Fabrication of Pneumatic Four Wheeler

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Abstract— **Compressed air is a source of energy that has the potential to become one of the most viable renewable resources in the near future. Clean energy is the need of the hour and every industry is aiming for emission free vehicles. The aim of the project is to design a four wheeler powered by pneumatics that can be used for various purposes. This paper discusses about various design parameters, the drive system used, advantages and disadvantages of this energy source and various factors to be considered. The principle of the drive system is a slider crank powered by a single double acting piston. Since compressed air is a clean source of energy, there are no waste products like COx or NOx, thus preventing pollution or damage to the environment. There is a lot of research going on in this field and compressed air could be the future of automobiles.**

Index Terms— **Compressed Air, Clean energy, Double Acting Pneumatic Piston, Four Wheeler, Slider Crank Mechanism, Renewable Resource.**

I. Introduction

Nowadays, energy inadequacy and environmental pollution problems has become intense that it even influences the traditional automobile industry. It is vital to explore possible opportunities in unconventional alternative-fuel vehicles to gratify the call for environment protection whilst saving resources [1]. Air is a freely available resource that is present all around us. The attempt to tap this resource of energy in the automotive field began since 1870 when the Polish engineer Loise Merkaski made the first compressed air vehicle. The principle of Merkaski was to use compressed air to increase gas enthalpy of hot water. In 1892, Robert Hardie introduced a new method of heating that at the same time served to increase the range of the engine that could be travelled at a stretch. Using the engine as a compressor during deceleration, air and heat were added to the tanks, increasing the range between fill-ups. However, the first urban transport locomotive was not introduced until 1898, by Hoadley and Knight, and was based on the principle that the longer the air is kept in the engine, the more heat it absorbs and the greater its range. As a result they introduced a two-stage engine. Charles B. Hodges will always be remembered as the true father of the compressed air concept applied to cars, being the first person, not only to invent a car driven by a compressed air engine, but also to have considerable commercial success with it. After twelve years of research and development, Guy Negre has developed an engine that could become one of the biggest technological advances of this century. A French engineer by profession, he has designed a low consumption and low pollution engine for urban motoring that runs on compressed air technology. “Air car” – an initiative from Motor Development International is a significant step for zero emission transport, delivering a compressed air-driven vehicle that is safe, quiet, has a top speed of 110 km/h and a range of 200 km. Guy Nègre is the head of Research and Development at Moteur Development International (MDI) cars, where the Zero Emission Vehicle (ZEV) prototypes have been in production since 1994. Recently TATA motors India developed a model powered by compressed air called Air Pod which was due to launch in year 2008.

Air in itself does not have stored energy, but when compressed and stored in a tank it can be used to do work rather produce output. Generally four wheelers are powered by means of fossil fuels that cannot be replenished, the most common being by-products of crude oil like petrol, diesel etc. Nowadays electric vehicles are popular as well but even then recharging of batteries are a problem.

The aim of the project is to produce a four wheeler powered by compressed air that can be used for various purposes that are industrial or otherwise. The project is a prototype model and is designed to hold up to 100 kg excluding its own weight. The vehicle is powered by compressed air stored in an air tank at a pressure of about 10 bars and the drive system works on the slider crank mechanism actuated by a double acting pneumatic actuator (piston).The drive is transmitted to a gear system having a gear ratio of 2:1 and the rotary motion transferred to the shaft by means of a chain drive. The design is such that it is rear drive and the control unit is placed near the air tank right at the front of the four wheeler. A Factor of Safety (FOS) of 2 is considered during the entire design calculation. The chassis of the vehicle is made of mild steel rods with a rectangular cross section. There is a pair of drum brakes installed at the front wheels that are controlled by means of a pedal.

The pneumatic four wheeler, more popularly known as an air car is powered by compressed air and is used for both commercial and industrial transportation. The high pressure is used to power an actuator and the linear motion is converted to rotary motion through various means that are discussed in the paper. A few examples are Rack and Pinion mechanism, Scotch Yoke Mechanism, Slider Crank Mechanism etc.

The requirement of having a clean source of energy is the need of the hour, and since air is all around us it is one of the best options. Global warming has become one of the main concerns of the entire world bringing countries together for finding a solution to this problem. Compressed air is a possible solution to that problem and if researched can be used as a viable energy source in the near future.

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II. OVERVIEW OF MAIN ALTERNATIVE FUEL VEHICLES

Presently, the evolution of new energy vehicles has spellbound many vehicle manufacturers around the world. Different types of alternative fuel vehicles are blooming at a rapid pace. Fuel cell vehicles, battery electric vehicles, and hybrid electric vehicles are often mentioned in the papers [2–5].

Battery electric vehicles is a fully fledged industry. Tesla Motors is the epitome of such an industry, having already launched commercial products [6–7]. Similar to the fuel tank equipped in traditional vehicles, an on-board rechargeable battery is used to store energy. Prevention of release of harmful exhaust gases is ensured by installing electric motors and motor controllers, substituting the internal combustion engines [8–10]. Despite this achievement, pollution and carbon emissions still show great persistence, in the process of electricity generation, depending on the power generation mode.

Hybrid electric vehicles which have been relatively young in the market, consist of an internal combustion engine (IC engine) and an electric motor [11–13]. In most cases, this class of vehicles are better than its counterpart which are equipped with IC engine in terms of fuel efficiency and dynamic performance, although there is a large requirement for space to house the power system. Hybrid electric vehicles portray as a viable interim solution to the depletion of fossil fuels and rigid environmental regulations [14–15].

Collating with the above mentioned vehicles, air-powered vehicles are significantly advantageous. Exhaust air is only pure air, which is highly in contrast to the COx and NOx emissions of traditional vehicles used. Once the demand shoots for air-powered vehicles, compression of air – which is a boundless resource – will be remarkably cheaper.

Table 1 shows a brief comparison of the different new energy vehicles that have potential in the market.

TABLE 1. Comparison of new energy vehicles.

Category	**Development Process**	**Power Source**	**Pollution**	**Cost**
Hybrid Electric Vehicle	Relatively mature	Gasoline, Batteries	Relatively low	Medium
Battery Electric Vehicle	Transition stage	Batteries	Zero pollution on road; Battery pollution	High
Air Powered Vehicle	In development	Compressed air	Zero pollution	Low

III. DESIGN

The four wheeler is designed for a weight of 200kg (including the chassis) and a FOS of 2 has been considered for all the calculations. Mild steel is selected as the primary material for the chassis and there were various parameters that were studied before deciding on different systems of the vehicle. These parameters were selected according to convenience of fabrication and availability of technology to do the same. Also, efficiency of each system was compared before finalizing the design of the entire four wheeler.

A. Drive Mechanism

The project undertaken has been designed by installing a slider crank mechanism. This allows the transmission of the linear motion of the double acting cylinder to rotary motion. Fig 1 shows a slider crank mechanism having four links connected by three revolute joints and one prismatic joint of lower pair or surface contact. The project is designed with such a mechanism wherein the reciprocating motion of the pneumatic actuator is converted to rotary motion using this slider crank arrangement. The driver crank is about the pinion shaft, i.e. the shaft on which the pinion is attached. This oscillatory motion of the shaft in turn rotates the output shaft by means of gear drive and chains [1].

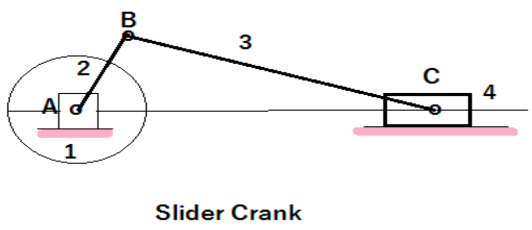

Fig 1. Slider crank mechanism *(Source:http://mechanical-engineering-concepts.blogspot.in/2014/03/car-engine-crankshaft-piston-rod-and.html)*

B. Steering Mechanism

Four wheel vehicles use four-bar linkages, often called Ackermann-type steering mechanism. The driver provides the input motion at the steering wheel, which gets transmitted to the steering control linkage to one of the steering knuckles and then gets transmitted to the other through the Ackermann steering linkage. Ackermann steering mechanisms are widely used in many vehicles and is most commonly found in trucks and off-highway vehicles that have a rigid design for steering axle [1]. Fig 2 shows the typical arrangement of Ackermann steering mechanism.

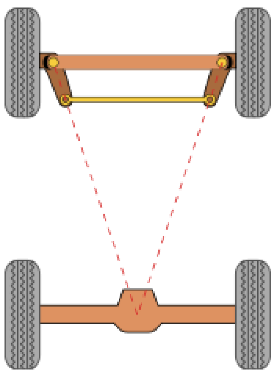

Fig 2. Ackermann Steering Mechanism *(Source:https://en.wikipedia.org/wiki/Ackermann_steering_geometry#/media/File:Ackermann_simple_design.svg)*

C. *Pneumatic Control Systems*

1. **Double acting Pneumatic Cylinder:** Pneumatic cylinders use compressed air to produce a force in a reciprocating linear motion. Compressed air directs the piston to move in the direction controlled by the operator. Stringent requirements for clean energy makes pneumatics the best candidate as leakage of the operating fluid, viz. air, does not contaminate the environment. Expansion of the compressed air is the driving force of the piston, allowing it to move in two directions in the cylinder. After analysing the requirement, the decided size of the bore diameter and stroke length were 100mm and 300mm respectively.
2. **5/2 Direction Control Valve (DCV):** Regulation, control and reversing action of air is necessary to control the forward and backward motion of the pneumatic cylinder. While ensuring this, it is also crucial to control the pressure and flow rate in order to obtain the desired level of force and speed actuation.

To control the to and fro motion of a pneumatic cylinder, the air energy has to be regulated, controlled, and reversed with a predetermined sequence in a pneumatic system. Similarly one has to control the quantity of pressure and flow rate to generate desired level of force and speed of actuation. To achieve these functions, valves are used to-

(i) Start and stop pneumatic energy,
(ii) Control the direction of flow of compressed air,
(iii) Control the flow rate of the compressed air and
(iv) Control the pressure rating of the compressed air. A direction control valve has two or three working positions generally. They are neutral and zero position; and working position

Fig 3 shows the schematic representation of the pneumatic system deployed for the project.

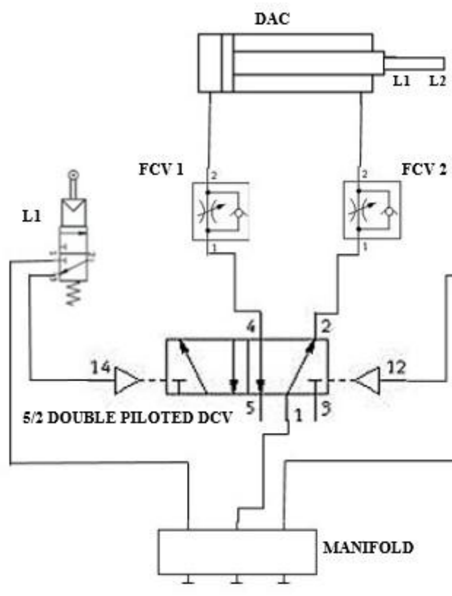

Fig 3. Schematic representation of pneumatic system

IV. CALCULATIONS

STARTING TORQUE REQUIRED

When selecting drive wheel motors for mobile vehicles, a number of factors must be taken into account to determine the maximum torque required. The following example presents one method of computing this torque.

Vehicle design criteria:

▪ Gross vehicle weight (GVW): 3924 N
▪ Radius of wheel/tire (Rw): 12 in
▪ Desired top speed (Vmax): 8.04672 kmph (2.23 mps)
▪Desired acceleration time (ta): 1 sec
▪ Maximum incline angle (α): 5^{O}
▪ Working surface: Asphalt (friction coefficient: mu=0.6)

To choose motors capable of producing enough torque to propel the example vehicle, it is necessary to determine the total tractive effort (TTE) requirement for the vehicle:

TTE [N] = RR [N] + GR [N] + FA [N]

Where:

TTE = total tractive effort [N]
RR = force necessary to overcome rolling resistance [N],
GR = force required to climb a grade [N],
FA = force required to accelerate to final velocity [N].

The components of this equation will be determined in the following steps.

Step One:

Rolling Resistance (RR) Rolling Resistance is the force necessary to propel a vehicle over a particular surface. The worst possible surface type to be encountered by the vehicle should be factored into the equation.

RR [N] = GVW [N] x Crr [-]

Where:

RR = rolling resistance [N]
GVW = gross vehicle weight [N]
Crr = surface friction
RR = 3924 N x 0.018 (asphalt – fair) = **66.708 N**

Step Two:

Determine Grade Resistance Grade Resistance (GR) is the amount of force necessary to move a vehicle up a slope or "grade". This calculation must be made using the maximum angle or grade the vehicle will be expected to climb in normal operation. To convert incline angle, α, to grade resistance:

GR [N] = GVW [N] x sin(α)

Where:

GR = grade resistance [N]
GVW = gross vehicle weight [N]
α = maximum incline angle [degrees]
GR = 3924 N x sin(5°) = **341.99 N**

Step Three:

Acceleration Force Acceleration Force (FA) is the force necessary to accelerate from a stop to maximum speed in a desired time.

FA [N] = GVW (N) x Vmax (m/s) / [9.81 (m/s^2) x ta (s)]

Where:

FA = acceleration force [N]
GVW = gross vehicle weight [N]
Vmax = maximum speed [m/s]
ta = time required to achieve maximum speed [s]
FA =3924 N x 2.23 m/s / (9.81 m/s^2 x 1 s) = **892 N**

Step Four:
Determine Total Tractive Effort – The Total Tractive Effort (TTE) is the sum of the forces calculated in steps 1, 2, and 3. (On higher speed vehicles friction in drive components may warrant the addition of 10%-15% to the total tractive effort to ensure acceptable vehicle performance.)

TTE [N] = RR [N] + GR [N] + FA [N]
= 66.708N + 341.99N +892N= **1300.69 N**

Step Five:
To determine Wheel Motor Torque to verify the vehicle will perform as designed in regards to tractive effort and acceleration, it is necessary to calculate the required wheel torque (Tw) based on the tractive effort.

Tw [N-m] = TTE [N] x Rw [m] x RF [-]

Where:
Tw = wheel torque [N-m]
TTE = total tractive effort [N]
Rw = radius of the wheel/tire [m]
RF = "resistance" factor [-]

The "resistance factor" accounts for the frictional losses between the caster wheels and their axles and the drag on the motor bearings. Typical values range between 1.1 and 1.15 (or 10 to 15%).

Tw = 1300.69 x 0.1524 x 1.1 = **218.047 N-m**

Step Six: Reality Check
The final step is to verify the vehicle can transmit the required torque from the drive wheel(s) to the ground. The maximum tractive torque (MTT) a wheel can transmit is equal to the normal load times the friction coefficient between the wheel and the ground times the radius of the drive wheel.

MTT = Ww [N] x μ [-] x Rw

Where:
Ww = weight (normal load) on drive wheel [N]
μ = friction coefficient between the wheel and the ground (~0.65 for Asphalt and rubber tyre) [-]
Rw = radius of drive wheel/tire [in]

Example: MTT = 3924 N x 0.6 x 0.1524 = **358.81 N-m**

Interpreting Results:
Total Tractive Effort is the net horizontal force applied by the drive wheels to the ground. If the design has two drive wheels, the force applied per drive wheel (for straight travel) is half of the calculated TTE.

The Wheel Torque calculated in Step Five is the total wheel torque. This quantity does not change with the number of drive wheels. The sum of the individual drive motor torques (see Motor Specifications) must be greater than or equal to the computed Wheel Torque.

The Maximum Tractive Torque represents the maximum amount of torque that can be applied before slipping occurs for each drive wheel. The total wheel torque calculated in Step Five must be less than the sum of the Maximum Tractive Torques for all drive wheels or slipping will occur.

EXPECTED RESULTS
REQUIRED TORQUE >= Total Wheel Torque
Thus, RT = 218.047 Nm; approx. = 220 Nm
Pneumatic Cylinder specs: Bore diameter: 100mm
Stroke Length: 300 mm

Assume maximum pressure = 7 bar (after losses)

Force transmitted by actuator
Fp = Pressure x Cross sectional area
= $(7 \times 10^5) \times (\text{pi}*0.1^2/4)$
= 5497.78 N

Torque transmitted = Force x perpendicular distance x Gear ratio
= Force x Radius of crank x Gear ratio
= 5497.78 x 0.045 x 2
= 494.80 Nm

Since torque transmitted is greater than the wheel torque, desirable motion can be achieved.

V. Conclusion

The goal of the project is achieved by using the methods and calculations as said in the paper. Four wheeler working on pneumatic supply helps us overcome the problems caused by fuel-powered vehicles such as pollution, etc.

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