet and outlet valves open and close at the same time. Main advantage of doing this is to achieve better scavenging system. Also this will result in conversion of 4 stroke engine into 2 stroke air engines, which in turn gives us the benefit of low mean effective pressure requirement in addition to other operational benefits.

DETAIL WORKING OF ENGINE

Operation

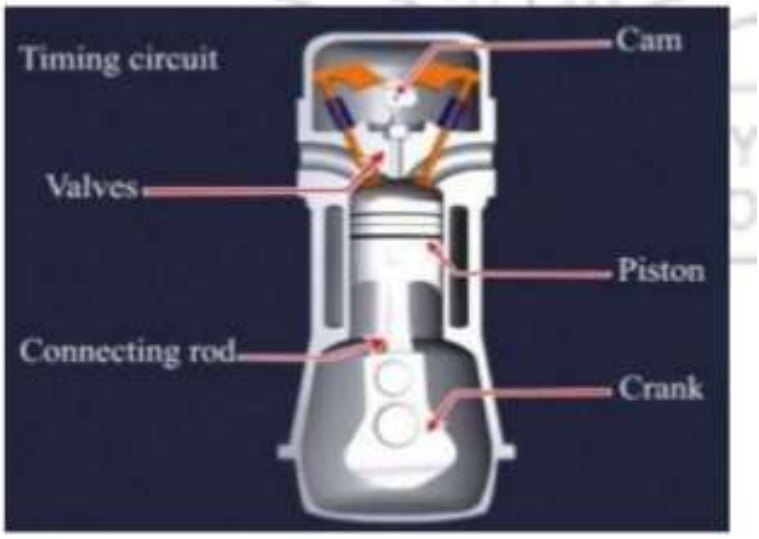
Initial torque is supplied from the DC exciter motor, and then the engine operation starts.

STAGE 1: When the piston is in the TDC, compressed air is injected through the pulsed air firing valve, which pushes the piston to BDC



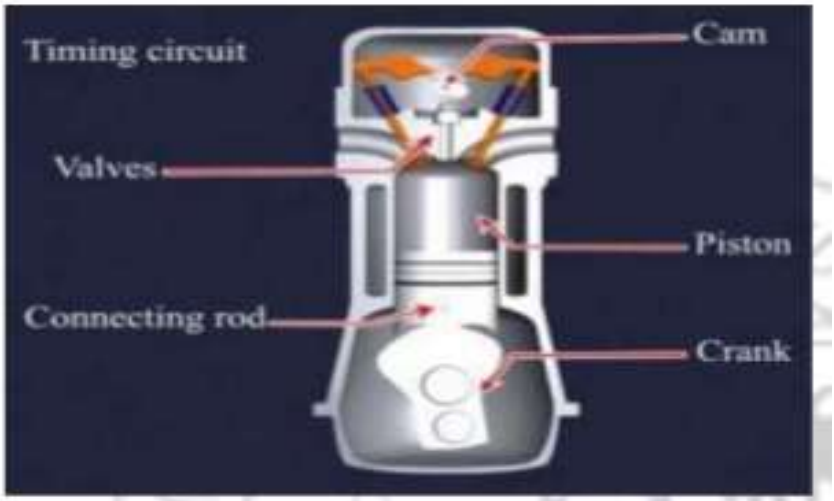
STAGE 1 OF OPERATION

STAGE 2: Due to the motion of the engine and its inertia, the piston moves back to TDC, pushing the air out of the valves.

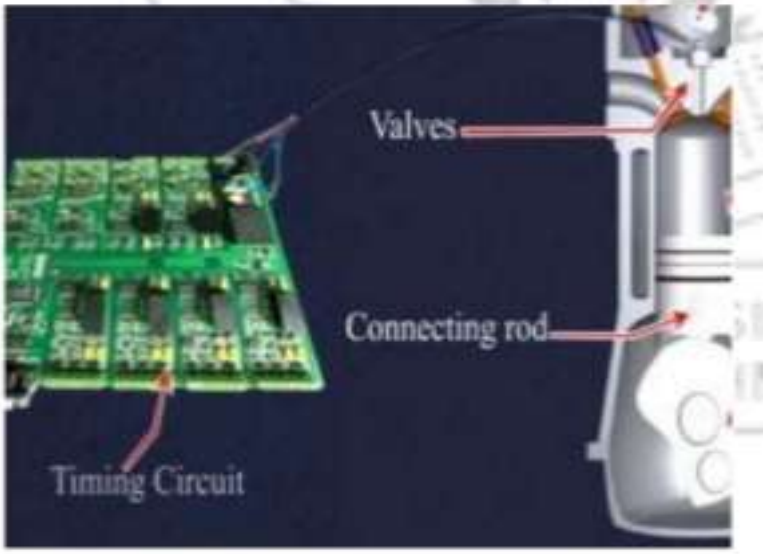


STAGE 2 OF OPERATION

The plunger of the pulsed firing valve is controlled by a timing circuit which is specifically a PLC programmed circuit. It supplies the electronic signals by which the plunger moves so that it opens and closes the pulsed firing valve.



STAGE 3 OF OPERATION

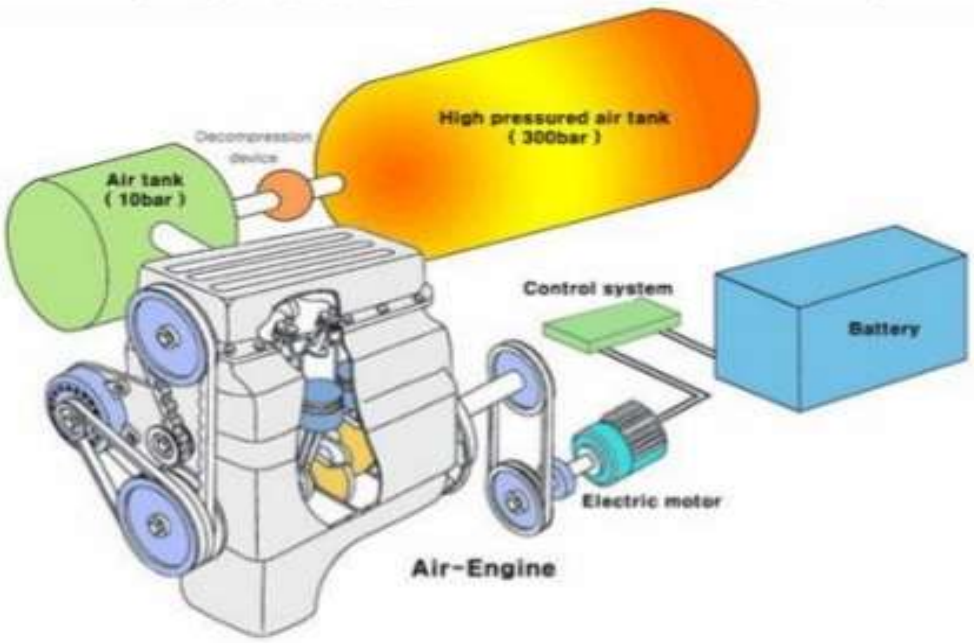


ELECTRICAL CONTROL OF CRANK SHAFT

On comparing it with the working of normal SI 4 stroke engine, we can say that:

- "Stage 1" of the air engine comprises of the combined operation of "Suction stage" and "Power stage" of the normal 4 stroke SI engine.
- "Stage 2" of the air engine comprises of the combined operation of the "Compression stage" and "Exhaust stage" of the normal 4 stroke SI engine.

LAYOUT OF THE ACTUAL WORKING



Layout of the Actual Working

WORKING DETAILS FOR 2 WHEELER

To develop the air powers bike first is to convert a regular scooter to a compressed air moped.

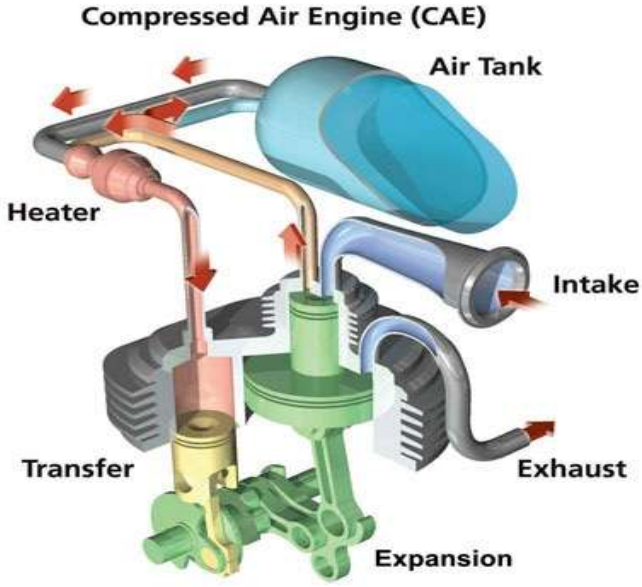
ARRANGEMENT OF AIR ENGINE ON 2 WHEELS

This has been done by equipping the scooter with a compressed air engine and air tank. The air bike is created by strapping two high-pressure tanks onto the side of his Punch moped. The tanks are basically scuba tanks. He uses the electricity from his house to fill the tanks. The power is then "stored" there, much like a battery, ready for use. The tanks used are carbon-fiber tanks of the sort used by firefighters for oxygen. But still, they're far cheaper than even the lead acid battery used in car now. Of course, the compressor works on electricity, so that's not always a clean power source but recharging options at night or off peak will enhance the chances to use the power that would be wasted otherwise. The top speed is about 18 mph, and it can only go7 miles before the air pressure runs out and a lot more power could probably be pulled by tweaking his configuration. A small gear on the end of the air drill, connected to the chain of the bike would make a much more elegant solution.

Several companies are investigating and producing prototypes, and others plan to offer air powered cars, buses and trucks. The compressed air is stored in carbon-fiber tanks that are built into the chassis. As the air is released, the pressure drives pistons that power the engine and move the car, and the pistons compress the air into a reservoir so that the process continues. After making a revolution by producing the world's cheapest car Tata nano, India's largest automaker (Tata Motors) is set to start producing the world's first commercial air powered vehicle.

The "Air Car" will make use of compressed air, as opposed to the gas-and oxygen explosions of internal-combustion models, to push its engine's pistons. Zero Pollution Motors (ZPM) (USA) also expects to produce the world's first air-powered car for the United States by 2010. An earlier version of the car is noisy and slow, and a tiny bit cumbersome but then this vehicle will not be competing with a Ferrari or Rolls Royce and the manufacturers are also not seeking to develop a Formula One version of the vehicle. The aim of air powered vehicles is the urban motorist: delivery vehicles, taxi drivers, and people who just use their vehicles to nip out to the shops. The latest air car is said to have come on leaps and bounds from the early model. It is said to be much quieter, a top speed of 110 km/h (65 mph), and a range of around 200 km before you need to fill the tanks up with air.

WORKING DETAILS FOR 4 WHEELER



WORKING OF ENGINE IN CAR

Air powered car is worked on the compressed air instead of gasoline. Since the car is working on air there is no pollution. A two cylinder compressed air engine, powers the car. The engine can run either on compressed air alone or act as an internal combustion engine. The compressed sir is stored in the fiber or glass fiber tanks at a pressure 4351 pounds per square inch. The air is fed through an air injector to the engine and flows into a small chamber, which expands the air. The air pushing down on the piston moves the crankshaft, which gives the power to the vehicles.

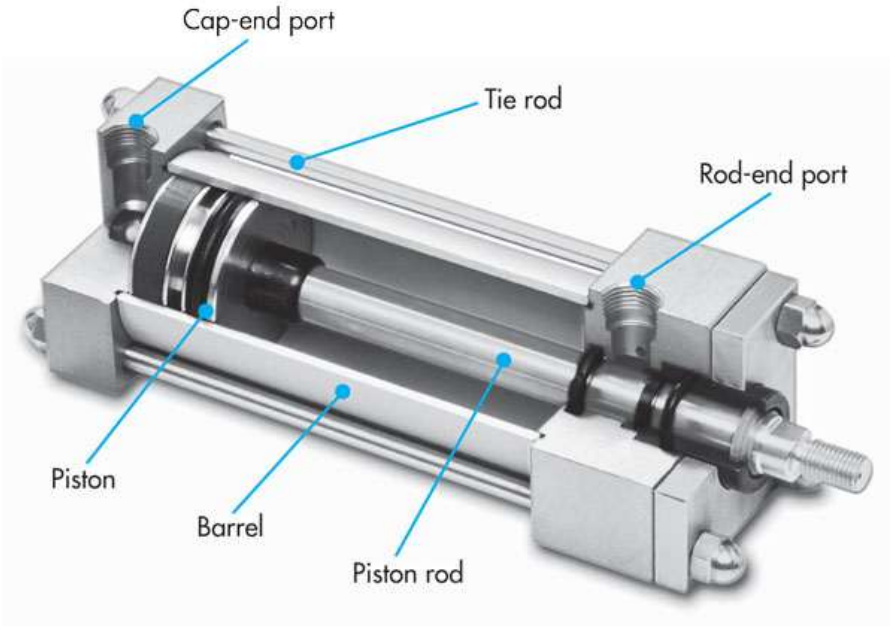
The car is also working on a hybrid version of their engine that can run on the traditional fuel in combustion with air. The change of energy source is controlled electronically. When the car is moving at a speed below 60kph, it runs on the air and at a higher speed it runs on a fuel such as gasoline diesel or a natural gas. Air tank is fixed to the underside of the vehicle can holds about 79gallons (300liters) of air. This compressed air can fuel the car up to 200kms at a top speed of 96.5kmh. When the tanks near empty it can be refilled at a nearest air pump. The car motors requires a small amount of oil 0.8liters worth that have to change just every 50,000km.

V. COMPONENTS

Composite material	**: As required**
MS rods	**: As required**
Rear axle	**: 1**
Front axle	**: 1**
Pneumatic	**: 1**
Steering system	**: 1**
Seat	**: 1**
Control unit	**: 1**

PNEUMATIC CYLINDER

Pneumatic cylinder are mechanical devices which use the power of compressed gas to produce a force in a reciprocating linear motion. Like hydraulic cylinders, something forces a piston to move in the desired direction. The piston is a disc or cylinder, and the piston rod transfers the force it develops to the object to be moved. Engineers sometimes prefer to use pneumatics because they are quieter, cleaner, and do not require large amounts of space for fluid storage.



Pneumatic Cylinder

When applications involve linear motion, high speed, and moderate loads, air cylinders are often the first choice to provide the actuation. Compressed air is available as a utility at almost every industrial facility, and economical air cylinders can be obtained from many manufacturers. One of the most fundamental fluid-power components, cylinders have evolved into an almost endless array of configurations, sizes, and special designs. Their versatility not only makes more innovative designs possible, but also makes a reality of many linear applications that would not be practical or possible without cylinders.

A cutaway model reveals key features of a typical double-acting pneumatic cylinder with standard tie-rod construction.

Cylinders are simple devices, and calculating their theoretical force output is fairly straightforward. However, sizing a cylinder properly for a real-world application is more complex. Undersizing, for example, is a common mistake that results in sluggish performance and cycling problems in automated equipment. Oversizing a cylinder wastes energy by using more air than is necessary. However, by following a few simple guidelines, you can quickly learn how to determine the right cylinder to fit their specific needs.

Calculate the force

The theoretical force output of a cylinder is the product of the air pressure applied and usable piston area exposed to it,

$$F = P \times A,$$

where F = force in lb, P = supply pressure in psi, and A = piston area in in.^{2}

For example, a cylinder with a 1½-in. bore supplied with 80-psi air would generate:

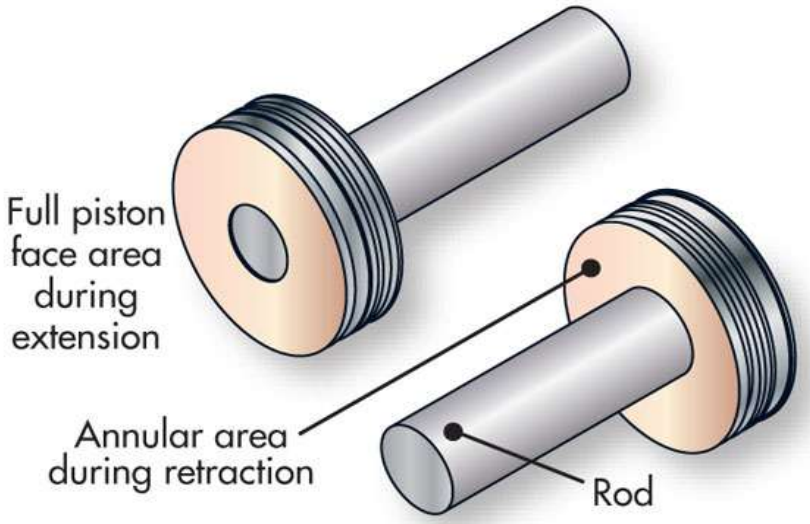
$$F = 80 \times \pi(0.75)^2$$

$$F = 141 \text{ lb.}$$

Area is fixed once the cylinder is selected and installed. Pressure can be varied, but only over a limited range. Therefore, it behooves the designer to calculate force, and, hence, area, very carefully early in the project. Also note that the formula calculates the *theoretical* force output. Several factors can and will lower it in a real application. Keep the following issues in mind whenever you size a cylinder.

Account for internal friction

Internal friction prevents a cylinder from achieving its theoretical output force. This friction is produced by piston and rod seals, bushings, wear bands, and other load-support and sealing components. A common general rule is to allow 5 to 10-psi additional input pressure to overcome internal friction, depending on the cylinder's design and bore. Cylinders with side load, misalignment, or specialty features may have even higher internal friction. A cylinder converts pressure to linear force, so considerable side loads and bending moments should be avoided or accommodated separately.



Full Piston Face Area

The face area of a piston that is exposed to pressure is a key factor in force equation. For calculations where a load will be moved during the cylinder's return stroke, the cross-sectional area of the piston rod must be subtracted from the piston surface area. This is known as the *annular* area. The previous example used the full-bore area, but if you are moving a load on the return stroke, or using a cylinder with a rod at both ends, then the annular area must be used to calculate the usable piston area. (Rodless cylinders, however, have the full-bore area available on both faces of the piston, which eliminates the annular area.)

Know the actual operating pressure

Although a compressor may produce a specified pressure, the pressure at the cylinder can be much lower due to flow restrictions in compressed-air lines and air consumption by other devices in the air-supply network. An air system that runs at 100 psi may drop to 80 psi or less during peak air-usage times of the working day.

Know the true load

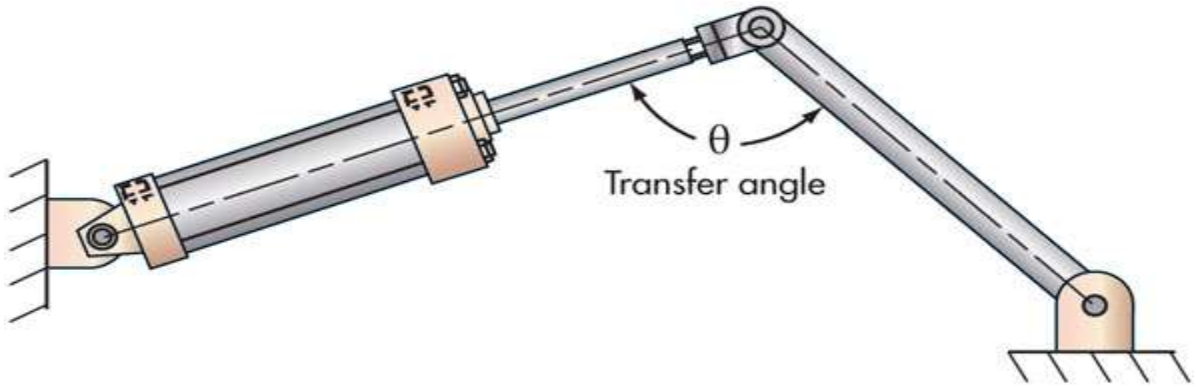
Unless you are lifting a load vertically, it can be somewhat difficult to determine the true load because of external friction. Even if a load is lifted vertically, if it is guided in any way, there will be additional friction. Calculating the force loss due to sliding friction must include friction factor:

$$Ff = F_p \times f_c,$$

where F_f = friction force, lb; F_p = force perpendicular to the sliding surface, lb; and f_c = the coefficient of friction.

If the sliding surface is level, the perpendicular force is the object's weight. If the sliding surface is inclined, the perpendicular force is the product of the cosine of the incline angle and the object's weight.

Extensive information is available that documents coefficients of friction for various materials, but small variances in this number can make large differences in the required force. If you are sizing a cylinder for an existing application, try to physically measure the required force. If the application is new, do as much physical experimenting as possible to verify any calculated numbers you use.



Transfer Angle

Transfer angle, θ, in linkage path diminishes the cylinder force available at the load.

After summing all the forces, the remaining (net) force is what causes motion. Acceleration of the load will be equal to the net force divided by the total mass being moved,

$$F_n = m \times a$$

Unfortunately, it's usually not this simple. Coefficient of friction often changes with speed. Furthermore, if net force is low, the cylinder may exhibit stick-slip operation, sometimes called *stiction*. Stiction occurs when force from pressure is great enough to overcome static friction and begin moving the cylinder's piston. Once the piston starts moving, dynamic friction comes into play. If static friction exceeds dynamic friction, the piston may suddenly stop when moving at very low speed because static friction has taken over. As pressure builds, the piston again overcomes static friction force, and the piston lurches ahead. This start-stop motion can occur repeatedly and rapidly, resulting in a condition sometimes called "chatter." Correcting the condition requires redesigning some aspect of the assembly, such as higher pressure or a larger bore. If these solutions are not possible, then seal and bearing materials with a lower coefficient of friction or additional lubrication may be called for.

Ensure adequate piping

The compressed air must reach the cylinder's piston quickly to build the pressure that will produce the force to move the load. Lines sized too small and with too many bends, turns, and restrictions will restrict airflow, causing sluggish operation and low force or torque from the actuator. Sizing lines and components too large will increase the volume of air that must be pressurized, increasing system response time.

A helpful analogy is that one person may be able to push a car at 1 mph, and two people may be able to push it at 2 mph. But 100 people cannot push a car at 100 mph. The reason they can't is because they reach their terminal velocity. Although the 100 people have more than enough strength to push the car, they can't move more than their own maximum (terminal) speed. Compressed air is subject to the same limitations. If air can't be delivered through the system quickly enough, then the pressure (force) at the cylinder will not reach that required to move the load. This potential problem is a result of inadequately sized components or an unbalanced system, not just too small a cylinder.

Consider the angles

If the cylinder in an application deals with linkages or has a force transfer angle or other pivoting member, allow for force losses in those angles. The force actually transmitted to the system is equal to the net force multiplied by the sine of the transfer angle:

$$F_t = F_n \times \sin\theta$$

where F_t= force applied to the load, F_n = net force, and θ = the transfer angle.

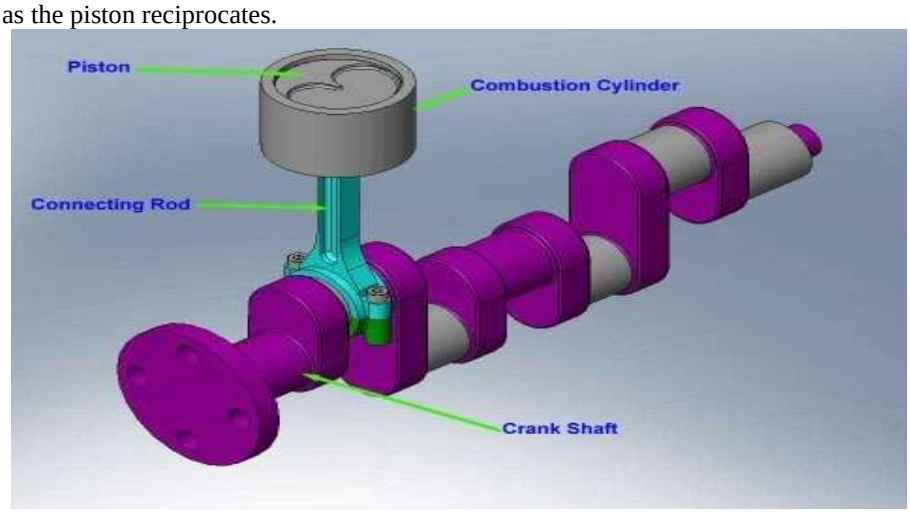
The force absorbed by the pivot is equal to the net force multiplied by the cosine of the transfer angle:

$$F_t = F_n \times \cos\theta$$

When the transfer angle is greater than 135° or less than 45°, more cylinder force is acting against the pivot than is being transmitted to the application. Transfer angles greater than 150° and less than 30° transfer less than half the cylinder force to the application, so they should be avoided. In these cases, a different mechanical arrangement or a rotary actuator could be used.

CRANK SHAFT

Crankshaft converts reciprocating motion to rotational motion. It is how you get your car to move. If you know how an engine operates, the piston reciprocates as fuel burns and the gases are emitted. The piston is connected to the crankshaft via a connecting rod. This makes the crankshaft rotate as the piston reciprocates.



Crank Shaft

COMPRESSED AIR TANKS

One of the most frequently asked questions is about the safety of the compressed air storage tanks. These tanks hold 90 cubic meters of air compressed to 300 bars. Many people ask whether this system is dangerous in case of an accident and if there is a risk of explosion. Because these are the same tanks used to carry the liquid gas used by buses for public transport. The tanks enjoy the same technology developed to contain natural gas. They are designed and officially approved to carry an explosive product: methane gas.

In the case of a major accident, where the tanks are ruptured, they would not explode since they are not metal. Instead they would crack, as they are made of carbon fiber. An elongated crack would appear in the tank, without exploding, and the air would simply escape, producing a loud but harmless noise. Of course, since this technology is licensed to transport an inflammable and explosive gas (Natural gas), it is perfectly capable inoffensive and non-flammable air.

It is fitting, therefore, that MDI has reached an agreement with the European leader in aerospace technology Airbus Industries for the manufacture of the compressed air storage tanks. With a remote supervision arrangement, Airbus Industries oversees the making of the storage tanks at each MDI factory. The coiled carbon fibre technology used in the construction of the tanks is complex and requires a substantial quality control process which the multinational company, home of the Airbus aircraft, will provide for our vehicles.

BRAKING SYSTEM

Principle of Braking System

While operating the braking system the kinetic energy of the moving vehicle is converted into heat energy.

Drum Brakes

The concept here is simple, two semicircular brake shoes sit inside a spinning drum which is attached to the wheel. When you apply the brakes, the shoes are expanded outwards to press against the inside of the drum. This creates friction, which creates heat, which transfers kinetic energy, which slows you down. As the brakes are applied, the cable which is connected to one end of the lever is pulled and the other end transfers the forces against the brake shoes and in turn forces them to expand outwards. The return spring is what pulls the shoes back away from the surface of the brake drum when the brakes are released. This is the simple working of the braking system which is incorporated in Compressed Air Car for easy halt of the vehicle because of the low speed ranges.

Brake Power Recovery

The MDI vehicles will be equipped with a range of modern systems. For example, one mechanism stops the engine when the car is stationary (at traffic lights, junctions etc). Another interesting feature is the pneumatic system which recovers about 13% of the power used.

THE BODY

The MDI car body is built with fibre and injected foam, as are most of the cars on the market today. This technology has two main advantages: cost and weight. Nowadays the use of sheet steel for car bodies is only because of cost - it is cheaper to serially produce sheet steel bodies than fibre ones. However, fibre is safer (it doesn't cut like steel), is easier to repair (it is glued), doesn't rust etc. MDI is currently looking into using hemp fibre to replace fibre-glass, and natural varnishes, to produce 100% non-contaminating bodywork.

The Air Filter

The MDI engine works with both air taken from the atmosphere and air pre-compressed in tanks. Air is compressed by the on-board compressor or at service stations equipped with a high-pressure compressor.

Before compression, the air must be filtered to get rid of any impurities that could damage the engine. Carbon filters are used to eliminate dirt, dust, humidity and other particles, which unfortunately, are found in the air in our cities.

This represents a true revolution in automobiles - it is the first time that a car has produced minus pollution, i.e. it eliminates and reduces existing pollution rather than emitting dirt and harmful gases. The exhaust pipe on the MDI cars produces clean air, which is cold on exit (between -15º and 0º) and is harmless to human life. With this system the air that comes out of the car is cleaner than the air that went in.

The Chassis

Based on its experience in aeronautics, MDI has put together highly resistant, yet light, chasses, aluminium rods glued together. Using rods enables us to build a more shock-resistant chassis than regular chasses. Additionally, the rods are glued in the same way as aircraft, allowing quick assembly and a more secure join than with welding. This system helps to reduce manufacture time.

Electrical system

Guy Nègre, inventor of the MDI Air Car, acquired the patent for an interesting invention for installing electrics in a vehicle. Using a radio transmission system, each electrical component receives signals with a microcontroller. Thus only one cable is needed for the whole car. So, instead of wiring each component (headlights, dashboard lights, lights inside the car, etc), one cable connects all electrical parts in the car. The most obvious advantages are the ease of installation and repair and the removal of the approximately 22 kg of wires no longer necessary. Whats more, the entire system becomes an anti-theft alarm as soon as the key is removed from the car.

Steering System

Like most things in a car, the concept of steering is simple -you turn the steering wheel, the front wheels turn accordingly, and the car changes direction. How that happens though is not quite so simple. So for our project Compressed Air Car we used Rack And Pinion type Steering System. In a rack and pinion System, toothed bar with the tie rods attached to each end. On the end of the steering column there is a simple pinion gear that meshes with the rack. When you turn the steering wheel, the pinion gear turns, and move the rack from left to right. Changing the size of the pinion gear alters the steering ratio. This steering mechanism follows the Ackerman's Steering Principle which is very best suited for our project to eliminate the weight of the vehicle because of the simple construction of the steering mechanism.

Suspension System

The suspension points of the vehicle for a chassis should be considered before the chassis itself. Suspension and all the chassis requirements will involve much compromise. For this text into consideration we thought of coil spring type of suspension. This is because the vehicle weight is so much optimized because of internal physics involving in the propulsion of the Compressed Air Car as well they store energy and subsequently releases it. These can easily withstand the weight excreted and avoid uneven forces on the tire causing loss of traction. It absorbs the shocks and disturbances created while the vehicle is in dynamic phase. This also protects the tanks which are stored with compressed air while the vehicle is passing through any ditches or bumps. This is the simple suspension system attached for Compressed Air Car.

TESTING AND PERFORMANCE

Road Testing

Car was tested at various pressures of compressed air keeping the vehicle dynamics into consideration. Maximum permissible load was tested and the result depicted fair values. Brake tests were conducted and the joint efficiencies were observed. They withstood the impacts and could resist the jerks.

Leak Testing

Leak testing is required by most codes prior to initial operation and each piping system must be tested to ensure leak tightness. The field test is normally a hydrostatic leak test. There are several other types of testing depending on service fluid and there are six different testing methods that can be used at most construction sites.

1. Hydrostatic testing which uses water under pressure.
2. Pneumatic testing which uses gas or air under pressure.
3. In-service testing which involves a walk down for leakage when the system is put into operation.
4. Vacuum testing which uses negative pressure to check for leakage.
5. Static head testing which is normally done for drain piping with water with a known static head pressure left in a standpipe for a set period of time.
6. Tracer leak method for inert gas leak detection.

Pneumatic Leak Testing

The fluid medium used for pneumatic testing is either compressed air or Nitrogen gas. The test pressure by code is usually 1.1 times the design line pressure. Pneumatic testing involves the potential hazard of releasing energy stored in the compressed gas. Care must be taken by gradually increasing pressure in steps up to the test pressure, holding only as long as the code requires, then reducing to the design pressure for inspection of the joints. The inspection of joints is done utilizing a soapy water mix that bubbles when air is escaping.

Soap solution test

This is one of the simplest and cheapest methods to spot the leaks in a pneumatic circuit. A soap solution is prepared and is applied at all the joints, fixtures of the hoses, valves, reservoir connections and other sensitive parts. This solution is applied after the tanks are filled to a rated level. All the valves are opened and air starts rushing through the connections. Whenever there is a leak present, with the movement of air molecules, soap bubbles start emerging at the leak spot. Thus the leak spot is observed.

POWER TRANSMISSION

The power transmission undergoes the following processes. Air is stored in the tank at a pressure of 11.03bar. From the tank, air flow is synchronized by a regulator. This maintains pressure to the downstream.

Components as long as there is a pressure difference between the reservoir and the required operating pressure. Controlled discharge from the tank is proportional to the release of butterfly valve. From there, air is boosted to the pneumatic wrench inlet. Hence this compressed air expands at the rotor blades where its pressure energy is converted to rotational energy of the rotor. Ultimately spindle connected to the rotor is given drive in turn is given to the rear wheel.

BASIC FUNCTION OF COMPRESSED AIR ENGINE

In compressed air engine there will only be two strokes. Engine will be supplied with the mean effective pressure which will directly push the piston in downward direction hence giving the piston power to drive the engine. But as soon as the piston comes up the exhaust valve will have to be opened so that the compressed air driving the piston may go out and piston may cover its distance in the upward direction without any hurdle. Now to minimize forces on the head of the piston the intake valve will also have to be closed while piston is coming up. As the basic idea has been grasped now the amendments will have to be made in the engine.

Modifications Required

As the engine is supplied with the compressed air so compression stroke will not be required because when the compressed air will again be compressed the power output would not be sufficient. So the remaining strokes that we are left with are 3. If we study these remaining strokes then it is obvious that the intake stroke and the power stroke are same which leaves us with two strokes only. Now it is required to convert the selected 4-stroke engine to 2 stroke engine. Before going any further let us define these two strokes which will act in the compressed air engine.

Stroke 1

In the first stroke the intake valve will open and the compressed air will make impact with the piston. As a result the piston will go down from the top dead center to the bottom dead center. Hence the intake stroke will also act as power stroke as well. Therefore, there will be no need of extra power stroke.

Stroke2

In the second stroke the exhaust valve is opened and the compressed air which gave its energy to piston in the last stroke to make it move goes out as the pressure of the ambient is even lower.

Valves' Timing

The timing of the engine is to be adjusted such that the intake stroke or the exhaust stroke opens just once in the four strokes that is the valves open only once for the two revolutions of the crankshaft. But for the compressed air engine it is has been evaluated that both the inlet and exhaust valves will open for two times during the two revolutions of the crankshaft or it can be said that both intake and exhaust will opens once for every revolution of the crankshaft. Now a way has to be adopted through which the timing of the shaft can be controlled. This can be done by changing the camshafts design.

Alterations in Camshafts

Mechanical component in the engine which is controlling the movements of the valves is camshaft. Camshaft controls the motion of the valves and if the profile of the camshaft is changed then the valves motion can be changed as is desired. Shown in the Figure below, is the camshaft's profile which is used in the four-stroke engine.

The speed of camshaft is half the speed of crankshaft. Now if the crankshaft has moved two revolutions and both valves open just for once then during that rotation the camshaft moved one revolution. Now if we want to make the valves open for two times during one revolution of camshaft then we will have to make two more lobes that are at 180 degrees to each of the lobes shown above. Now the

camshaft like this opens the valves once for every revolution of the crankshaft that is for every two strokes. The Valve Timing Diagram, when the modified camshaft is used is shown below:

Other Alterations Possible

In order to get maximum efficiency the pressure at the piston head during intake stroke should be same as the pressure of air compressed. For that purpose the air should be sent in the cylinder directly from the top, perpendicular to piston head's surface. That is the air inlet should be made through the spark plug instead of intake valve, because of following two reasons:

i. Intake through intake valve is not normal to the piston head's surface, which obviously will not be able to produce the same pressure in the engine's cylinder as it was in the cylinder containing compressed gas.

ii. Intake valve doesn't lie exactly at the center of cylinder head but is located at one edge of cylinder head instead, this will also cause the power loss because the more is the energy required to move the piston by pushing it not exactly from the center as compared to the amount of energy required to move the piston by pushing it from the center. (it is a basic law of physics) In view of above discussion, one must use the spark plug location to intake the compressed air, but we are not doing so in our project because when you enter the air this way, you need an extra valve system like solenoid valves in order to close and open the compressed air supply.

Now the problem is that if we employ solenoid valves, then an extra electronic system will have to be used to control these solenoid valves, which will not only make our project rather complicated but also will cost too much to afford.

Also, there is another way to accomplish our job of changing the valve timings according to one required for compressed air engine by replacing the gears connecting camshaft to crankshaft (these gears rotate the camshaft half the speed of crankshaft) by a simple belt or chain system causing the camshaft move at same rpm at which crankshaft is moving. This is an even better option but this might be creating problems in the engine geometry and we can't counter these problems as we can't get a new design of whole engine and can't get it fabricated as well. So we opt to modify the camshaft only giving it a new shape or geometry as shown in the models above.

Mathematical Calculations of Certain parameters

We know that the engine 'indicated horse power' (IHP) can be calculated as following,

$$1\ HP = P_m L A\ n\ k/60$$

Where,

P_m = mean effective pressure
L = length of stroke
A = piston cross section area
n = rpm of crankshaft
k =number of cylinders

For our case,

P_m = Pressure at which the air is compressed can be found using the Tachometer when engine is running. (As there is only one cylinder present)

" L " and " A " are specific for a given engine.

When we have the engine's parameters (bore and stroke) and rpm, we can simply calculate the engine's I.H.P. using the above mentioned formula.

Then we find the B.H.P. using the Dynamometer Torque.

Then the ratio of this I.H.P. to B.H.P. will give us the efficiency of our Engine as:

$$\eta = B.H.P./I.H.P.$$

The Friction Horse Power will simply be the difference of B.H.P and I.H.P.

To calculate the work done we make use of formula:

$$\text{Work done} = m.e.p. * Vd$$

VI. RESULT AND CONCULSIONS

They designed the proto type for low speed, the output power; applied load was also kept low. The prime aim being to test the concept of application along with its related advantages.

$$\text{Indicated power} = ip = p\ L\ A\ n\ K/\ 60{,}000\ kW$$

Here, K = 2, L = 0.11, A = 0.00079

for 450 RPM

ip = p L A N K/ 60 000 kW
= 05 x 100000 x 011 x 000079 x 450 x2 /60000
= 0.065 kW

Similarly for 570 RPM

ip = 0.165 kW

And for 650 RPM

ip = 0.282 kW

TECHNICAL BENEFITS

- The temperature of the engine while working will be slightly less than the ambient temperature.
- Smooth working of the engine due to very less wear and tear of the components.
- There is no possibility of knocking.
- No need of cooling systems and spark plugs or Complex fuel injection systems

ECONOMIC BENEFITS

- Reduces the cost of vehicle production by about 20% as no need to build a cooling system, fuel tank, Ignition Systems or silencers.
- Compressed air which is relatively much cheaper and widespread.
- Compressors use electricity for generating.
- Smooth working will lead to less wear & tear, so lesser maintenance cost 20

A PROVEN FACT

Research by MDI shows that an Air Powered Car can travel 171 km by using electricity costing about Rs. 80-100 which would cost about Rs. 570 for a normal S.I. engine car giving an average of 15 kmpl.

MAJOR TECHNICAL LIMITATIONS

1. When air expands it cools dramatically and must be heated to ambient temperature using a heat exchanger similar to the Intercooler used for internal combustion engines.
   i. The heating is necessary in order to obtain a significant fraction of the theoretical energy output.
   ii. The heat exchanger can be problematic.
   iii. While it performs a similar task to the Intercooler the temperature difference between the incoming air and the working gas is smaller.
   iv. In heating the stored air, the device gets very cold and may ice up in cool, moist climates.
2. Tanks get very hot when filled rapidly.
   i. SCUBA tanks are sometimes immersed in water to cool them down when they are being filled.
   ii. 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.
3. Limited capacity of storage tanks.
4. Limited Range (140- 150 Km.)

ADVANTAGES

- Economical
- Pollution free
- Better Fuel efficiency
- Better comfort
- Less Maintenance
- Low Cost

APPLICATION

- Motorcycles
- Mopeds
- Cars
- Buses
- Locomotives
- Trams
- Three-wheeler

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