Palestine Polytechnic University

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Graduation project

COMPRESSED AIR VEHICLE (CAV)

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2010-2011

ABSTRACT

In the field of combustion engines, it is well known that fuels such as gasoline, diesel, and ethanol are used in a combustion process to power engines. However, it is also well known that the use of such fuels generates byproducts which are harmful to the environment. Further, aside from environmental concerns, the use of such fuels is costly to the consumer.

In view of these concerns, it is desirable to at least substantially reduce, if not eliminate, the use of combustible fuels. One source of power is compressed air, or pneumatics. Several devices have been developed for using pneumatic power to operate engines.

In this proposed project an air-operated engine system used for driving a vehicle by means of compressed air from a rechargeable air storage tank. The engine used in the system has cylinders containing driving pistons connected to a crankshaft. Compressed air from the storage tank is supplied at a regulated pressure to the cylinders in power strokes by means of solenoid valves and then the air is exhausted from the cylinders at the ends of the power strokes exhausting by means of the same valves. The solenoid valves are operated by a distributor which controlled by electrical signal from the crankshaft. The air is compressed by a compressor which operated electrically.

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CHAPTER ONE

INTRODUCTION

1.1 Overview:

Commercial vehicle is required recently to change its power sources and materials for every part more ecological and to consider any environmental problem such as CO_2 emission, air pollution and exhausting natural resources. To respond these requirements, many automobile manufacturers have been trying to develop new ecological vehicles such as electrics, fuel cells, diesels, and hybrids. One of these concepts could be introduced here, which is considered to get zero emission performance and extremely low energy consumption for the construction and the customer use, is the compressed air vehicle.

A compressed air vehicle (CAV) is proposed to develop a zero emission car driven by compressed air. There might be some difficulties to have enough performance to run the car on public road. To build the CAV for a practical use, a hybrid system with an electrical powered motor and a recompressing energy recovery system are applied to get further acceleration and longer distance per one-time filling compressed air to the car. The present study will show an analysis of the theoretical performance and a method of how to use our idea to give an advantage to the CAV.

We are living in a very mobile society so light utility vehicles 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 fueled by alternative energies. When at present level of technological development fuel-less 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 to make air-powered vehicles as one possible alternative. Engineers are directing their sincere efforts to make use of air as an energy source which will make small cars running with air power for daily routine distances and the travel will be free from pollution and cost effective.

Researchers have been working for many years to produce "eco-friendly " cars but so far these attempts have not bean successful. One of these energies used is compressed air. It depends on storing air with high pressure in a tank, which may be used for operating mechanical actuators as air motors and cylinders.

Some inventors through few years used this energy to operate vehicles, but some of them success and other failed. They used air engines to propel vehicles, which were bikes or mini-cars. These engines expand compressed air by using heat to duplicate the power delivered. Many attempts were taken place in this direction.

Until now a little information is known about these engines because of industrial security of the companies .

1.2 Description Of Compressed Air Vehicle (CAV) Technology:

Mankind has been making use of uncompressed air power from centuries in different application as windmills, sailing, balloon car, hot air balloon flying and hang gliding etc. The use of compressed air for storing energy is a method that is not only efficient and clean, but also economical and has been used since the 19th century to power locomotives, and was previously the basis of naval torpedo propulsion. In 1903, the Liquid Air Company located in London manufactured a number of compressed air and liquefied air cars. The major problem with compressed air cars was the lack of torque produced by the "engines" and the cost of compressing the air. Recently several companies have started to develop compressed air vehicles, although none has been released to the public so far. [13]

They tie or beat batteries in the charge / recharge efficiency and totally kill them on lifespan. Higher pressures are their big problem of compressed air vehicles while efficiency, cost, toxic chemicals, and lifespan are the big problems associated with chemical batteries. 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.[12]

Air motor operated vehicle is a simple pneumatic system, which chosen for special purposes such as transporting between the university buildings, hospitals, playgrounds, and arboretum.

1.3 Block Diagram :

The proposed system is show in Fig.1.1. It shows the three parts of the system which are: the air compressing components, actuating components, and control parts. Beginning with the first stage the charging system depends on the max pressure allowed in the tank, a pressure sensor is used to sense the pressure's tank. When pressure reaches the lower value, the sensor send a signal to the controller to switch on the internal combustion engine , controller close switch(1), by a signal, which starts the starter of the engine then compressor compresses the air into the tank. This operation continue until the pressure in tank reaches to the higher allowed value, and again a signal sent to the controller to stop the compressor by switch(1).

The speed of air car will depend on the pressure value in the tank, if pressure in the tank reaches a value less than air motor need, the vehicle cannot run. But if the pressure reaches a value suitable to run the air motor or air engine, the vehicle can run. Maximum value of pressure determines the time during which the car travel without recharging. By knowing the period of air engine operation and speed of the car, the volume of air needed can be computed.

The compressor takes energy from an external engine and compressed air from an atmosphere to a specified value of pressure. Now the energy converted from mechanical form to potential form in the tank. When the driver needs to drive the car, he turns on at first the valve which change direction of directional control (two directional-two way control valve) and compressed air flowing to reach the second valve which is regulator valve at this moment the car ready to run by pressing on the accelerator pedal of the car by driver's foot. The speed is controlled by changing the flow rate in regulator valve, that can be done by combining a potentiometer as shown Fig.1.1.

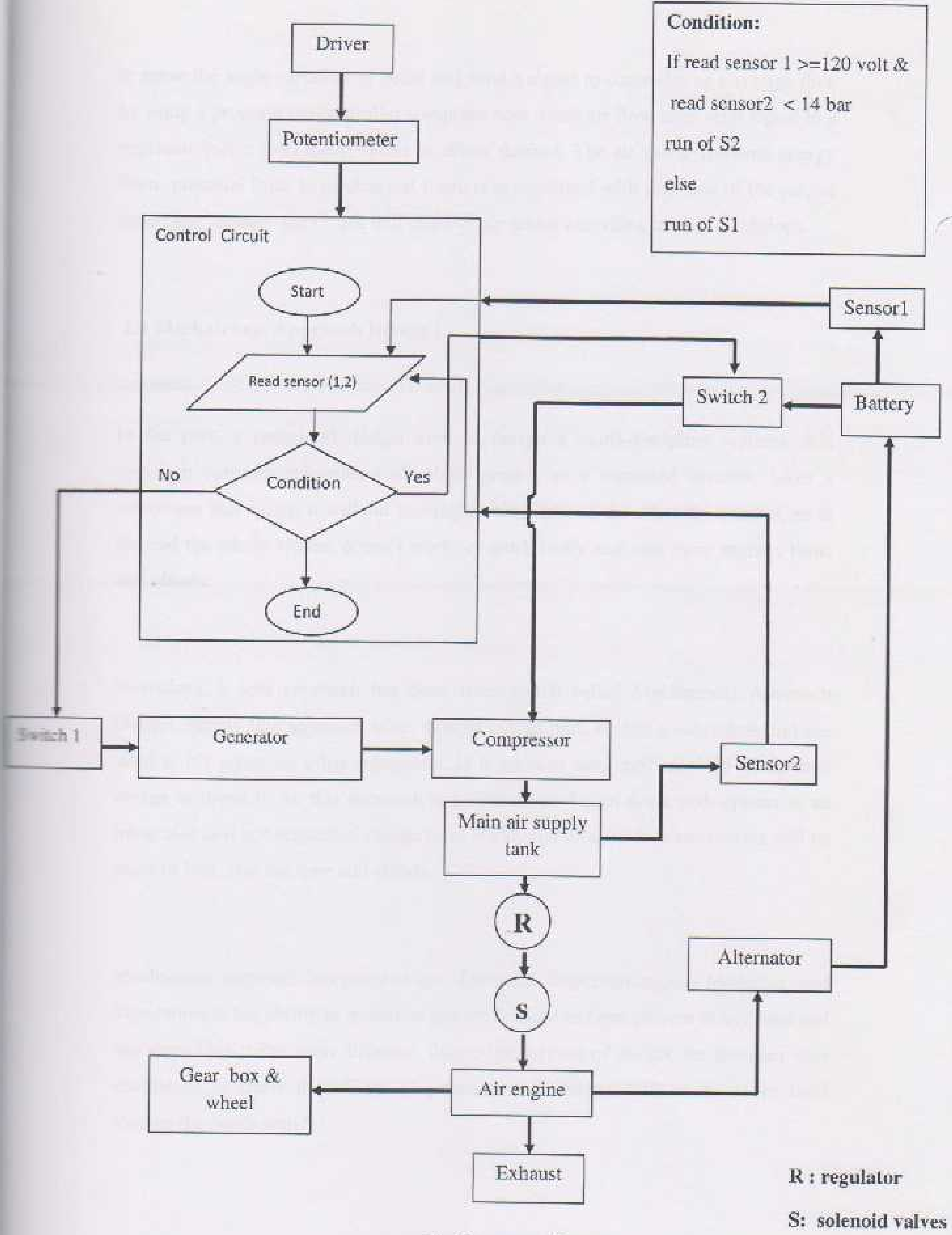


Fig.1.1: present diagram

to sense the angle variation of pedal and send a signal to controller as a voltage then by using a program the controller computes how much air flow must send signal to a regulator valve, then speed varies as driver desired. The air motor converts energy from potential form to mechanical form, it is combined with gear box of the car, so driver can change the torque delivered by air motor according to road conditions.

1.4 Mechatronic Approach Design :

In the past, a sequential design used to design a multi-discipline systems, this approach consider subsystems of whole project as a separated systems, takes a subsystem and design it without looking to it's effect on the other subsystems, so at the end the whole system doesn't work, or work badly and cost more money, time, and efforts.

Nowadays, a new approach has been risen which called Mechatronic Approach Design, simply this approach takes subsystems as unit, design a subsystem and see what is it's effect on other subsystem, is it good or not, until reach to an optimal design or round it. So this approach is a concurrent design deals with system as an integrated unit not sequential design as in traditional method then constraints will be more or less, also the time and efforts.

Mechatronic approach has many stages. The most important stage is Modeling and Simulation, it has ability to modulate system through designs process at any time and any step. This is the main different than other method of design, the designer uses simulation to know the effects of parameters variations, still in the loops until reaches the needs satisfy.

Of course this project is a multi-discipline system, it consists of mechanical subsystems which are, mechanical components and pneumatic system, electrical subsystem, computer subsystem, and information subsystem. Mechanical system is divided into mechanical components like motors, tank, compressor...etc show Fig.1.2. Also it contains pneumatic system. Electrical subsystem which is nearly every time combined with mechanical part and the two systems are called electromechanical system. In this project some of electrical components are: DC motor, controller, and sensors...etc. Computer subsystem is used to interface with a controller, so a program is written into a microcontroller which called information subsystem concerning modeling, simulation and numerical methods for optimization.

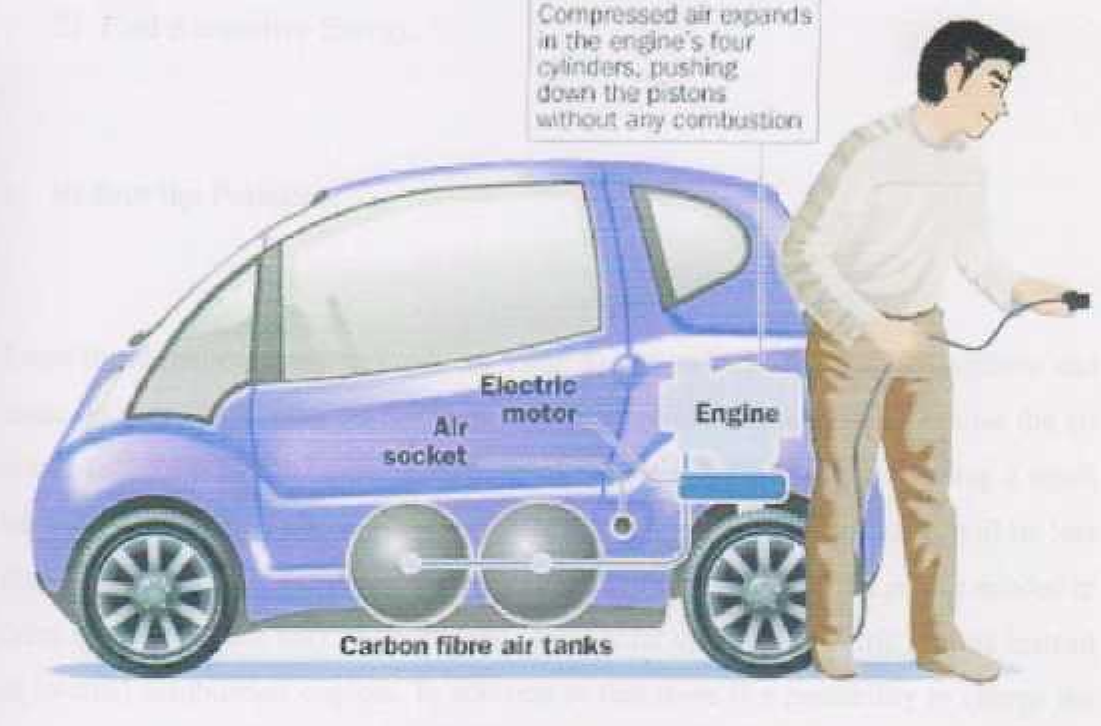


Fig.1.2: CAV

1.5 Objectives of Project:.

This project comes as a response to the modern tends in the automotive world ,which could be summarized into two main factors, namely, the growing interests in the protection of the environment and reduction of pollutants in the atmosphere.

So the project objectives are.

1) Reduce the Pollution.

2) Find Alternative Energy.

a) Reduce the Pollution:

Since fossil fuel combustion produces some danger exhaust gases to atmosphere and cause so many problems. So this project aims to reduce these gases, because the air enters to the car and exhaust without any kind of burning. Despite of using a small internal combustion to drive the compressor in this project, the pollution will be less than of vehicles fully working on conventional types of fuel, and the power needed to drive the compressor may be developed to use solar energy or electric motors instead of internal combustion engines. In addition to that there is a possibility to charge the air tanks in a special stations for such purpose.

b) Find Alternative Energy:

Using alternative sources of energy such as compressed air is not a new idea . In recent decades, the earth's natural resources decrease in significantly, energy researchers have begun to search for alternative and renewable energy sources, one of these energy source is air power.

The air engine is an emission-free piston engine using compressed air as fuel. Unlike hydrogen, compressed air is about one-tenth as expensive as fossil oil, making it an economically attractive alternative fuel.

One incredible new alternative energy source for use in automobiles is the Air Engine. It is an engine that works by expanding compressed air and this releases energy. This method is not really anything new and has actually been around for a few centuries but the technology is starting to become very efficient during the last few years.

1.6 Well To Wheel Efficiency Of A Compressed Air Vehicle:

We are all familiar with the standard measure of vehicle efficiency. Miles per gallon, or the CO_2 emissions derived from it does not show the whole picture. The drilling, pumping, transporting, and refining of petroleum products such as gasoline and diesel requires additional energy that we often overlook. By some estimates this "well to tank" phase adds 15-20 per cent to the emissions/energy use. But where does the energy go once it gets into the vehicle's tank. First, the car must overcome the aerodynamic drag in order to maintain a given velocity. For this, figures for the vehicle's coefficient of drag, the cross sectional area and the density of air are required. Multiplying the coefficient of drag by the cross sectional area results in a good indicator of how aerodynamic a car is.

In case of the compressed air car, the electrical energy that is required to compress the air lowers the overall efficiency. Furthermore, environmental pollution generated at the electricity source should also be considered. To be precise, the efficiency from compressor to wheel of the air car is calculated to be ~40 per cent according to some reports. In comparison, the efficiency of electric vehicles from battery to wheel is 80 per cent. If the air compressor is powered by an ICE with an efficiency of about 40 per cent, then the overall efficiency of the air car from fuel to wheel is(40% x 40% – 16%), which is poor, as compared to an IC engine or battery-electric power train.[11]

If the dynamic performance and the energy efficiency are positive while running on the road, the overall (creating, transport the fuel, and transfer to the dynamic energy) efficiency, which is Well-to-Wheel energy efficiency, must be considered. People will not see CAV concept as a future environmental solution for the commercial cars without any advantages to the overall efficiency. In fact, for the environmental issue, (especially the natural resource exhaustion) the most important thing is to reduce the manufacturing energy and energy supplying efficiency, which are all related to the reduction of the amount of handling energy for every process of the car industry.[10]

Table1.1: Well-to-Tank for each energy source

Energy type	Well to Tank
LPG	0.90
Hydrogen	0.70
$\Delta G/\Delta H$	0.83
Electricity	0.37
Compressed Air (a)	0.27
Compressed Air (b)	0.43

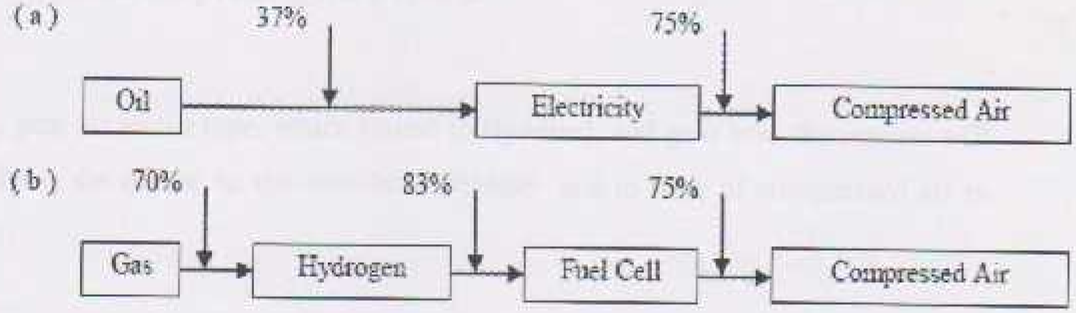


Fig.1.3: Well-to-Tank flowchart for Compressed Air generation

The general energy efficiency of Well-to-Tank for each source of energy is shown in Table 1.1. To store the compressed air to the tank of the vehicle, there are two ways shown in Figure1.2. The way (a) is to use the domestic electric outlet for operating the compressor. The way (b) is to use hydrogen fuel cells for operating the compressor. Each value of efficiency in Fig.1.3 is considered as an average value in the general situation.

1.7 Methodology Of Project :

For proposed Compressed air car in the project the design concepts are :

a) Using internal combustion engine as power supply:

For this project an internal combustion engine will be the power supply to feed compressor with power. The selection of this type of power supply is due to it's high torque, and other sources like electrical motors provide an additional weight due to batteries.

b) How to use this power to run a vehicle:

By using gear air motor type, which linked to flywheel, and gear box, the motion will transfer from the motor to the wheels of vehicle due to flow of compressed air in air motor.

c) Methods of distribution a compressed air that was followed in the proposed project.

After not being able to get in the proposed project an air engine, because of the high expenses, a decision was made to convert an internal combustion engine running on gasoline to run on compressed air instead of fuel combustion, the problem was how to distribute the compressed air into the cylinders in an appropriate timing in power strokes.

1.8 Scope:

This project consists of five chapters which are:

1st Chapter: Introduction.

2nd Chapter: compressed air vehicle (CAV).

3rd Chapter :Pneumatic System.

4th Chapter : Mechanical Design.

5th Chapter : Modeling and Simulation.

The system has been build and only the magnitude of pressure needs to select parameters of components. This is an advantage of this car (and in general pneumatic system) it's structure isn't complex and it is a simple pneumatic system.

2nd Chapter : compressed air vehicle (CAV):

This chapter includes historical studies about air vehicles from tenths of years to few months ago. But because this type of vehicle is new, the information is little and almost is secret .

3rd Chapter: Pneumatic system:

This chapter talks about pneumatics and it's components, the power supply, inputs, processing elements, and actuators. And what advantages of pneumatic system, and almost components of project like motor, compressor, tank, valves, and processing elements are include with it.

4th Chapter : Mechanical design:

This chapter talks about air motor operated vehicle subsystem's, and the method of it's design which includes Gases law, Newton's law, and Conservation of energy (Bernoulli's equation).

5th Chapter : Methods of distribution a compressed air that was followed in the proposed project:

This chapter describes the methods of distribution of compressed air which were analyzed and experimented during the designing of the project and the obstacles which were facing their implementation.

CHAPTER TWO

Compressed Air Vehicle (CAV)

2.1Introduction:

It is hard to believe that compressed air can be used to drive vehicles. However that is true, and the "air car", as it is popularly known, has caught the attention of researchers worldwide. It has zero emissions and is ideal for city driving conditions. MDI is one company that holds the international patents for the compressed air car. Although it seems to be an environmentally-friendly solution, one must consider its well to wheel efficiency. The electricity requirement for compressing air has to be considered while computing overall efficiency. Nevertheless, the compressed air vehicle will contribute to reducing urban air pollution in the long run.

Air car, compressed air automobile... A pneumatic vehicle is a car like the one you and I drive except that its power plant is an expansion engine that runs on the internal energy in than a combustion engine that runs on the explosive destruction of fuel.

Pneumatic options teaches the facts about the safest, cleanest, most accessible and most economical energy medium that exists anywhere on planet. By the end of this year, motor development international, a 12-year-old company headquartered in Luxembourg, says it plans to distribute model fleets of so-called "air cars" in Spain and France.[11]

2.2 Developments of(CAV):

Jem Stansfield, an English inventor has been able to convert a regular scooter to a compressed air moped shown in Fig.2.1.

Fig.2.1: Air Powered Moped.

This has been done by equipping the scooter with a compressed air engine and air tank. Jem Stansfield created the bike by strapping two high-pressure tanks onto the side of his Puch moped. The tanks are basically scuba tanks. He used 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 go 7 miles before the air pressure runs out and a lot more power could probably be pulled by tweaking his configuration.[12]

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.[12]

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.

2.3 ~~Air Vehicles~~ Previous Studies And Literature Review:

Eventually, Guy Negre, the French inventor of an engine that runs on compressed air, hopes to establish an international network of local manufacturer-dealerships to sell "air cars" in urban areas.

In 1991 Negre formed Motor Development International (MDI) to develop the technology and manufacture the cars. Its prototype factory is in the south of France and employs about 60 people. MDI claims it is approaching commercial deployment of the air car.

So far the story sounds like a technologist's dream, but reality has rudely intruded. There are currently only three working models of the air car, prototypes assembled piecemeal form materials on hand. In Negre's revolutionary engine, low-temperature compressed air reacts with warmer atmospheric air to push the pistons, powering the car up to a theoretical 60 mph and allowing it to travel up to 120 miles on a full supply of air car.[5]

But at MDI's grudging admission, the prototypes do not yet live up to their promised levels of performance. In fact, in the only published road test to date, one of the cars traveled a little over seven kilometers (4.5miles) on a full tank of air. With the proper materials and a few refinements, MDI insists it will go much further.

Perhaps more interesting than the technology is MDI's business model. Rather than setting up a single large factory to make and distribute the cars around the world. The car is prototype phase, which is way beyond the type of things people invested in during the dot-com age, where people just had an idea. This is way beyond just the concept stage. They have a model that works.

2.3.1 Dual Energy System:

Dual energy engines can be equipped with and run on dual energies-fossil fuels and compressed air and incorporate a reheating mechanism (a continuous combustion system, easily controlled to minimize pollution) between the storage tank and the engine.[18]

This mechanism allows the engine to run exclusively on fossil fuel which permits compatible autonomy on the road.

While the car is running on fossil fuel, compressor refills the compressed air tanks. The control system maintains a zero-pollution emission in the city at speeds up to 60km\h.

2.3.2 An Over View Of The Air Car:

The technology that MDI vehicles use is not new, in fact it had been around few years. Compressed air technology allows for engines that are both non polluting and economical. After ten years of research and development, MDI is prepared to introduce its clean vehicles onto the market. Unlike electric or hydrogen powered vehicles, MDI vehicles are not expensive and do not have a limited driving range. MDI cars are affordable and have a performance rate that stands up to current standards. To sum it up, they are non-expensive cars that do not pollute and are easy to get around cities in.

2.3.3 Two Technologies Have Been Developed To Meet Different Needs:

a) Single energy compressed air engines:

The single energy engines will be available in both Mini cats and City cats. These engines have been conceived for city use, where the maximum speed is 50 km\h and where MDI believes polluting will soon be prohibited. It is already possible see examples of this in some places, such as London, where you want to enter the city center with gasoline powered vehicles, you must pay a fee.

b) Dual energy compressed air plus fuel engines:

The duel energy engine, on the other hand, has been conceived as much for the city as the open road and will be available in all MDI vehicles. The engines will work exclusively with compressed air while it is running under 50 km\h, in urban areas. But when the car is used outside urban areas at speeds over 50 km\h, the engines will switch to fuel mode. The engine will be able to use gasoline. Gas oil, biodiesel, gas, liquidized gas, ecological fuel, and alcohol… etc.

2.4 Wind-to-Wheel Energy Assessment:

Hydrogen generation, battery electric storage, and compressed air energy storage are compared on an efficiency basis for effectively applying renewable electric energy to transportation goals. Results are presented as a driving range, in kilometers, achievable with a uniform input of 100 MJ of wind-generated, AC electricity to each type of energy storage technology. Lithium-ion battery electric vehicles can achieve up to 133 km of range with this input. In contrast, compressed air cars and fuel cell vehicles achieve 46 and 42 kilometers, respectively, with the same 100 MJ of input electricity. The vehicle ranges are compared for Taurus-class vehicles driving in a standard urban drive cycle.[8]

Renewable energy technologies are quickly penetrating the energy generation market, principally in response to an urgent need to reduce greenhouse gases (GHGs) released into the atmosphere. Central energy generators like megawatt-scale wind turbines, run-of-the- river hydroelectric plants, tidal and wave stations are well-suited to integrate into the electric grid. But how can these new resources be best used to displace the GHGs produced by the worldwide fleet of gasoline and diesel-fueled vehicles?

Even solar photovoltaic energy, well-suited for distributed applications, cannot power an independent, consumer-friendly vehicle directly. The energy density required for the automotive performance expected by consumers is simply too high to be available through commercially achievable photovoltaic products. Vehicles restricted to tracks can utilize energy transmitted from larger solar power installations or other renewable technologies, but independent vehicles always require energy storage.

As pressure grows to curtail the GHG emissions of vehicles, most of the resources considered for the purpose will be the same electric generating technologies currently being added to the power grid. So the questions and answers that will guide new vehicle development boil down almost entirely to comparative analyses of energy storage technologies.

2.4.1 Energy Storage Technologies:

Three methods of energy storage are evaluated for this comparison: chemical storage in the form of hydrogen gas, electrical storage in batteries, and mechanical storage in compressed air. System diagrams representing the three paradigms are presented in Figure 2.2. For each, we briefly describe efficiency losses in the associated fuel chain, from the wind turbine to the automobile's drive shaft.

2.4.1.1 Hydrogen Vehicles:

The two hydrogen vehicles evaluated share an assumption of hydrogen generated by electrolysis at local "filling" stations. A previous analysis demonstrated that the efficiency differences between local and centralized hydrogen production are inconsequential and can be ignored. Specifically, compressed hydrogen gas can flow through large pipelines with a loss of about 0.77% per 100 km, while high voltage DC experiences a loss of perhaps 0.6% per 100 km.

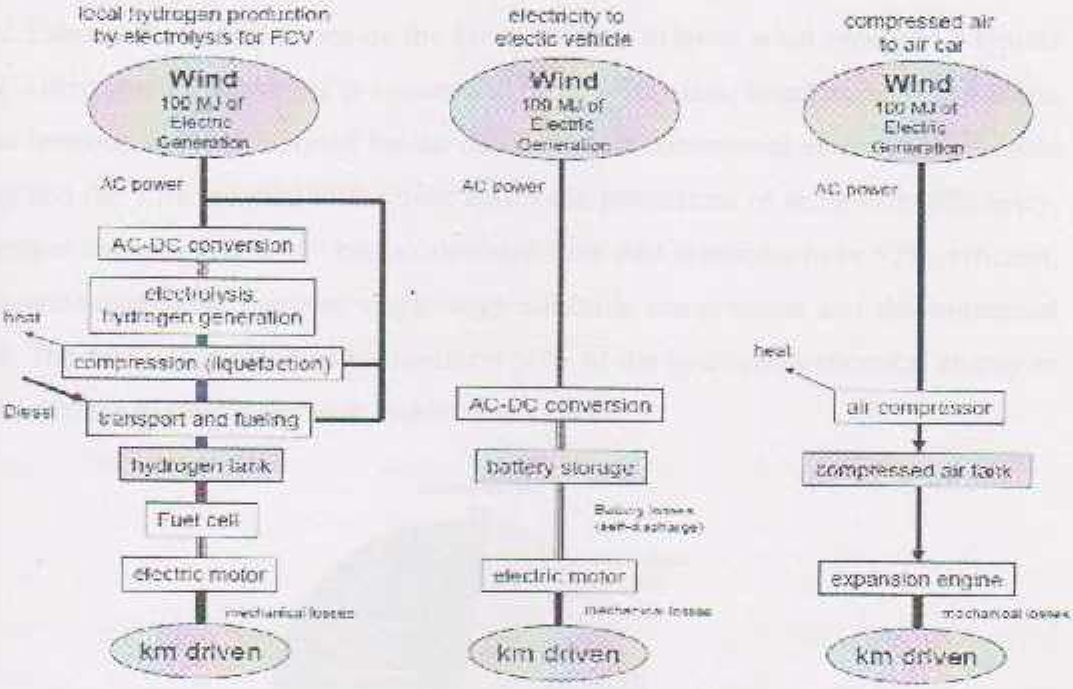


Fig.2.2: System diagrams describing vehicle fuel cycles for hydrogen, battery and compressed air energy storage.

The two types of hydrogen vehicle considered are a fuel cell vehicle (FCV) and a hydrogen-burning, internal combustion engine vehicle (ICEV). FCVs extract the chemical energy in the hydrogen gas through controlled oxidation process in an electrochemical cell. IC-EVs extract the energy from hydrogen using a traditional, spark-ignition heat engine to combust the gas in the same manner as modern cars are fuelled by gasoline. IC-EVs are not considered a likely, ultimate technology for extracting transportation energy from hydrogen gas, but could play an important, intermediate role before FCVs become commercializable.

Fig.2.3 shows the energy losses on the fuel path from original wind energy to a typical FCV's driveshaft. Electrolysis is assumed to be 80% efficient, based on an intermediate value between the 74% reported for the most efficient commercial electrolyze available today and the 90% reported in the most optimistic projections of achievable efficiency. Hydrogen compression to 350 bar is calculated from first principles to be 92% efficient, an intermediate value between single-stage adiabatic compression and the isothermal ideal. The fuel cell is assumed to transform 50% of the hydrogen's chemical energy to electricity, the highest realistically achievable value.

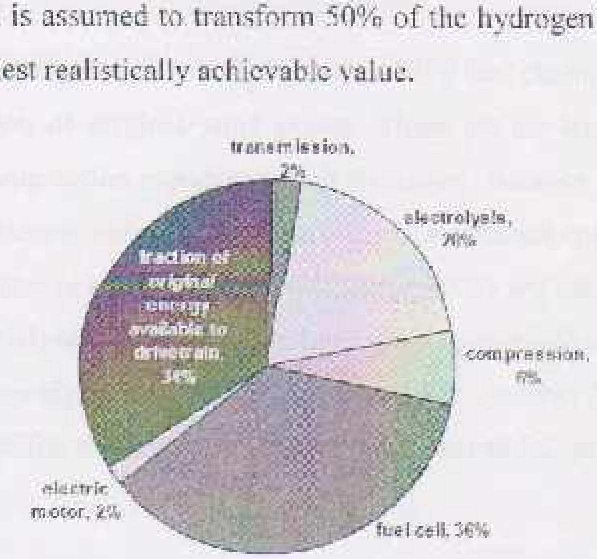


Fig.2.3: Energy losses on the FCV fuel path.

2.4.1.2 Battery Electric Vehicles:

Battery electric vehicles (BEVs) are presumed to be charged directly from the same electric grid that supports the hypothetical wind turbine energy source. In fact a large, grid-connected BEV fleet can perform an important grid service by providing direct energy storage for intermittent, renewable energy resources like wind.

Two types of battery are considered in this analysis: nickel metal hydride (NiMH) and lithium ion (Li-ion). NiMH batteries are the current favored battery chemistry for automotive applications, Li-ion batteries are a less mature technology with significantly better characteristics that most analysts believe is the likely, ultimate chemistry for long-range automotive applications. Li-ion batteries are quickly maturing, driven primarily by the portable electronics market that already favors them for nearly every application.

Fig.2.4 shows the energy losses associated with a BEV fuel chain, again beginning with the basic assumption of original wind power. There are no losses equivalent to the electrolysis and compression associated with hydrogen, because it is not necessary to convert the native electric output of wind turbines to a different energy form. There is an additional 6% loss due to electric distribution, since BEVs are charged on a completely distributed (residential) electric grid, while hydrogen is generated at local filling stations that can be located on high-voltage trunk or feeder lines. Another 5% loss is due to heat generated by the rectifier that converts the grid AC power to DC needed for charging the car battery.

The car battery has a native loss known as self-discharge, that is strongly dependent on use patterns. We assume an 8% self-discharge loss, a very high value equivalent to leaving a Li-ion vehicle standing one to two months between drives.

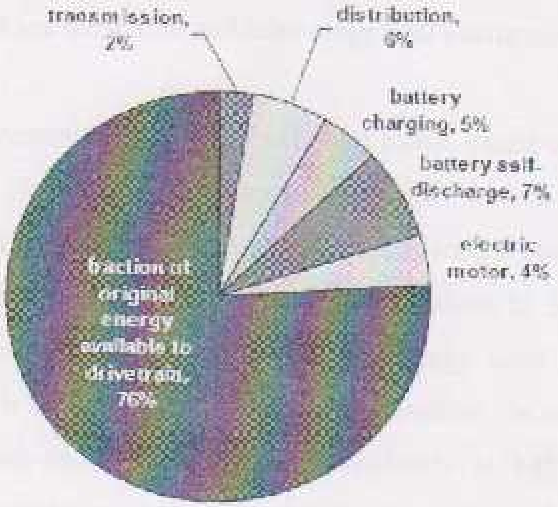


Fig.2.4: Energy losses on the Li-ion BEV fuel path

2.4.1.3 Compressed Air Vehicle (CAV):

One other technology that has been receiving attention recently is compressed air energy storage. The paradigm would most likely be implemented similarly to the hydrogen paradigm, in which electric energy is transmitted to local filling stations that compress air and transfer it to vehicles. Compressing air produces substantial heat which is lost to the atmosphere, but some of this heat can be recovered when the car operates. The compressed air powers the car with expansion turbines; the air exhausting from the turbines is extremely cold due to the basic thermodynamics associated with rapid expansion of a gas. By using a multi-stage expansion turbine with heat exchangers between the stages, the cold air can be reheated at each stage to extract energy from the ambient atmosphere before being expanded through the next turbine.

Designing a commercially acceptable air car will still require overcoming engineering hurdles associated with ice formation and inter-stage heat exchange efficiency.

For our analysis we presume a very optimistic fuel chain, based on an air compression pressure of 300 bar, four-stage air compression with intercooling and four-stage expansion with heat exchange from the ambient air. Figure 2.5 shows the energy losses associated with such a compressed-air vehicle. Compression to 300 bar is an energy-intensive operation that leaves only 46% of the energy used present in the final compressed air (once it has cooled to ambient temperature). In comparison, the four-stage expansion turbine operates much more efficiently at 84%, since most of its thermodynamic losses can be recovered from heat in the ambient air.

Note that compression of air appears profoundly less efficient than compression of hydrogen in our analysis. This is an illusion. Electrical energy is stored in hydrogen by electrolysis of water. Relatively small volumes of the energetic gas have to be compacted for better handling. On the other hand, electrical energy is stored by pressurizing larges volumes of air. Air compression is the energy storage, while the compression of hydrogen is a matter of convenience. However, because of the different densities hydrogen compression requires 15 times more energy than air compression for identical initial volumes and identical pressure limits. For hydrogen, the main losses are associated with electrolysis and fuel cell, while the heat generated in the process of compacting air is considered a loss in this context. However, the waste heat could be recovered and used for water and space heating by operating the compressor in a cogeneration mode.

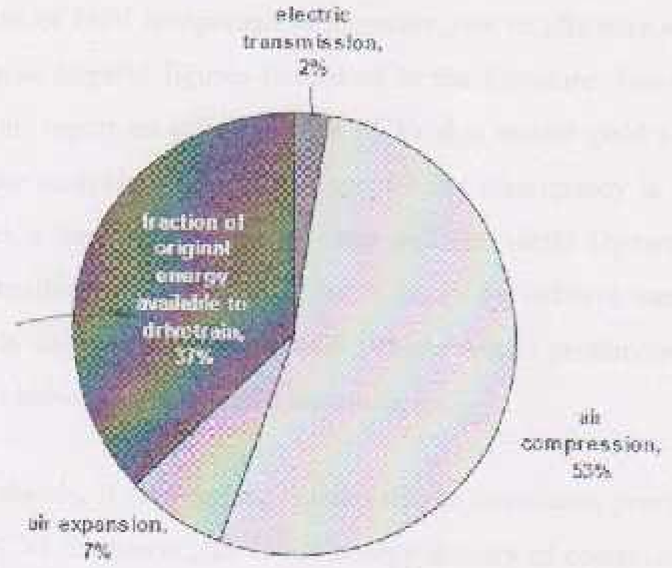


Fig.2.5: Energy losses on the compressed air car fuel path

2.4.2 Results:

The results for all five vehicles evaluated are displayed in Fig.2.6. For each hypothesized vehicle the figure displays the driving distance achieved with the same 100 MJ of original electricity. 100 MJ is an arbitrarily chosen quantity that allows an intuitive comparison of the technologies. The length of each horizontal bar in the figure is proportional to the driving distance possible in the U.S. Environmental Protection Agency's urban driving cycle, with each technology after energy transmission and storage.

The NiMH and Li-ion battery electric technologies, able to drive 127 and 133 kilometers respectively, stand out in their performance over the others. In contrast, a nominal, high performance FCV achieves only 42 km of range with the same input energy. Despite our optimistic estimates of FCV component efficiencies, our results may seem to fall short of some of the more hopeful figures published in the literature. For instance, Ogden, Williams & Larson report an efficiency for FCVs that would yield a range of 69 km when treated in our analysis. The main reason for the discrepancy is that our analysis uniformly assumes a very heavy, Taurus-class vehicle, while Ogden et al and other authors assume smaller vehicles in their work. It is the relative ranges that matter; repeating this study using a smaller nominal vehicle would produce roughly the same performance ratios between the different technologies.

Compressed air vehicles, if engineering hurdles can be overcome, promise an efficiency equal to that of FCVs. However, the lower energy density of compressed air will limit the maximum range of such cars to values appropriate only for in-city commuting.

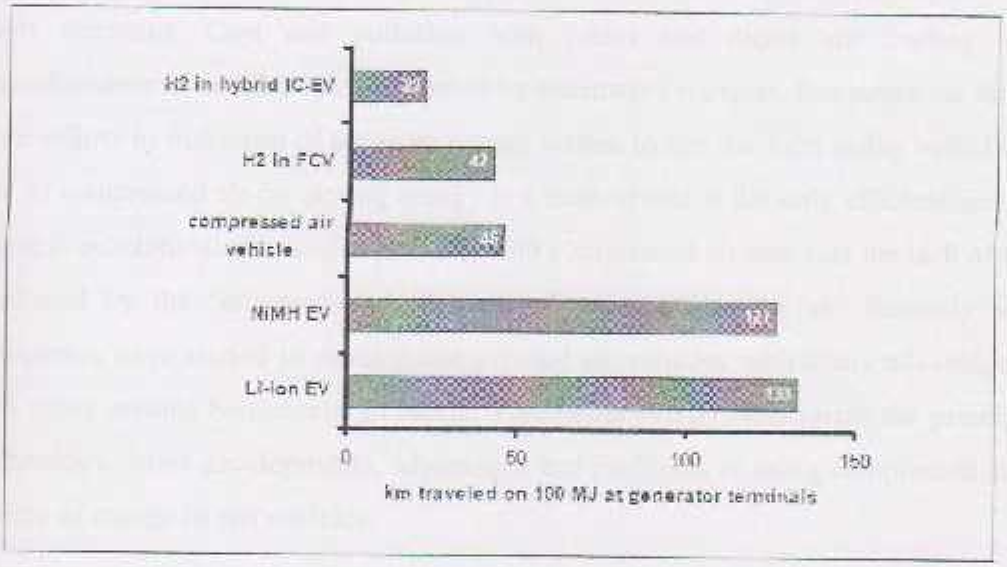


Fig. 2.6: Kilometers traveled on an equal amount of original electricity

Across all environmental, performance, and economic metrics, compressed air vehicles are inferior to similarly-sized gasoline and electric vehicles. The carbon footprint and fuel costs of CAVs are 1.6-2.5x greater than that of a gasoline vehicle and 4x greater than an electric vehicle, depending on the carbon intensity of electricity generation.

As a fuel, compressed air stores just 1% of energy in gasoline, per volume. This, combined with the inefficiencies of compression and expansion, limit the CAV's range to just 29 miles on a tank of air. As a result, the viability of CAVs as a transportation option is severely constrained.

These results indicate that while CAVs are an unconventional idea for current transportation challenges, they are inferior to other transportation options.

Light utility vehicles are becoming very popular means of independent transportation for short distances. Cost and pollution with petrol and diesel are leading vehicle manufacturers to develop vehicles fueled by alternative energies. Engineers are directing their efforts to make use of air as an energy source to run the light utility vehicles. The use of compressed air for storing energy is a method that is not only efficient and clean, but also economical. The major problem with compressed air cars was the lack of torque produced by the "engines" and the cost of compressing the air. Recently several companies have started to develop compressed air vehicles with many advantages and still many serious bottlenecks to tackle. This paper briefly summarize the principle of technology, latest developments, advantages and problems in using compressed air as a source of energy to run vehicles.

2.5 The History of Compressed Air Vehicles:

It cannot be claimed that compressed air as an energy and locomotion vector is precisely recent technology. In fact at the end of the 19th century the first approximations to what could one day become a compressed air driven vehicle already existed, through the arrival of the first pneumatic locomotives. Yet even two centuries before that Dennis Papin apparently came up with the idea of using compressed air (Royal Society London, 1687).

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.

In 1872 the Mekarski air engine was used for street transit as figure 2.7, consisting of a single-stage engine. It represented an extremely important advance in terms of pneumatic engines, due to its forward thinking use of thermodynamics, ensuring that the air was heated, by passing it through tanks of boiling water, also increasing its range between fill-ups. Numerous locomotives were manufactured and a number of regular lines were even opened up (the first in Nantes in 1879).

Mékarski system tram networks were also built in other towns in France: Vichy (1895), Aix-les-Bains (1896), La Rochelle (1899), and Saint-Quentin (1901).

The H. K. Porter Company in Pittsburgh sold hundreds of these locomotives to coal-mining companies in the eastern U.S. With the hopeful days of air powered street transit over, the compressed air locomotive became a standard fixture in coal mines around the world because it created no heat or spark and was therefore invaluable in gassy mines where explosions were always a danger with electric or gas engines.

Fig.2.7: The Mekarski air engine

After years of working on a system for driving an automobile by means of compressed air Louis C. Kiser, a 77 year old from Decatur USA has succeeded in converting his gasoline engine into an air compressed system as figure 2.8. Kiser removed the entire gasoline line, the cylinder head, water-cooling system, and self starter. A special cylinder head is substituted and a compressed-air tank added in place of the gasoline tank.

Fig.2.8: compressed air Louis C. Kiser

In 1926 Lee Barton Williams of Pittsburg USA presented his invention: an automobile which, he claims, runs on air as figure 2.9. The motor starts on gasoline, but after it has reached a speed of ten miles an hour the gasoline supply is shut off and the air starts to work. At the first test his invention attained a speed of 62 miles an hour.

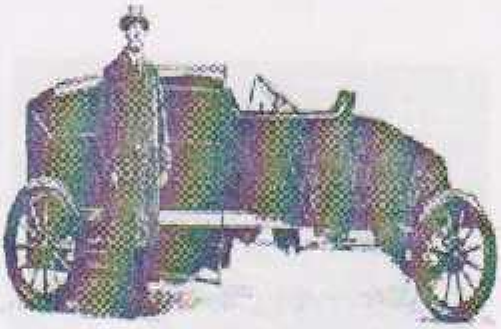


Fig.2.9: Burton Williams

In the 1970's Willard Truitt presented his invention in McKees Rocks, USA as fig.2.10. But because he did not have the financial means to develop his compressed air car further he gave the rights of his invention to NASA and the US Army in 1982.

Fig.2.10: Willard Truitt

In 1979, Terry Miller decided that compressed air was the perfect medium for storing energy. He developed Air Car One, which he built for $ 1,500. Terry's engines showed that it was feasible to manufacture a car that could run on compressed air as figure 2.11. He patented his method in 1983.

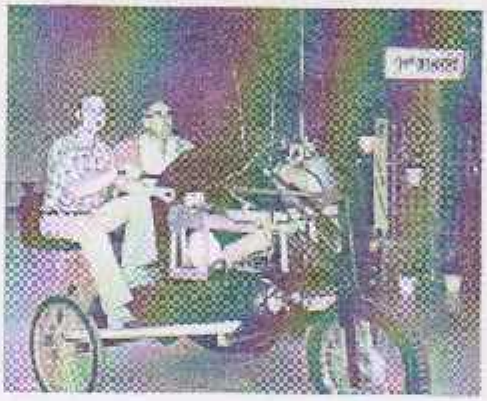


Fig.2.11: Terry Miller

In 1925, an article appeared in the Decatur Review about a man named Louis C. Kiser who converted his gasoline powered car to run on air. Lee Barton Williams in 1926 claimed to have invented the first air car. Williams was from Pittsburg and claimed the car started on gasoline but after 10 mph it switched to compressed air only.

Currently the tram association in Bern Switzerland (BTG) is developing a locomotive according to the original plans. It is expected to be ready in 2010.

At present (2008) various persons and companies are developing compressed air motors applicable to transportation, apart from the many companies that produce and commercialize compressed air motors for industrial purposes.

Compressed air for vehicle propulsion is already being explored and now air powered vehicles are being developed as a more fuel-efficient means of transportation. Some automobile companies are further exploring compressed air hybrids and compressed fluids to store energy for vehicles which might point the way for the development of a cost effective air powered vehicles design. Unfortunately there are still serious problems to be sorted out before air powered vehicles become a reality for common use but there is a hope that with the development in science & technology well supported by the environmental conscious attitude and need to replace costly transportation methods, air-powered vehicles will definitely see the light of the day.

CHAPTER THREE

Pneumatic systems

3.1 Introduction to Industrial Compressed Air Systems:

Compressed air is used widely throughout industry and is often considered the "fourth utility" at many facilities. Almost every industrial plant, from a small machine shop to an immense pulp and paper mill, has some type of compressed air system. In many cases, the compressed air system is so vital that the facility cannot operate without it. Plant air compressor systems can vary in size from a small unit of 5 horsepower (hp) to huge systems with more than 50,000 hp. In many industrial facilities, air compressors use more electricity than any other type of equipment. Inefficiencies in compressed air systems can therefore be significant. Energy savings from system improvements can range from 20 to 50 percent or more of electricity consumption. For many facilities this is equivalent to thousands, or even hundreds of thousands of dollars of potential annual savings, depending on use. A properly managed compressed air system can save energy, reduce maintenance, decrease downtime, increase production throughput, and improve product quality.

Compressed air systems consist of a supply side, which includes compressors and air treatment, and a demand side, which includes distribution and storage systems and end-use equipment. A properly managed supply side will result in clean, dry, stable air being delivered at the appropriate pressure in a dependable, cost-effective manner. A properly managed demand side minimizes wasted air and uses compressed air for appropriate applications. Improving and maintaining peak compressed air system performance requires addressing both the supply and demand sides of the system and how the two interact.

Air motor operated vehicle used the potential energy which is stored in air by a compressor, until reaches the actuator (air motor), to convert the potential energy form to kinetic energy form . Any system working with energy of air is called pneumatic system; this word comes from the Greek pneumatic, which meaning air or wind.[18]

This chapter talks about characteristics, advantages, and principles of pneumatics subsystems, which work together to convent the potential energy form to kinetic energy from as Fig.3.1.

Fig.3.1: pneumatic converter.

3.2 Fundamentals of pneumatic system:

The pneumatic system is part of fluid power which use air from atmosphere and compressed it to do work of some kind (extend and retract a cylinder or turn air motor) then exhausted back to the atmosphere. Knowledge of pneumatic system has become more important with the growing number of applications in industry.[5]

Pneumatic has been used for carrying out on simplest mechanical tasks but in recent time has played an important role in development of pneumatic technology for automation; i.e. Earlier the pneumatics used as working medium in the form of stored energy, now a days sensing and processing roles developed in parallel with working requirement. This development enable working operation to be controlled using sensors for the measurement of machine states and condition, and that has led to the introduction of pneumatic system.

The applications of pneumatic system are many and varied and a few are listed below:

1. Carrying work.

2. Information on processing.

3. Switching actuators by means of final control elements.

A basic advantage of pneumatic system is the high efficiency. For example, a relatively small compressor can fill a large strong tank to meet intermittent high demands for compressed air. Unlike hydraulic system, no return lines are required. Other advantages are: high reliability, mainly because of fewer moving parts; compactness; forces, torques and speeds readily variable over a widely useful range; easy control and coordination with other machine system functions; low cost; simple installation and maintenance; and the availability of a wide range of standard sizes and capacities.

Pneumatic system structure and signal flow as Fig.3.2:

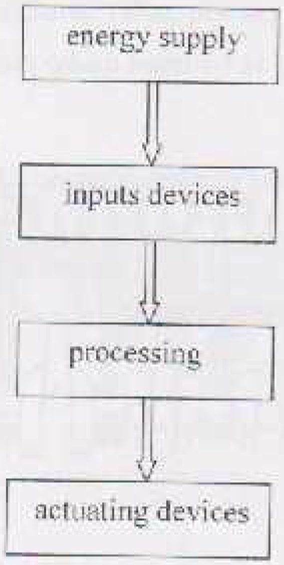


Fig.3.2: Signal flow.

3.3 Energy supply:

To rotate the compressor and generate a compressed air we need a source for doing this function. The selection of source depends on the type of compressor.

In this project we would like to describe two types of source as the following:

3.3.1 Internal combustion engine (ICE):

This source is used to convert the chemical energy of fuel to kinetic energy, this energy are released by burning or oxidizing the fuel inside the engine.

The main component of internal combustion engine is combustion engine is camshaft and crank shaft, intake and exhaust value, pistons and cylinders. These part are working together to do the aim function which required as shown in Fig 3.3.

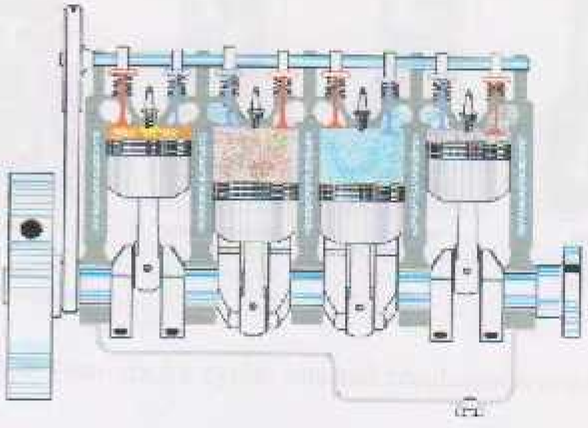


Fig.3.3: ICE.

Most of this type is reciprocating engines, where the piston moves back and fourth in a cylinder and transmit power through the connecting rod and crank mechanisms.

The piston comes to rest at the top center and bottom center when the cylinder volume is a min and max. These engine types operate in two classifications as follow:[4]

a) Four – stroke operating as shown in fig.3.4:

Intake stroke

Compression stroke

Power stroke (expansion stroke)

Exhaust stroke

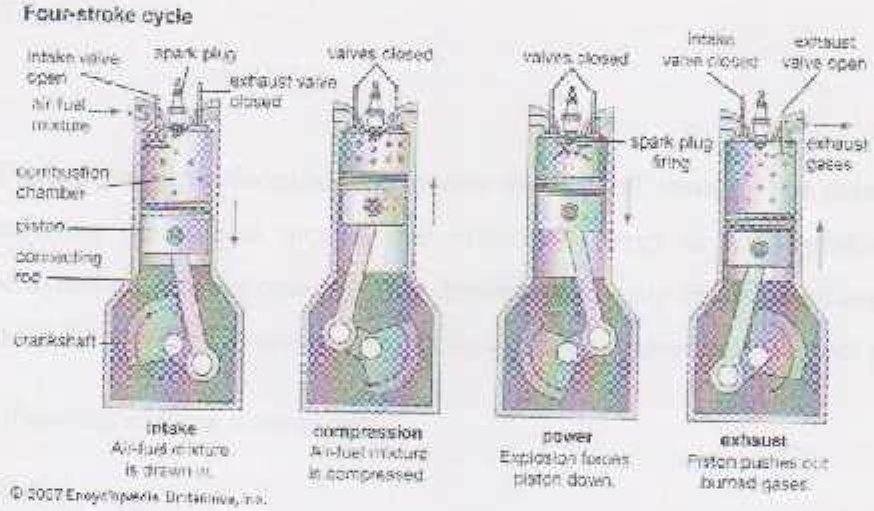


Fig.3.4: Four-stroke cycle, internal combustion engine.

b) Two-stroke operating as shown in Fig.3.5:

Compression stroke

Power or exhaust stroke

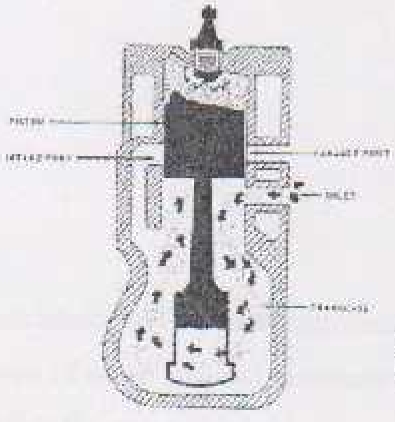


Fig.3.5: Two-stroke cycle, internal combustion engine.

3.3.2 Electric Motor:

An electric motor converts electrical energy into mechanical motion. The reverse task that of converting mechanical motion into electrical energy is accomplished by a generator or dynamo. In many cases the two devices differ only in their application and minor construction details, and some applications use a single device to fill both roles.

The classifications of these sources are:

a. DC motors.
b. AC motors.

3.4 Input Devices:

This section discusses the type and characteristic of input devices of pneumatic system, which includes:

1. Air compressor.
2. Air receiver
3. Air dryer
4. Air service unit

3.4.1 Air compressor:

Air compressor is a mechanical device that increases the pressure of an air by reducing its volume. Compression of an air naturally increases its temperature. Its often attached on top of a tank to holding the pressurized air.

Air compressors has many types depended which the customers would prefer i.e upon quantity of air. (pressure, quality and cleanliness and how dry the air should be). So; main types and characteristics of compressors will be explain as the follow:

3.4.1.1 Reciprocating Compressor:

It's very common which can be general a wind range of pressure and delivery rate. Uses pistons driven by a crankshaft. They are both stationary and portable, can be single or multi-staged, and can be driven be electric motors or internal combustion engines as shown in fig.3.6. Small reciprocating compressors from 5 to 30 HP are commonly seen in automotive applications and are typically for intermittent duty. Larger reciprocating compressors up to 1000 HP are still commonly found in large industrial applications.[5]

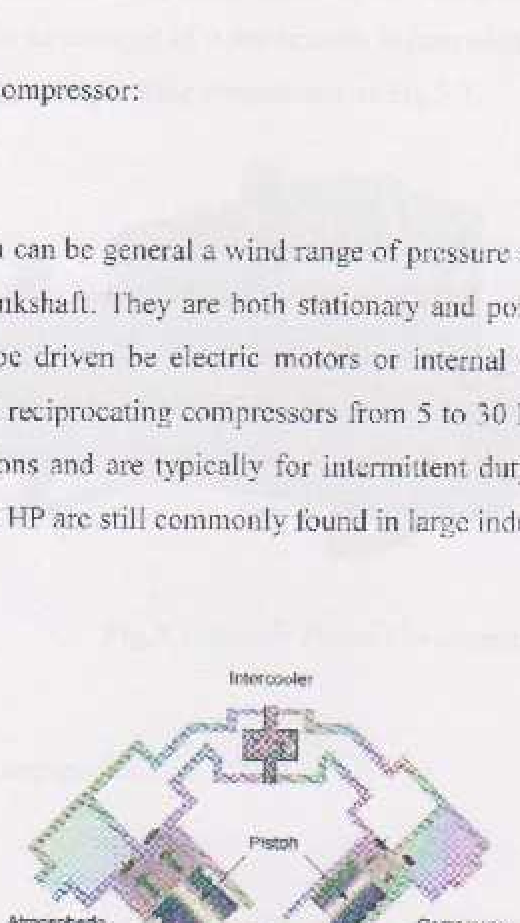


Fig.3.6: Reciprocating Compressor

3.4.1.2 Rotary Piston Compressors:

Rotary piston compressor used rotating member to compressed and increase the pressure of air. The main advantages of it are smooth in operation but the compression is not higher than multistage recuperating compressor as Fig.3.7.

Fig.3.7: Rotary Piston Compressors

3.4.1.3 Rotary Screw Compressors:

Rotary screw compressors uses two meshed rotating positive–displacement helical and spiral lobe oil flooded screws to force the gas into a smaller space. These are usually for continuous, commercial and industrial applications and are both stationary and portable. Their application can be from 5 hp (3.7kw) to over 500 hp (375kw) and from low pressure to very high pressure (1200psi or 8.3MPa). They are commonly seen with roadside repair crews powering air tools. This type is also used for many automobile engine superchargers because it is easily matched to the induction capacity of a piston engine as show in Fig.3.8.

These compressors consist of two rotors within a casing where the rotors compress the air internally. There are no valves.[3]

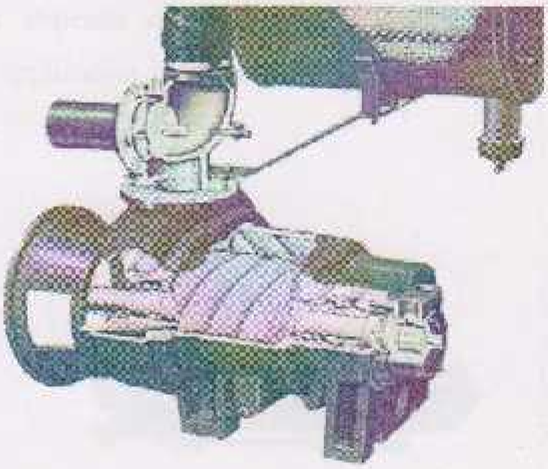


Fig.3.8: Rotary Screw Compressors.

3.4.1.4 Flow compressors (turbine):

This type has blades, when the blades are rotates produce large volume of air at small increase in pressure.[2]

3.4.3 Air Receiver:

Receiver can provide a constant air pressure regardless at changing in consumption, while compressor cannot provide air pressure in continuously way as receiver.

The larger surface area cools the air so this portion of moisture in the air separated directly from the receiver as water as shown in Fig.3.9.

The size of receiver depends on the delivery volume of the compressors, air consumption for the application, net work size, and type of the compressor cycle regulator.

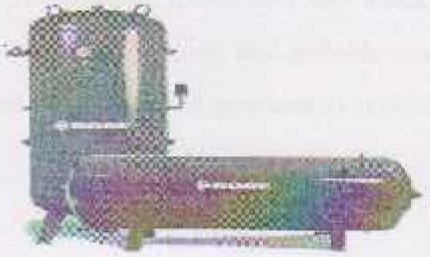


Fig.3.9: Air Receiver.

3.4.3 Air Dryer:

The moisture has significant role of the service life to pneumatic system where it increases the life of pneumatic system is decrease. So it's important to reduce the moisture.

There are three auxiliary method of reducing the moister:

1. Low temperature drying.
2. Adsorption dryers.
3. Absorption dryers.

This methods is not important for our project so we do not talk about it in detail, just we mention that it's using in sensitive devices.[1]

3.4.4 Air Service Unit:

The compressed air may pass through filters and lubricators to clean the air and add lubricant to ensure that equipment has a long and reliable working life. It may also pass through regulators to control the amount of pressure available in the system.

3.5 Valves and Sensors:

In any system must be subsistence devices to modulating system function, so this section describes the fundamental control functions performed by valves and sensors.

3.5.1 Valves:

The valves are integral components of pneumatic system, they:

1. Direction control valve.

2. Non return valve.

3. Rate of air flow control valve.

4. Control pressure valve.

These valves are named according to the functions they serve in the circuit.

3.5.1.1 Direction control valve:

Direction control valve primarily provide a means of controlling when and where the air is delivered in the circuit to perform various functions. It start, stop, accelerate, decelerate and control the direction of motion of actuators pneumatic, and it's characterized by its number of controller connections or ways and by the number of switching position. General of this valves symbol is adequate to represent the operational characteristics.

3.5.1.2 Non return valves:

This valve is preferentially stopped the flow in one direction and permit flow in the opposite direction, which the pressure on the downstream side acts against the restrictive component. Type of return valve is:

a) Check Valve:

Check valve is stopping the flow completely in one direction and free flow in other side with minimal pressure drop due to the resistance of the valve (which can be affected by cones, balls, plants of diaphragms).

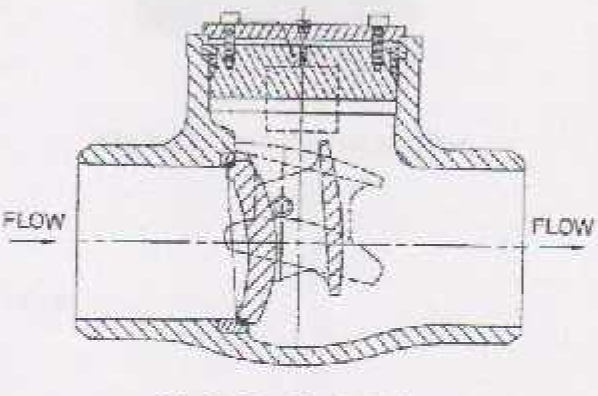


Fig.3.10: Check Valve.

b) Two Pressure Valve:

The two pressure valve has two inlets and one outlet. Compressed air flow through the valve only if the signal is applied to both inlets. One input signal blocks the flow.

If signals are applied to both x and y, the signal which is last applied passes to the outlet. If the input signal is of different pressure, the larger of the two pressures closes the valve and the smaller air pressure is transferred to the outlet as an output signal.

The two pressure valve is used mainly for interlocking control, safety controls, safety controls, check functions and logic operation.

Fig.3.11: Two Pressure Valve

3.5.1.3 Flow Control Valve:

Flow control valve influence the volumetric flow of the compressed air in both direction but the influence of speed control is in one direction only, and it is have two types as follow:

a) Throttle Valve (bi-direction):

This valve is normally adjustable and it's used for speed control of cylinder with in range of valves. Care must be taken that the flow control valve is not closed fully.

Throttle valve is characterized according to constructer principle:

- Throttle valve:

    Length of throttling section is bigger than the throttle valve diameter.

- Diaphragm valve:

    Length of throttling section is less than diaphragm the valve diameter.

Fig.3.12 Throttle Valve.

b) One Way Flow Control Valve:

With this type, the air flow is throttled in one direction only. A check valve blocks the flow of air in the bypass leg and the air can flow only through the regulated cross-section. In the opposite direction, the air can flow freely through the opened check valve.

These valves are used for speed regulation of actuators and if possible, should be mounted directly on the cylinder.

b)Pressure Limiting Valve:

It's used mainly as safety valve (pressure relief valve) if the maximum pressure has been reached at the valve inlet, the valve outlet is opened and the excess air pressure exhausts to atmosphere, the valve remain open until it is closed by the built-in spring after reaching the preset system pressure.

3.5.2 Sensors:

A sensor is a device that converts a quantity of energy form into another output signal form, like electrical form, or mechanical form. Because there are analog and digital signals, so as sensors have also two categories. In analog signals data come continuously (not interrupted) not as digital type where data comes as pulses.

In this part of section studies two sensors measure pressure and angle (angular displacement), the two sensors are:

3.5.2.1 Pressure Sensor:

There are several types of sensors measure pressure, like: capacitance sensor, piezoelectric sensor, microphone, and other types.

Selecting the appropriate one depends one the conditions of pneumatics; how much the pressure, accuracy, repeatability, resolution.

3.5.2.2 Potentiometer:

Its principle is voltage divider role, it is an electromechanical device containing a rotatable wiper arm that makes an electrical contact with a resistive surface and can move across this surface. The wiper is coupled mechanically to a movable member or linkage. The wiper and resistive surface form a voltage divider circuit.

It also has different types: wire wound, carbon film, metal film, cermets. These types differ in range of voltages, accuracy, and shape. And the system requirements determine which sensor is the perfect, beside to sensor cost.

3.6 Processing Elements:

The control system of pneumatics is a major step to obtain the best result. If the sequences of the operations are not as the designer like, then the whole process will fail, so by using processing elements the system will be controlled in desired operations. Processing elements are directional control valves, logic elements, pressure and flow control valves.

Control of a system need first to draw the circuit diagram of the system with the standard symbols, also the flow chart of the process must be determined. The contain signals and energy, beginning from energy power supply to the final element, which is the actuator device, described in Fig.3.2.

Control system can be classified in accordance with the signal types, which are: analog, and digital control systems. Analog control system operates by analog signals within the signal processing section, such as amplifiers and resistors … ect. Digital control system operate by digital signal within the signal processing section as in computers and microcontrollers. Other types of controllers and used extensively in pneumatic systems are, Programmable Logic Controllers (PLC), it has so much enough components to control most of automatic control, some of its components are contactor timers counters, and memory. So PLC becomes more and more like microcontrollers, in some systems it is better than it.[12]

As mentioned before, control of pneumatics means control of direction and velocity of flow, so it is valve control like directional control valve and flow control valve, to control direction and speed of flow (respectively).

Digital control as in microcontroller, increasingly used in analog systems, this because of advantages of microcontrollers which are: reliability, flexibility and accuracy. Of course to convert from analog to digital or opposite need (A/D) and (D/A). Control elements which are valves, also have analog and digital components, for digital it can be as on off valve like those in directional control valves, and some are analog so they need a motor (almost DC-motor like solenoid, serve, and stepper) to actuate them as desired, this can be by writing a software into memory of controller to change plant parameters as desired.

3.7 Output Devices (Actuators):

In any mechanical system must be exist output devices to convert the supply energy into useful work, an actuator produce rotational power developed at an output shaft when compressed air is supplied to an inlet port. The actuators in pneumatic system are divided under two groups as following:

3.7.1 Linear Motion:

Linear motors generate force only in the direction of travel. They are capable of extremely high speeds, quick acceleration, and accurate positioning. They may be single-acting(with a spring return) or double-acting.

3.7.1.1 Single Acting Cylinder:

In this type the force (compressed air) is applied on one side of piston face, so its work only in one direction, the other side is open to atmosphere. The return movement of the piston is effected by a spring or by application of an external force.

3.7.1.2 Double Acting Cylinder:

The force (compressed air) is applied on two side of piston so its work in two direction. When the air is simultaneously exhausted back from the other side through a valve to atmosphere.

3.7.2 Rotary Motion (Air Motor):

It is provided continually motion of operation than against reciprocation motor which works as pulses. Air motors are categorized according to design so it divided to many type as we last said.

3.7.2.1 Piston Motors:

This type is farter subdivided into radial and axial piston, where very wide speed ranges are desired. The power of this motor depends on input pressure, number of piston, piston surface area, stroke, and piston speed.

3.7.2.2 Sliding Vane Motor:

This particular motor provides rotation in two directions forward and reversed. The rotating element is a slotted rotor which is mounted on a drive shaft. This motor operates on the principle of differential areas. When compressed air is directed into the inlet port, its pressure is exerted equally in all directions.

3.7.2.3 Gear motor:

This type is used in application a very high power rating (60) hp to overcome a specified torque level and operate at a desired rpm. The direction of rotation is also reversible when spur or helical gearing is used.

3.7.2.4 Turbine (flow motor):

Turbines motors can be used only where a low power is required, and very high speed.

Characteristics Of Air Motor:

- Smooth regulator of speed and torque.
- Small six (weight).
- Over load safe.
- Direction of rotation easily reversed.
- Large speed selection.

CHAPTER FOUR

Mechanical design

4.1 Introduction:

This chapter talks about the procedures of mechanical design(vehicle dynamics calculations, air motor calculation, air receiver calculations, internal combustion engine calculation, reciprocating compressor calculations) as show the figures (4.1&4.2) and the methods of linking various parts in this system together to achieve the final aim of this project, to run the air motor operated vehicle.

The procedure of design is running in the opposite direction of air flow i.e. The calculation beginning from actuator (air engine) then returns to the input devices and energy supply, this will take place after determining the characteristics of vehicle prototype such as weight, tire radius, maximum speed, etc.

The procedure of design based on theoretical back ground of pneumatics and mechanical systems, such as Gases laws, Newton's laws, and conservation of energy laws (Bernoulli's equation).

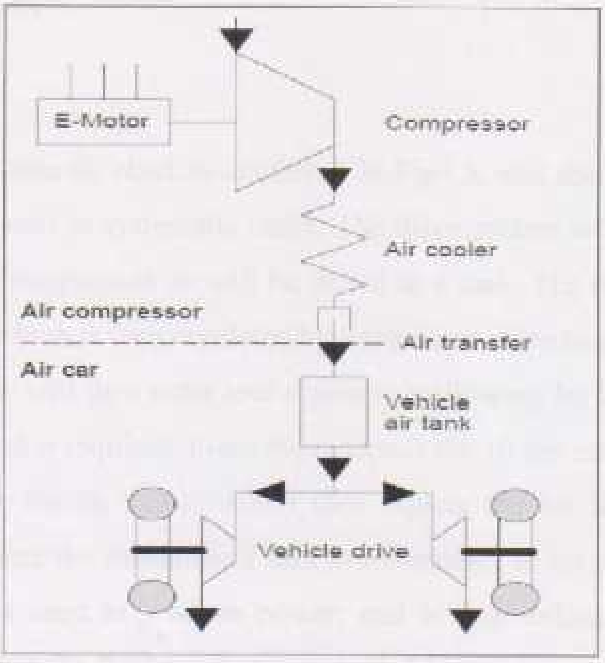


Fig4.1: Schematic of air compression, compressed air transfer to car and the use of compressed air for vehicle propulsion

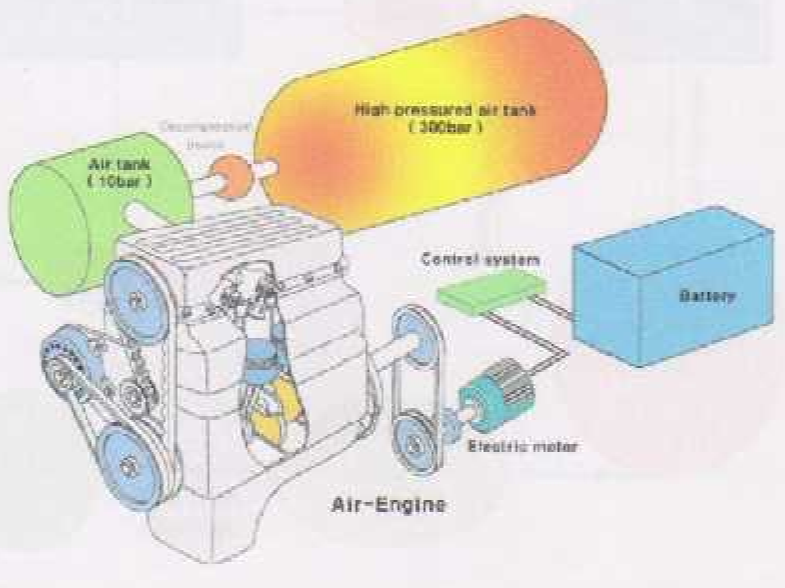


Fig4.2: Schematic of air vehicle component

4.2 Total Design Flow:

The drive system schematic chart is displayed in Fig4.3, and shows all the power transmission components in systematic order. The drive system will be powered by compressed air. The compressed air will be stored in a tank. The tank has an initial pressure of 300 bar, which is then regulated by a regulator valve to about 10 bar. The 10 bar compressed air will then enter into a reservoir allowing for less restriction of flow when acceleration is required. From the reservoir the 10 bar compressed air will be throttled into the timing valve, which then injects the air into the (internal combustion engine after the amendment and development) at set intervals. The air through the engine is used to produce power, and is then exhausted. In order to provide an idea of what the final product may look like, a conceptual rendering has been included below in Fig4.4.

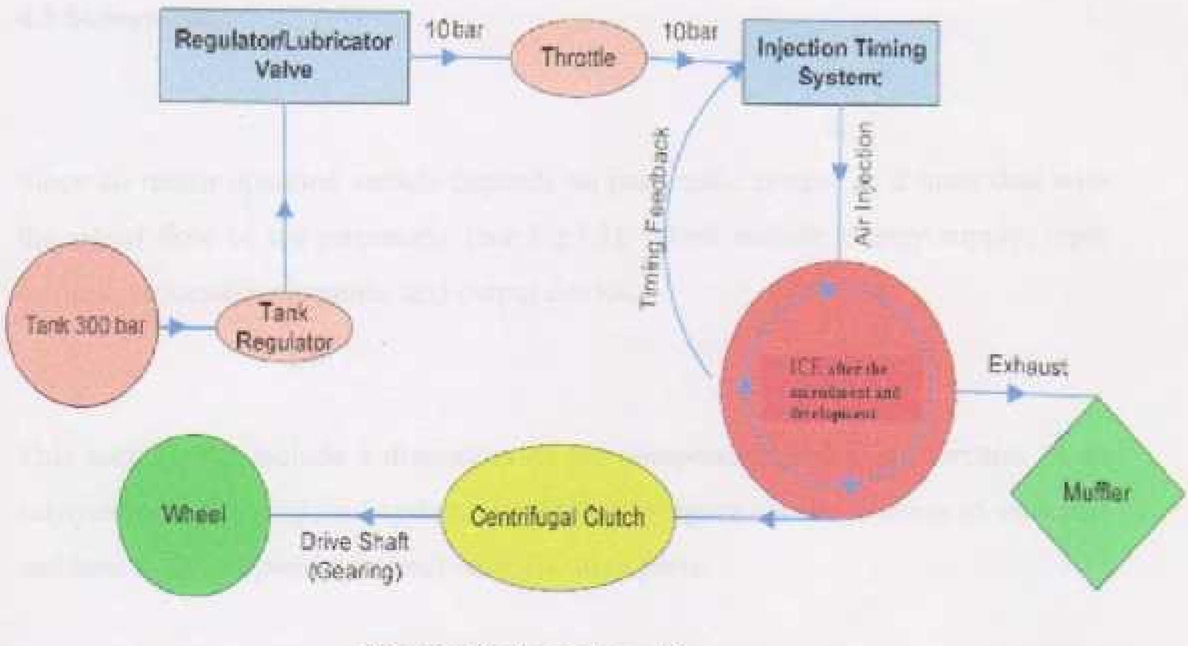


Fig4.3: Design schematic.

Fig4.4: Air Power Drive: conceptual drawing of finished prototype.

4.3 Subsystems:

Since air motor operated vehicle depends on pneumatic system so it must deal with the signal flow of the pneumatic (see Fig3.2), which include energy supply, input devices, processing elements, and output device.

This section will include a discussion of the components and characteristics of all subsystems in the proposed system, in addition to figure out the location of each part and how each component interact with the other parts.

<u>Hint</u> : (all parameters comes from next section).

4.3.1 Internal Combustion Engine:

Internal combustion engine is the main and the only source of energy in the proposed system, and one in which combustion of the fuel takes place in a confined space, producing expanding gases that are used directly to provide mechanical power.

Air motor operated vehicle used internal combustion engine as an energy supplier and only to rotate the compressor, since operated by four-stroke to feed the compressor with power which is(69.43 Kwatt) and rotational velocity is (30rev/sec).

Hint : (all the numbers comes from next section).

4.3.2 Air Compressor:

The compressor is the first part of the input devices which are taking volumes of air from atmosphere which is confined within as closed space and elevating this air to a higher pressure. According to this process, the air will have potential energy.

The positive displacement reciprocating unit, was chosen, because it provide a value of pressure higher than other types.

4.3.3 Air Reservoir:

This subsystem is the second part of the input devices which used to store the potential energy (compressed air) between two levels of pressures maximum pressure (P_2=10.08 bar) and minimum pressure (P_1=1.41 bar), and supply a continuously flow rate of air.

Since the air motor consumption is (1.18 m^3/min) and pressure is (1.41bars) so the volume of tank should be (1.374 m^3) to reach operating time (10 min) and resting time (5 min) approximately.

4.3.4 Service Unit (Filter, Regulator, Lubrication), (F.R.L):

the function of a filter is to remove contaminants from the air before it reaches pneumatic components such as valves and actuators. so that a constant pressure is available for a given pneumatic system, a pressure regulator is used. a lubricator ensures proper lubrication of internal moving parts of pneumatic components.[8]

4.3.5 Valves & Sensors:

These parts belong to processing elements which are very important to control and regulate of fluid energy (mechanical or potential energy), but we need only three valves and one sensor as shown in the following to operate the system.

1) **Check Valve:**

Allowing the flow to pass from compressor to the tank, and prevent air to flow in reverse direction.

2) **Two Directional Valve:**

Used as a switch valve, located between the tank and one way flow control valve (Operating manually).

3) **Pressure Sensors:**

Because the pressure in the tank must not exceed the maximum allowed pressure then a pressure sensor must be used to evaluate the pressure inside the tank and send a signal to the micro controller. So the micro controller can control the pressure inside the tank.

4.3.6 Piping System:

The piping distribution system not only controls how the air gets from the compressor room to the components, it is a major factor in the energy consumed by the compressor. Poorly designed increase pressure losses and increase operating costs. A common error is to increase compressor delivery pressure to compensate for distribution problems. This substantially increases energy costs. Higher pressure increases leak rates, another major source of waste, thus the waste and increased cost is compounded.[3]

4.3.7 Air Motor:

Gear air motor is chosen in this project because it has a good characteristics such as light weight, continuously operating and can give high power as needed. An actuator used to convert the potential energy of compressed air to mechanical energy used to actuate the gear box.

Given that the air engine is expensive, and to apply this proposed project, we will work on transforming the internal combustion engine to be running on compressed air.

4.4 Air motor operated vehicle calculation:

Since the system operated by the energy stored in the compressed air, and this energy is not huge so the vehicle prototype is chosen to serve for special purposes such as transporting within the campuses of institutions such as universities, hospitals, playgrounds, and arboretum. Most researchers of the air operated vehicle consider a mass of the air operated vehicle around (300) kg, since the source of energy supply is an electrical motor and used for only one person.

But in current project the used vehicle prototype is with wheel radius (r=0.15m) and mass (m=700kg) used for four persons including the driver, with internal combustion engine as an energy source to avoid the need to build up a specialized vehicle because of the limitation of the available material resources.

4.4.1 Vehicle dynamics calculations:

When vehicle transporting between the buildings of universities, hospitals, playgrounds, and arboretums the velocity must not exceed (20-30 km\h) because these areas are always full of people and for quietness and to save the environment so the maximum speed which will be considered is 30km\h.

Assuming that, this car will reach a maximum speed in a distance (100m) with a constant acceleration. From Newton's Second Law (N.S.L) the acceleration will be calculated as shown in equation (1) and time required to reach maximum speed will be calculated by equation (2)

$$V_f^2 = V_i^2 + 2 * a_x * X \quad \text{.........(1)}$$

Where:

V_f = final speed of vehicle.[m\s]

V_i = initial speed of vehicle. [m\s]

a_x = acceleration of vehicle. [m\s²]

X = distance which carried. [m]

From eq.(1)

V_i which equal zero.

V_f= 30*1000/3600 = 8.33[m\s]

$a_x = V_f^2/(2*X)$

→ $a_x = 69.388/(2*100)$ → $a_x = 0.347$ [m/s²]

$V_f = V_i + (a_x * t)$...(2)

Where:

t= time required reaching max speed.

From eq.(2)

$V_i = 0$ [m\s]

$t = V_f / a_x = 8.33/0.347$

→ t =24 sec

The tractive force (Fx) may be found by using Newton's Second Law (N.S.L):

$F_x = m * ax + Rx$..(3)

But:

$R_x = fr*Weight$

Where:

m = the mass of the vehicle [kg].

R_x = rolling resistance force [N].

fr = coefficient of rolling resistance =0.03 [21]

From eq.(3) the tractive force is:

Fx=(700*0.347) + (0.03*(700*9.8)) $[(kg*m/s^2)+(kg*m/s^2)] = [N]$

→ $F_x = 511.7$ N

The torque required (T) the vehicle may be found by:

$T = F_x * r$ ....(4)

Where: r = wheel radius[m]

T = 511.7 * 0.15

→ T = 76.755 N.m

The proposed project will be applied to a vehicle gearbox with reduction ratio as follows:

1st	2.785:1
2nd	1:.5451
3rd	1:1
4th	0.7:1
Reverse	2.272:1

And the combined efficiency of most transmissions and final drives (ηtf) is 0.9.

4.4.2 Air Motor Calculation:

The calculations of air motor depend on previous calculations of the vehicle characteristics, pneumatics laws and continuously equations will used in this section.

As mentioned in above paragraph the torque required from air motor is

$$Te = \frac{F_x * r}{\eta tf * Ntf} \quad \text{...(5)}$$

$$Te = \frac{511.7 * 0.15}{0.9 * 2 * 2.785}$$

Te = 15.311 N.m

Where:

Te: the torque of the engine [N.m].

r: radius of the wheel [m].

To find out the angular speed of the air motor the rotational speed of the wheel must be calculated.

$$\omega_{wheel} = \frac{v}{r} \quad \text{...(6)}$$

$$\omega_{wheel} = \frac{8.333}{0.15} = 55.55 \text{ rad/sec} = 530 \text{ rpm}$$

$$\omega_{engine} = \omega_{wheel} * N_{tf} \quad \text{...(7)}$$

= 530 * 2.785

= 1476.05rpm = 154.57 rad/sec

Where:

ω_{wheel}: the rotational speed of the wheel .

ω_{engine}: the rotational speed of the motor engine.

From these calculations the power air motor becomes known by:

$$Power = Te * \omega_{engine} \quad \text{.......(8)}$$

$= 15.311 * 154.57$

$=2365.4$ watt $= 2.3564$ kw

From eq(5) and displacement volume equal 800 cm^3 ($8x10^{-4}$ m^3) the minimum pressure of air motor can be evaluated.

$$P = \frac{Te * 2\Pi}{displacement} \quad \text{.......(9)}$$

$= \frac{15.311 * 2\Pi}{0.0008}$ =140935.6 Pascal = 1.41 bar

Air flow rate can be determined on the minimum pressure (1.205 bar) from this eq:

$$Q_{of\ motor} = displacement * N_{motor} \quad \text{.......(10)}$$

$= 0,0008 * 1476.05$

$=1.1808\ m^3/min$

4.4.3 Air Receiver Calculations:

To choose air receiver maximum and minimum pressure of system, inlet and outlet flow rate to receiver, and time that the compressor need to fill it must be known.

Since the maximum pressure difference in receiver does not exceed 4 bars to reach the perfect condition, and then maximum pressure must be 10.08 bars.

Considering the compressor efficiency is 0.80, so the theoretical pressure is:

Max. Pressure = [efficiency*(4+P_{min})] +(4+P_{min})

Max. Pressure = [0.8*5.6] +5.6= 10.08 bar

Qc =0

Because the compressor not working

Let the time needed for the tank to become full is 10 min.

$$V_{reciever} = \frac{101 * t * (0 - Q_r)}{P_{max} - P_{min}} \quad \text{.........(12)}$$

$$V_{reciever} = \frac{101 * 10 * (0 - 1.1808)}{(10.08 - 1.41) * 10^2}$$

$V_{reciever}$ = 1.374 m^3

Where:

$V_{receiver}$: Volume of receiver.

t : Time needed for the tank to become full.

Q_r : Outlet flow rate from receiver.

Q_c : Inlet flow rate to receiver.

After these calculations it can be find the time between two fillings, this time important to increase the efficiency.

$$t = \frac{V_{receiver}*100*(P_{max} - P_{min})}{101* Q_r} \quad ....(13)$$

$$= \frac{1.374*100*(10.08-1.45)}{101*1.1808}$$

t_{rest}= 10 min

4.4.4 Reciprocating Compressor Calculations:

The calculation of air compressor, which is reciprocating- 3 stage type, is the main component in this project, because it supplies the system by a compressed air to reach the aim of the project.

$Q_{compressor} = Q_{inlet\ to\ the\ receiver.}$

Because air having ability to compress then it must be use this eq.

$$Q_{1[Standard]} = Q_2 * \frac{P_2}{P_1} * \frac{T_1}{T_2} \quad ....(14)$$

$$Q_1 = 1.808 * \frac{11.08}{1.01} * \frac{298}{323}$$

$= 11.9511$ standard m^3/min

Where:

Q1:actual air flow rate which necessary to calculate power of compressor.

Q2: air flow ate which exhaust from compressor.

P1: max pressure.

P2: pressure atmospheric.

T1: air temperature at atmospheric pressure.

T2: air temperature after compressed.

Now, the power of compressor becomes known by eq(15) as follow.

$$Power = [(Pin * Q_1) / 17.1]*[(Pout/Pin)^{0.286} - 1] \quad (15)$$

$$Power = [(101 * 11.9511) / 17.1]*[(1108/101)^{0.286} - 1]$$

Power = 69.475 Kwatt

Where :

Pin: the atmosphere pressure.[Kpa abs]

Pout: actual outlet pressure.[Kpa abs]

Q_1: actual flow rate.[standard m^3/min]

$$[P_1/P_2] = [P_2/P_3] = [P_3/P_4] \quad (16)$$

$$K = \sqrt[3]{P4/P1} \quad (17)$$

$$K = \sqrt[3]{11.08/1.01}$$

K= 2.153

Where:

K: the pressure factor.

P_1: the atmosphere pressure.

P_2: the first stage pressure.

P_3:the second stage pressure .

P_4: the third stage pressure .

$P_2 = K*P_1$

$= 2.153*1.01= 2.174$ bar

$P_3 = K*P_2$

$= 2.174* 2.153 = 4.6717$ bar

$P_4 = K*P_3$

$= 2.153* 4.6817 = 10.08$ bar

Assume that the input rotational speed is be 10 rev/sec then

$Q_4 = 1.374\ m^3/min$

$Q_4= 1.374 * 1000 / 60$

$Q_4= 22.9$ L/s

$V_4= (Q_4/rev) = (22.9/ 10) = 2.29$ L

Where:

Q_4: the actual outlet rate from the compressor $[m^3/min]$.

V_4: the displacement volume in the third stage [litter].

Because we have an intercooling between the stages so the process isothermal:

$P_3 * V_3 = P_4 * V_4$ ....(18)

$$V3 = \frac{P_4 * V_4}{P_3}$$

$$V3 = \frac{10.08 * 2.29}{4.6817}$$

V3= 4.93L

$P_3 * V_3 = P_2 * V_2$ ....(19)

$$V_2 = \frac{P_3 * V_3}{P_2}$$

$$V_2 = \frac{4.681 * 4.93}{2.174} = 10.615 \text{ L}$$

$$V_1 = \frac{P_2 * V_2}{P_1}$$ ....(2

$$V_1 = \frac{2.174 * 10.615}{1.01}$$

$V_1 = 22.9$ L

From eq(8)and (15) the efficiency of all system is:

$$\text{Efficiency} = \frac{P_{air\ motor}}{P_{compressor}} * \frac{t_{operte} + t_{rest}}{t_{operte}} * 100\%$$ ....(21)

$$\text{Efficiency} = \frac{4.260}{69.457} * \frac{10+10}{10} * 100\% = 17\ \%$$

P_V diagram

$$V_c = \frac{\prod d*d*L}{4} * 1000$$

Where:

Vc: Clearance volume[L]

d: Diameter of piston [m]

L: The distance between TDC and head of engine [m]

$$V_c = \frac{\prod*0.08*0.08*0.01}{4} * 1000 = 0.05 \text{ L}$$

$$P_s * (V_{cut})^{1.3} = (V_s + (V_c)^{1.3} * P_{atm}$$

Where :

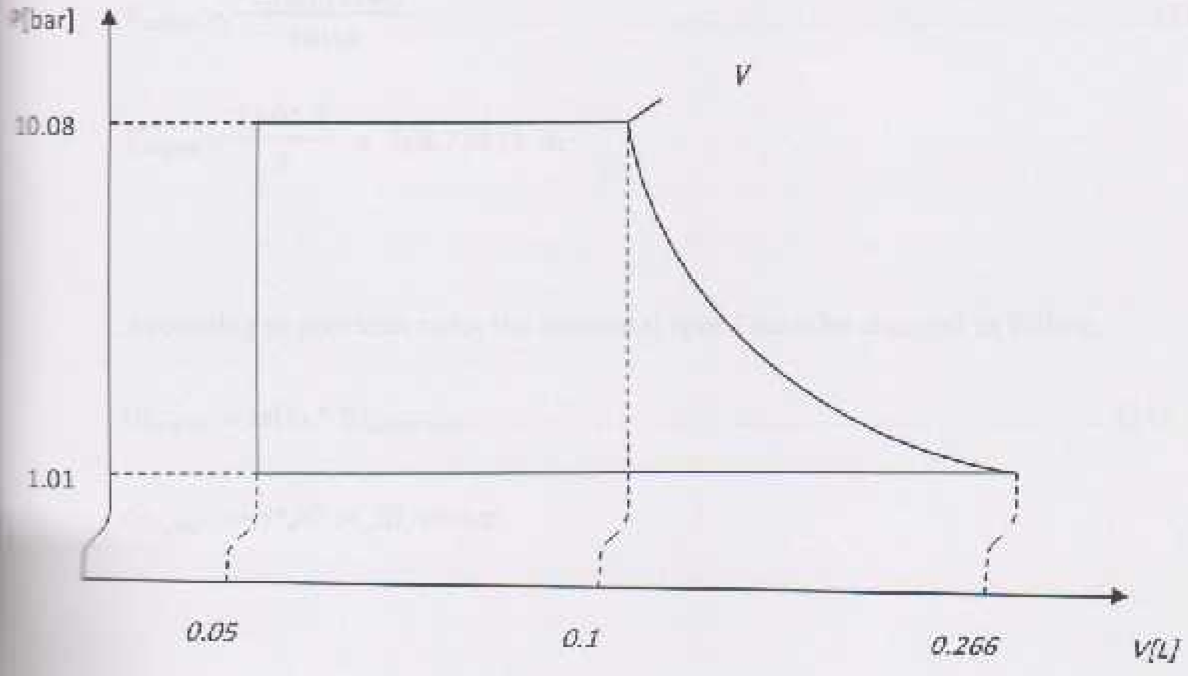
P_s: Supply pressure [bar]

V_{cut}: Volume cut of [L]

V_s: Volume of cylinder[L]

$$10.08 * (V_{cut})^{1.3} = 0.266 + (0.05)^{1.3} * 1.01$$

$$V_{cut} = 0.1 \text{ L}$$



4.4.5 Internal Combustion Engine Calculations:

The internal combustion engine (I.C.E) is the main component in the air motor operated vehicle system because it's the main and the only source of energy.

Because the internal combustion engine (I.C.E) is linked with the compressor and feed it by energy then the power of (I.C.E) equal the power of compressor .

$$Power = T*\omega \qquad (22)$$

$$69.475 * 1000 = T * (10 * 2\Pi)$$

$$T = 1106.2\ N.m$$

Suppose that we have a torque reduction between the compressor and (I.C.E) by a ratio 3:1, so the torque required to rotate compressor is (368.736 N.m) by eq.(23).

$$T_{engine} = \frac{T_{compressor}}{ratio} \qquad (23)$$

$$T_{engine} = \frac{1106.2}{3} = 368.736\ N.\ m$$

According to previous ratio, the rotational speed must be changed as follow:

$$\omega_{engine} = ratio * \omega_{compressor} \qquad (24)$$

$$\omega_{engine} = 3*10 = 30\ rev/sec$$

For two cylinder engine (ICE), the displacement volume (Vd), bore(b), and stroke(S) are related by,

$V_d = 2*(\prod/4) * b^2 * S$……………………………………………………………(25)

From table (4.1), chose the diameter bore is 0.11m and length of stroke is 0.11m,so the displacement volume become known by eq(25).

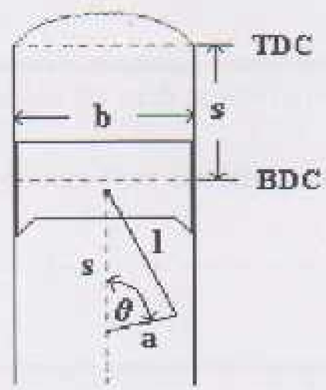


Fig4.1:Geometry of cylinder, pistion, and crank

$V_d = 2*(\prod/4) * 0.11^2 * .11 = 0.00209\ m^3$

where: 1 dm = 10 cm,

$V_d = 2.1\ dm^3$

While torque is a valuable measure of particular engine ability to do work, it depends on engine size. A more useful relative engine performance measure is obtained by dividing the work per cycle by the cylinder volume displaced per cycle, the parameter is called the mean effective pressure (Mep).

$$Mep(Kpa) = \frac{P(Kw) * nR * 1000}{Vd(dm3) * \omega(rev/sec)} \quad \text{...(26)}$$

$$Mep(Kpa) = \frac{86.7 * 2 * 1000}{2.1 * 30}$$

Mep = 2752.4 Kpa

Where :

nR : Is the number of crank revolution for each power stroke.

It is important to know the ratio between bore and piston stroke (R_{bs}).

R_{bs} = b/L ....(27)

R_{bs} = 0.11/0.11

R_{bs} = 1

After these calculation, and table (4.1) the type and parameters of I.C.E be known which follow the trucks type.

$$Mep(Kpa) = \frac{P(Kw)*nR*1000}{Vd(dm3)*\omega(rev/sec)} \quad \text{.........(26)}$$

$$Mep(Kpa) = \frac{86.7*2*1000}{2.1*30}$$

Mep = 2752.4 Kpa

Where :

nR : Is the number of crank revolution for each power stroke.

It is important to know the ratio between bore and piston stroke (R_{bs}).

R_{bs} = b/L ....(27)

R_{bs} = 0.11/0.11

R_{bs} = 1

After these calculation, and table (4.1) the type and parameters of I.C.E be known which follow the trucks type.

Table 4.1: Typically design for (I.C.E)

Typical design and operating data for internal combustion engines

	Operating cycle	Compression ratio	Bore, m	Stroke/ bore	Rated maximum: Speed, rev/min	Rated maximum: bmep, atm	Rated maximum: Power per unit volume kW/dm^3	Weight/ power ratio, kg/kW	Approx. best bsfc, g/kW·h
Spark-ignition engines:									
Small (e.g., motorcycles)	2S,4S	6–11	0.05–0.085	1.2–0.9	4500–7500	4–10	20–60	5.5–2.5	350
Passenger cars	4S	8–10	0.07–0.1	1.1–0.9	4500–6500	7–10	20–50	4–2	270
Trucks	4S	7–9	0.09–0.13	1.2–0.7	3600–5000	6.5–7	25–30	6.5–2.5	300
Large gas engines	2S,4S	8–12	0.22–0.45	1.1–1.4	300–900	6.8–12	3–7	23–35	200
Wankel engines	4S	≈ 9	0.57 dm^3 per chamber		6000–8000	9.5–10.5	35–45	1.6–0.9	300
Diesel engines:									
Passenger cars	4S	17–23	0.075–0.1	1.2–0.9	4000–5000	5–7.5	18–22	5–2.5	250
Trucks (NA)	4S	16–22	0.1–0.15	1.3–0.8	2100–4000	6–9	15–22	7–4	210
Trucks (TC)	4S	14–20	0.1–0.15	1.3–0.8	2100–4000	12–18	18–26	7–3.5	200
Locomotive, industrial, marine	4S,2S	12–18	0.15–0.4	1.1–1.3	425–1800	7–23	5–20	6–18	190
Large engines, marine and stationary	2S	10–12	0.4–1	1.2–3	110–400	9–17	2–8	12–50	180

Chapter Five

Methods of distribution a compressed air that was followed in the proposed project.

5.1 Introduction:

After not being able to get in the proposed project an air engine, because of the high expenses, a decision was made to convert an internal combustion engine running on gasoline to run on compressed air instead of fuel combustion, the problem was how to distribute the compressed air into the cylinders in an appropriate timing in power strokes.

At the beginning the idea was to use a re-formation of camshaft for the distribution of air, in a manner commensurate with the opening and closing valves in a cylinder where the power stroke, this idea facing several problems in the application, this idea leads to think other way, to distribute the air and that was to use an "Apparatus To Convert A Four-Stroke Internal Combustion Engine To A Two-Stroke Pneumatically Powered Engine", this method to some extent similar to the previous one in terms of working principle, and also had been subjected to several problems, then to overcome many obstacles after a brain storming with supervisor and many others among the staff of mechanical engineering department, the team of the project decided to use an electronic valves for distribution the compressed air, saluting this method was applied in the proposed project positive results have been obtained , but were not free of problems.

The methods of distribution of compressed air which were analyzed and experimented during the designing of the project and the obstacles which were facing their implementation will be discussed in the following:

5.2 Compressed Air-Operated Motor Employing Dual Lobe Cams

An air-operated engine system usable for driving a vehicle by means of compressed air from a rechargeable storage tank. The engine of the system has cylinders containing driving pistons connected to a crankshaft. Compressed air from the storage tank is supplied at regulated pressure to the cylinders for power strokes by means of intake valves and the air is exhausted from the cylinders at the ends of the power strokes by means of exhaust valves. The intake and exhaust valves are operated by dual lobe cams on a camshaft driven from the crankshaft.

In an engine system for driving a vehicle, a compressed air storage in the tank, an engine provided with a plurality of cylinders containing pistons and a crankshaft having crank elements connected to pistons, compressed air supply connecting storage tank to the cylinders and including respective intake valves controlling admission of compressed air to the cylinders for generating power strokes, exhaust connected to the cylinders and including respective exhaust valves controlling discharge of expanded air from the cylinders, camshaft coupled with the crankshaft, camshaft including a plurality of dual-lobed cams, and respective follower engaging cams and being operatively coupled to intake and exhaust valves, cams and follower being arranged to open the intake valves shortly after the pistons pass their extended dead center positions in the cylinders to generate the power strokes, and to open the exhaust valves shortly before the pistons reach their retracted dead center positions in the cylinders at the ends of power strokes.

5.2.1 Brief Description Of The way (Compressed Air-Operated Motor Employing Dual Lobe Cams)

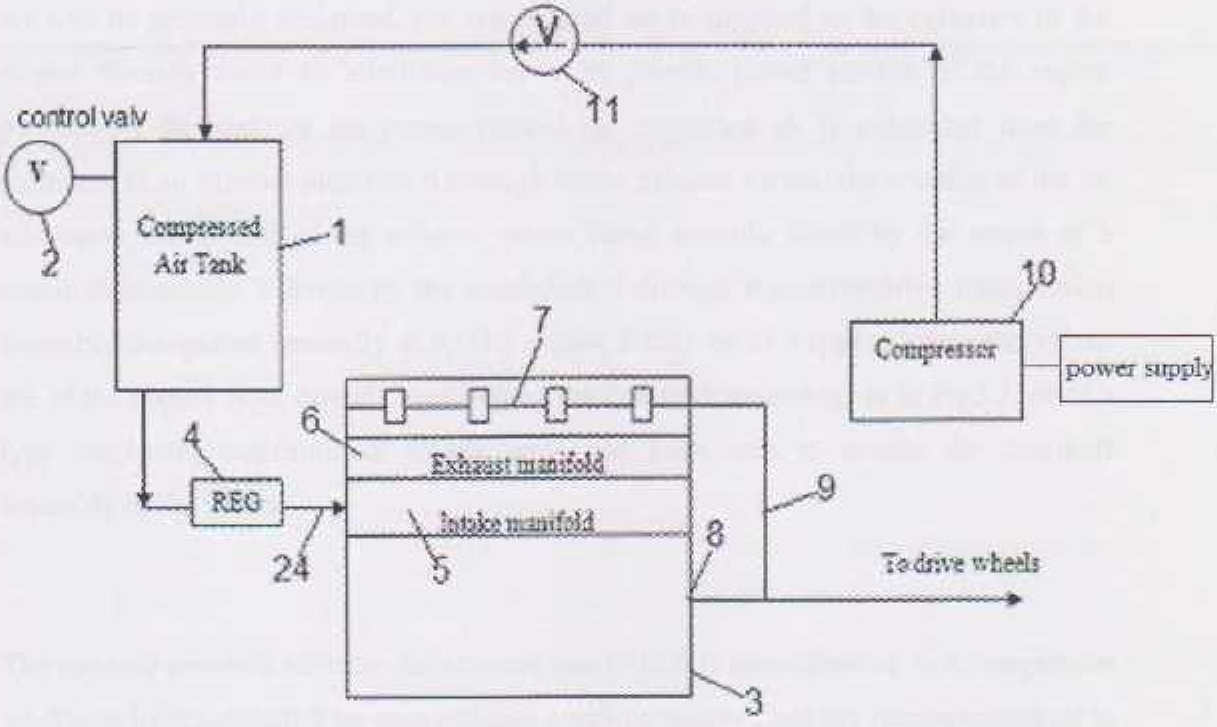


Fig:5.1: schematic diagram of a typical improved compressed air-operated engine system for a motor vehicle, in accordance with the present project.

Note: All this number indicate the names and location of parts according to the proposed project.

Schematically illustrates the fluid circuit of the engine system in a typical compressed air-driven motor vehicle according to the present project. The fluid circuit comprises a compressed air storage tank 1 which is chargeable with compressed air from a suitable external source through a control valve 2. Tank 1 is connected to a compressed air_driven engine 3 through a conventional pressure regulator 4, whereby to furnish air at a suitable pressure to the intake manifold 5 of the engine.

As will be presently described, the compressed air is supplied to the cylinders of the engine through timed air admission valves to provide power strokes of the engine pistons. At the ends of the power strokes the expanded air is exhausted from the cylinders to an exhaust manifold 6 through timed exhaust valves, the opening of the air admission valves and of the exhaust valves being suitably timed by the action of a camshaft assembly 7 driven by the crankshaft 8 through a positive-drive transmission assembly designated generally at 9. The engine 3 may be of a type wherein the valves are of the poppet type, directly operated by the camshaft assembly, as in Fig5.2, or of a type employing conventional rocker arms and push rods to couple the camshaft assembly to the valves.

The reduced-pressure air from the exhaust manifold 6 is recompressed in a compressor 10 driven by crankshaft 8 by conventional coupling means , and the recompressed air is returned to the storage tank 1 through a conventional check valve 11.

Crankshaft 8 is drivingly connected in a conventional manner through suitable clutch means and speed-changing means to the driving wheels of the associated vehicle.

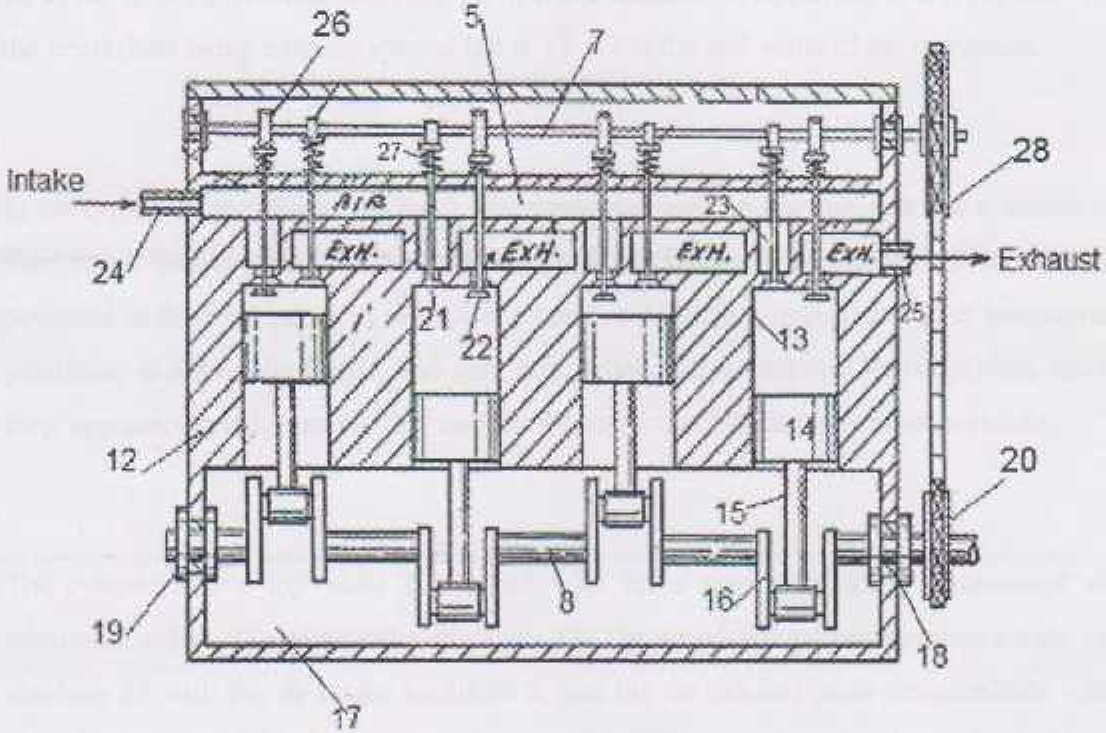


Fig:5.2 Longitudinal vertical cross-sectional view taken through a typical compressed air-operated engine

Is a longitudinal vertical cross-sectional view taken through a typical compressed air-operated engine which may be employed in the system of Fig5.1, the engine employing direct-operated admission and exhaust valves controlled by dual-lobed cams according to this project

Fig5.2 the typical engine, shown at 3, comprises a block 12 formed with four longitudinally aligned cylinders 13 containing pistons 14 connected by connecting rods 15 to the respective crank elements 16 of the crankshaft 8, contained in a crankcase 17, the crankshaft being suitably journal led at 18, 19 in the end walls of the crankcase.

In the typical four-cylinder engine 3, the crank elements 16 are coplanar but alternate in their crank configurations. Thus, the first and third pistons 14 reach their uppermost positions in their cylinders 13 when the second and fourth pistons reach their lowermost positions, as shown in Fig5.2, and similarly, when the second and fourth pistons reach their uppermost positions, the first and third pistons reach their lowermost positions.

The cylinders have top walls 20 formed with valve ports containing compressed air admission valves 21 and air exhaust valves 22. The air admission ports communicate via conduits 23 with the air intake manifold 5, and the air exhaust ports communicate with the exhaust manifold 6. An air supply conduit 24 connects regulator 4 to intake manifold5. An exhaust conduit 25 connects exhaust manifold 6 to the inlet of compressor 10.

The camshaft is positively driven by crankshaft 8 by a suitable driving coupling, for example, a chain drive assembly 27 having a camshaft gear 28, providing a 2:1 drive ratio, so that camshaft rotates at one-half the speed of crankshaft 8. Thus, considering the first cylinder 13, its air admission valve 21 opens every 180° of rotation of camshaft, namely, at each revolution of crankshaft 8 as the associated piston 14 passes its uppermost position. The associated air admission cam 26 preferably has its maximum radius 9° behind the top dead center mark on the camshaft driving gear 28.

In the arrangement illustrated in Fig.2, the air admission valves 21 for the first and third cylinders open simultaneously, providing simultaneous power strokes by the first and third pistons; the exhaust valves 22 for the second and fourth cylinders open simultaneously, allowing the expanded air therein to be discharged simultaneously into the exhaust manifold 6. The exhaust valves 22 for the second and fourth cylinders open before the opening of the compressed air admission valves 21 for the first and third cylinders, assuring that their power strokes will not be opposed by compression build-up in the second and fourth cylinders.

The above-described action reverses for every 180° of rotation of crankshaft 18 (every 90° of rotation of camshaft). Delay in the opening of the air admission valves 21 until the pistons have passed top dead center assures that the pistons will have begun their descent at the times that the compressed air is admitted into the associated cylinders.

5.2.2 Obstacles of implementation such method:

1) This way need to change in the design of the engine , and it is an expensive way.

2) The need of a high pressure to overcome the resistance of the spring return valve (entry and exit), which are not available in the local market.

5.3 Apparatus To Convert A Four-Stroke Internal Combustion Engine To A Two-Stroke Pneumatically Powered Engine:

Is a cylinder containing the side vents, the number of these openings equals the number of cylinders the engine.

A supply line is provided for delivering compressed air from the tank to the engine, after passing through the regulator, the compressed air enters the pneumatic distributor, a plurality of high pressure hoses is provided for finally communicating the compressed air to the cylinders of the engine via the spark plug orifices.

The pneumatic distributor has a rotor mountable to the existing timing mechanism, and the rotor opens the gate valves to supply compressed air to the cylinders where in the pistons are at top dead center, making every down stroke a power stroke, and get rid of the air after the completion of the power stroke by another device in the same way.

5.3.1 Brief Description Of The way (Apparatus To Convert A Four-Stroke Internal Combustion Engine To A Two-Stroke Pneumatically Powered Engine):

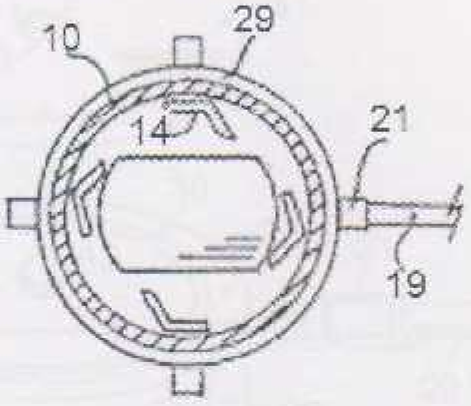


Fig5.3: Enlarged top plan view of the pneumatic distributor of the apparatus of this project with its upper housing member removed.

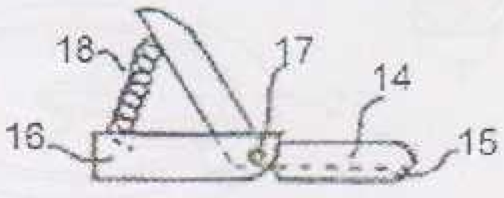


Fig5.4: Enlarged top edge view of the gate valve assembly of the pneumatic distributor.

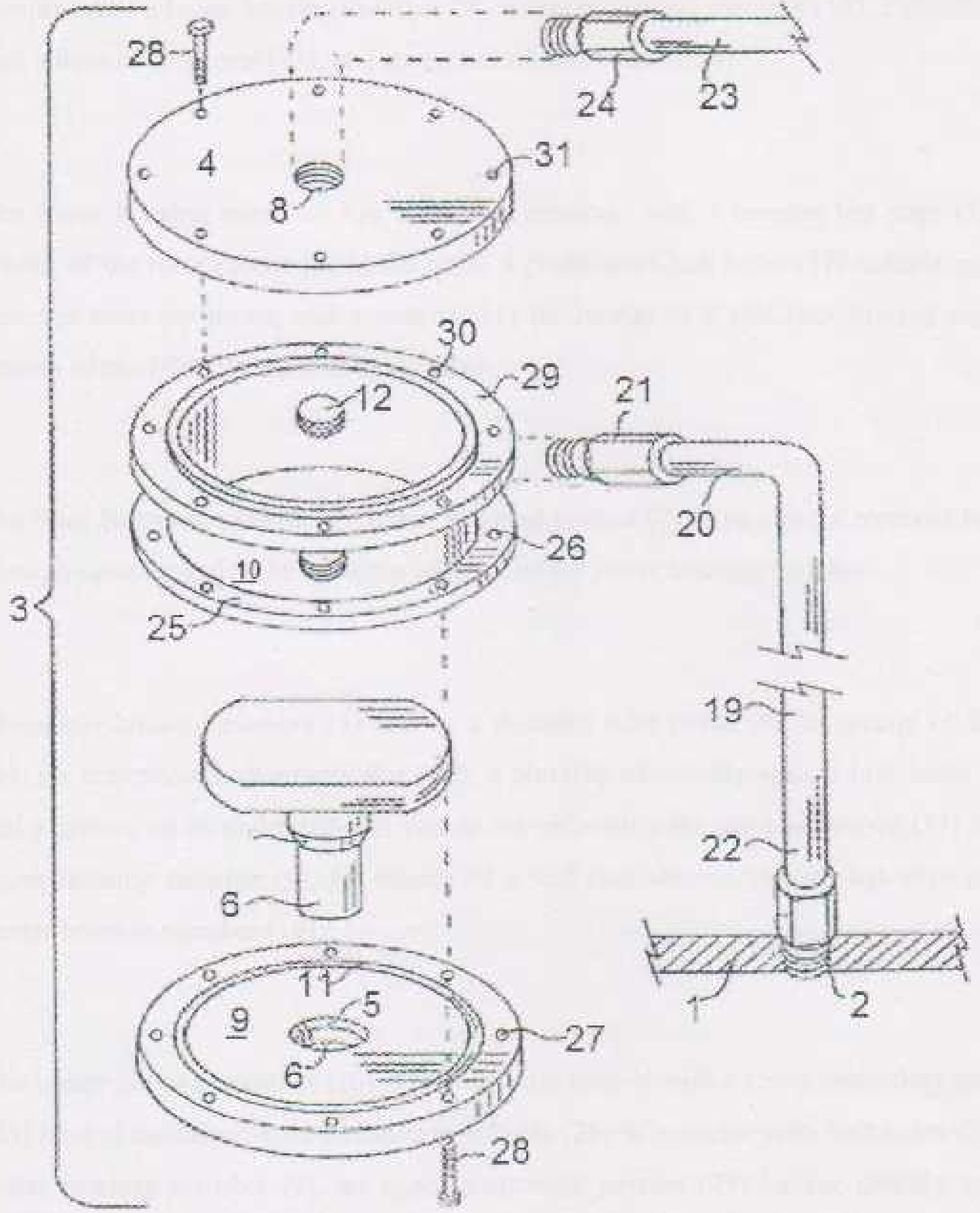


Fig5.5: Exploded view of the pneumatic distributor constructed in accordance with this project

The pneumatic distributor (3) is shown in Figs(5.3 and 5.5) The pneumatic distributor is comprised of a lower housing member (9), a center housing member (10), a plurality of gate valves (14), a rotor (13), and an upper housing member (4).

The lower housing member has a through opening with a beveled top edge (5) for receipt of the rotor mount (6) of the rotor, a plurality of bolt holes (27) radially spaced near the outer perimeter, and a groove (11) for receipt of a seal (not shown) and the bottom edge of the center housing member.

The rotor has a rotor mount (6) with a beveled portion (7) to be closely received by the through opening and its beveled top edge (5) of the lower housing member.

The upper housing member (4) defines a threaded inlet portal (8) for receipt of fitting (24) on compressed air supply line (23), a plurality of radially spaced bolt holes (31), and a groove on its underside, not visible but essentially the same as groove (11) in the lower housing member (9), for receipt of a seal (not shown) and the top edge of the center housing member (10).

The center housing member (10) is cylindrically shaped with a lower protruding portion (25) having radially spaced threaded bolt holes (26) to coincide with bolt holes (27) of lower housing member (9), an upper protruding portion (29) having radially spaced threaded bolt holes (30) to coincide with bolt holes (31) of upper housing member (4), a plurality of radially spaced threaded portals (12) for passage of compressed air to the individual cylinders . A gate valve mounting means (16) is secured to the inner wall of the center housing member (10) adjacent to each portal (12). As shown in Fig5.4, each gate valve (14) has a seal (15) for sealing portal (12) and a return spring (18) and is attached to the mounting means (16) by means of a pivot pin (17).

A plurality of high pressure hoses (19) is provided for finally communicating the compressed air to the individual cylinders of the engine (1). Each high pressure hose (19) is provided at one end (20) with a threaded fitting (21) for engaging a threaded portal (12) defined by the center housing member (10), and at the other end (22) with a threaded fitting for engaging the threaded spark plug orifice (2) defined by the engine (1). Thus the threaded fitting is substantially similar to the threaded portion defined by a conventional spark plug. High pressure hoses (19) are connected to the individual cylinders in the same order as conventional spark plug wires such that a proper sequence of compressing the pistons downward in their respective cylinders is accomplished.

Fig.2 shows the pneumatic distributor for a four cylinder application. As the existing timing mechanism of the engine is operating, the rotor (13) is continuously rotating and opening a pair of gate valves (14) to supply compressed air via portals (12)and high pressure hoses (19) to a pair of cylinders, and thereby creating a power stroke to the pair of pistons which are beginning the downstroke. As the rotor (13) continues to rotate, the rotor (13) releases one pair of gate valves (14) and engages the remaining pair. The return spring (18) closes the released gate valves (14) and the seal (15) ensures no compressed air can enter the associated portals (12).

5.3.2 Obstacles of implementation such method:

1) This way need a long time for design and rely on trial and error and this is not commensurate with the actual available time for the proposed project and very expensive.

2) Another reason is that many of these devices do not adequately address leakage problems, and engine efficiency is compromised.

5.4 Solenoid valves for distribution compressed air:

5.4.1 Introduction:

Using the solenoid valves, is the third way to distribute the compressed air in the cylinders of the engine after facing some problems in the previous ways (compressed air-operated motor employing dual lobe cams and apparatus to convert a four-stroke internal combustion engine to a two-stroke pneumatically powered engine), these problems may be summarized in to streams: high expenses and complications in design and implementation.

Using solenoid valve for each cylinder in the engine which will be connected in place of spark plugs, the number of the solenoid valves depends on the number of the cylinder, in the proposed project the engine which used with three cylinders (so we use three solenoid valves).

Distributing the electrical signal to the solenoid valves as the way used for the proposed project in which the rotor disc and reflective optical sensor which rotor disc divided into angels to appropriate with opening and closing the solenoid valves (on /off sensor) in a appropriate time. The method of distributing the electrical signal to solenoid valves will be explained in the following section.

5.4.2 Solenoid valve:

A solenoid is an electromechanical device which allows for an electrical device to control the flow of a gas or liquid. The electrical device causes a current to flow through a coil located on the solenoid valve. This current flow in turn results in a magnetic field which causes the displacement of a metal actuator.

The actuator is mechanically linked to a mechanical valve inside the solenoid valve. The valve then changes state, either opening or closing to allow a liquid or gas to either flow through or be blocked by the solenoid valve. A spring is used to return the actuator and valve back to their resting state when the current flow is removed.

Solenoid valves come in various configurations and sizes. Solenoid valves can be normally open, normally closed, or a two way valve. A normally open solenoid valve allows a liquid or gas to flow through unless a current is applied to the solenoid valve. A normally closed valve works in the opposite manner. A two way solenoid valve has three ports; one port is common, one is normally open and the third is normally closed, can send a signal to the solenoid valve to open, allowing the container to fill, and then remove the signal to close the solenoid valve and stop the flow of liquid until the next container is in place.

The process of selecting solenoid valves shows Fig5.6 depending on (Harris formula). As in the case for liquids, when air flows through a pipe, it loses energy due to friction. The energy loss shows up a pressure loss, which can be calculated using the Harris formula

Fig 5.6: solenoid valve

$$P_f = \frac{0.1025\, L\; Q^2}{CR\; d^{5.31}}$$

Where : Pf = pressure loss [psi]

Q = flow rate [scfs]

CR = compression ratio

d = inside diameter [in]

The illustration below depicts the basic components of a solenoid valve. The valve shown in the Fig5.7 is a normally-closed, direct-acting valve. This type of solenoid valve has the most simple and easy to understand principle of operation.

The media controlled by the solenoid valve enters the valve through the inlet port (Part 2 in the illustration above). The media must flow through the orifice (9) before continuing into the outlet port (3). The orifice is closed and opened by the plunger (7).

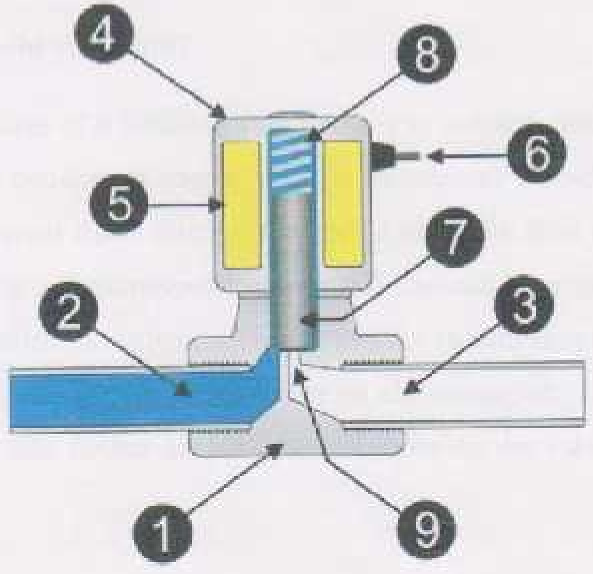


Fig.5.7: solenoid valve parts

1. Valve Body

2. Inlet Port

3. Outlet Port

4. Coil / Solenoid

5.Coil

6. Lead Wires Windings

7. Plunger

8. Spring

9. Orifice

The valve Fig.5.7 is a normally-closed solenoid valve. Normally-closed valves use a spring (8) which presses the plunger tip against the opening of the orifice. The sealing material at the tip of the plunger keeps the media from entering the orifice, until the plunger is lifted up by an electromagnetic field created by the coil.

5.4.3 Solenoid Valve Coil:

5.4.3.1 What is a solenoid valve coil?

Show Fig.5.8 The purpose of a solenoid valve coil is to convert electrical energy into linear motion. The coil consists of copper wire (or aluminum) wound around a hollow form. When electric current flows through the coil, a magnetic field is created. This is accomplished by placing a ferromagnetic core inside the coil. In a solenoid valve, the ferromagnetic core is called the valve plunger. When the current flows through the coil, the lines of magnetic flux turn the plunger into an electromagnet. The magnetic field causes the plunger to slide further up into the coil, opening the valve body orifice or pilot orifice.

Fig.5.8: solenoid valve coil

5.4.3.2 Solenoid Valve Coils (DC) and Electrical Polarity:

A common question about solenoid valve coils is whether the electrical current polarity matters in a DC coil. Most coils with lead wires use the same color wire for both terminals and have no polarity markings. The answer is that polarity does not matter. You can connect the positive terminal to either of the two wires without affecting the operation of the valve.

5.4.3.3 Solenoid Valve Coil Voltages:

Solenoid valve coils are available for both DC and AC electricity. Although a coil can be made to work with almost any imaginable voltage, the most common voltages available are:

6-Volt DC

12-Volt DC

24-Volt DC

24-Volt AC

120-Volt AC

220/240-Volt AC

The advantage of the low voltage coils is obviously electrical safety. Hobbyists and do-it-yourselfers often power the low voltage solenoid valves with wall transformers. Most smaller valves 12 VDC valves can be powered by a 12-Volt / 500 mA power supply. However, always make sure your power supply does meet or exceed the power requirement of the solenoid. The 24 VAC solenoid valves appeal to hobbyists as well since they can be easily controlled by irrigation timers. Most industrial applications and heavy machinery use solenoids with 24 VDC coils

5.5 Distribution of the electrical signal on the valves:

The number of the solenoid valves is depending on the number of the engine cylinders, so we need three solenoid valves, and it is connected directly to the cylinders through engine head, as it is shown in the Fig 5.9.

Fig.5.9: solenoid valves for engine

Controlling the operation of the solenoids is taking place by using a rotor disc and reflective optical sensor. The rotor disc is divided into three angles , and every angle equal 180°. These angles overlap as shown in Fig.5.10.

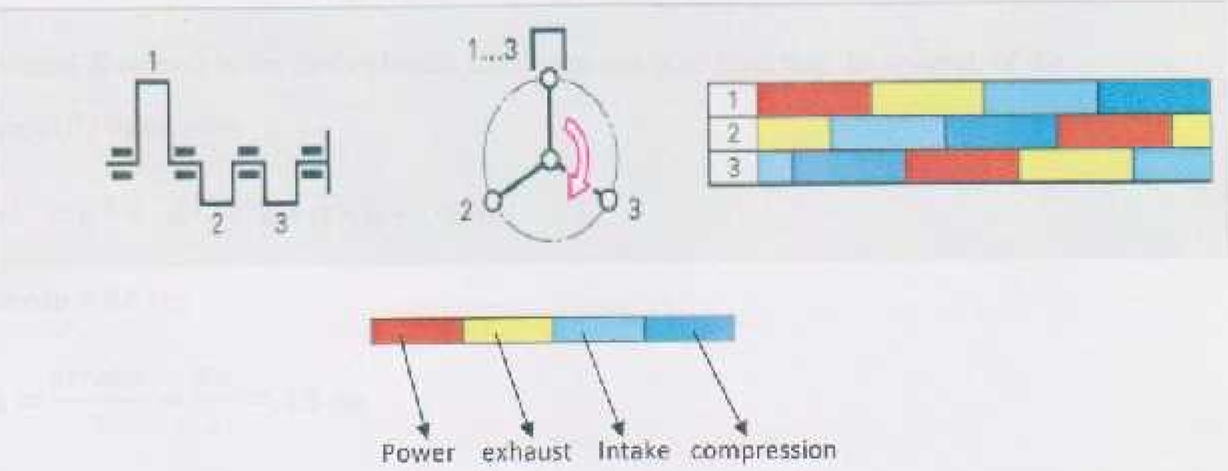


Fig.5.10: Engine timing (3_cylender)

Angles are painted black balloon on the disc surface and the rest will be white balloon, as the sensor responds to the black color and not responding to the white color Fig.5.11, so the distribution signals to the solenoid valves will be as required to manage the timing of opening and closing in appropriate sequence.

The amount of the overlap in the angles is 60°, which is calculated the by using the cosine law. The distributing sequence of electrical signal to the solenoid valves will be as following (1_3_2) cylinders.

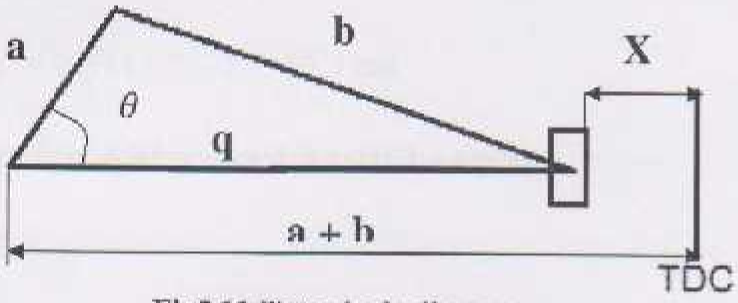


Fig5.11 Piston body diagram

When (X =zero) in the first cylinder, the piston one is in TDC that the amount of the angle(θ) equal zero.

$$b^2 = q^2 + a^2 - 2 * a * q * \cos\theta$$

Stroke = 8.6 cm

$$a = \frac{stroke}{2} = \frac{8.6}{2} = 4.3 \text{ cm}$$

b = 13.3 cm

$q = a + b - x = 4.3 + 13.3 - 0 = 17.3$ cm

$$b^2 = q^2 + a^2 - 2 * a * q * \cos\theta$$

$$13.3^2 = 17.3^2 + 4.3^2 - 2 * 4.3 * 17.3 * \cos\theta$$

$\rightarrow \theta = 0°$

When (X =7cm) in the first cylinder the amount of the angle(θ) equal 120° and piston number three will be TDC.

$q = a + b - x = 4.3 + 13.3 - 7 = 10.3$ cm

$$13.3^2 = 10.3^2 + 4.3^2 - 2 * 4.3 * 10.3 * \cos\theta$$

$\rightarrow \theta = 120°$

When (X = 8.6 cm) in cylinder one that the piston one is in BDC , and the amount of the angle(θ) equal 180°

$q = a + b - x = 4.3 + 13.3 - 8.6 = 9$ cm

$$13.3^2 = 9^2 + 4.3^2 - 2 * 4.3 * 9 * \cos\theta$$

$\rightarrow \theta = 180°$

The amount of the overlap of angles of the rotor disc ($\Delta\theta$) equal 60°.

$\Delta\theta = \theta_{(x=8.5)} - \theta_{(x=7)}$

$\Delta\theta = 180 - 120 = 60°$

After finding these angles and designing the rotor disc, the rotor disc is putted on the crankshaft to rotate with it and the reading sensor putted opposite to the rotor disc, when it begins in moving in circles the rotor disc start working on the hacking signal for each sensor (on / off) in the rotor disc in appropriate time and with appropriate angle as it is shown in the Fig 5.12.

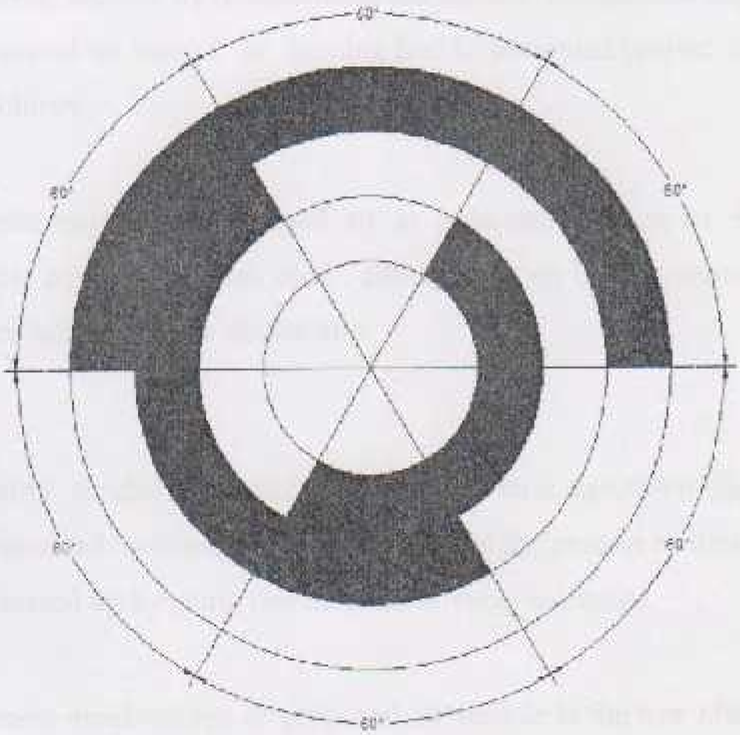


Fig.5.12: Rotor disc

Chapter six :

Conclusions and Recommendations

Conclusions:

1- Compressed air is one of alternative sources of energy which can be used for vehicle transportation especially those which used for special purposes inside campuses which crowded by people and travelling needed mostly for short distances.

2- Two ways may be followed to operate compressed air vehicle, first : by using air motor, second: by transforming the internal combustion engine to operate compressed air instead of burning fuel In presented project the second way was followe.

3- To gain required compressed air in presented project an external source (electric compressor) was used , although, an on board compressor may also be used which operate electrically.

4- A control mechanism which operate by electric signal sending from rotating disk mounted on crankshaft used to manage the process of timing and exhaust compressed air by using two directional valve solenoids.

5- The main disadvantage of proposed air vehicle is the low efficiency and the need of relatively huge balloons to store compressed air in the vehicle.

Recommendations:

At the end me recommend to those who will carry on developing the air vehicle to research and focus in the following directions.

1- The possibility to operate the vehicle by dual sources of power as a hybrid vehicle.

2- To use a more efficient solenoids such as 3 quick exhaust solenoid, which manage the exhausting process more accurate.

3- To reuse the exhausting air for charging the air balloons.

4- To use an on board compressor to charge the air balloons.

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