Compressed air car

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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.

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The history of compressed air vehicles

One cannot accurately claim that compressed air as an energy and locomotion vector is recent technology. At the end of the 19th century, the first approximations to what could one day become a compressed air driven vehicle already existed, with the arrival of the first pneumatic locomotives. In fact, two centuries before that Dennis Papin apparently came up with the idea of using compressed air (Royal Society London, 1687). In 1872 the Mekarski air engine was used for street transit, 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, which ensured that the air was heated, by passing it through tanks of boiling water, which also increased its range between fill-ups. Numerous locomotives were manufactured and a number of regular lines were opened up (the first in Nantes in 1879). In 1892, Robert Hardie introduced a new method of heating that at the same time served to increase the range of the engine.

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. Figure 1 shows the early compressed air vehicles.

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. The H.K. Porter Company of Pittsburgh sold hundreds of these vehicles to the mining industry in the eastern United States, due to the safety that this method of propulsion represented for the mining sector. Later on, in 1912, the American's

Figure 1: Some early compressed air vehicles

Figure 2: MDI vehicles

method was improved by Europeans, adding a further expansion stage to the engine - 3 stages.

Compressed air technology

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 (Figure 2). The CATS (Compressed Air Technology System) “air car” 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. Costing next to nothing to run, the Zero Emission Vehicle (ZEV) range - which includes a pick-up truck and van - was released in 2005. Guy Nègre is the head of Research and Development at Moteur Developement International (MDI) cars, where the Zero Emission Vehicle (ZEV) prototype has been in production since 1994. The two-stroke engine is powered by compressed air stored in tanks at about 150 times the pressure in car tyres. The expansion of the compressed air drives the pistons to create movement, replacing the burning of fossil fuel in a conventional engine. In an air-refilling station (currently unavailable as service stations have not been fitted yet) it is estimated to take between three and four minutes to re-fuel. At home, with a 220V plug, it takes three and a half hours.

CAT vehicles have significant economical and environmental advantages. With the incorporation of bi-energy (compressed air + fuel) the CAT Vehicles have increased their driving range to close to 2000 km with zero pollution in cities and considerably reduced pollution outside urban areas. Also, the application of the MDI engine in other areas, outside the automotive sector, opens a multitude of possibilities in nautical fields, co-generation, auxiliary engines, electric generators groups, etc.

Compressed air is a new viable form of power that allows the accumulation and transport of energy. MDI is very close to initiating the production of a series of engines and vehicles. The company is financed by the sale of manufacturing licenses and patents all over the world. Table 1 lists the technical specifications of the vehicle.

Design of the compressed air vehicle

Compressed air engine

This engine was developed between the end of 2001 and the beginning of 2002. It uses an innovative system to control the movement of the 2nd generation pistons and one single crankshaft. The pistons work in two stages - one motor stage and one intermediate stage of compression/expansion. The engine has 4 two-stage pistons, i.e. 8 compression and/or expansion chambers. They have two functions: to compress ambient air and refill the storage tanks; and to make successive expansions (reheating air with ambient thermal energy) thereby approaching isothermal expansion. Figure 3 shows the compressed air engine.

Two technologies have been developed to meet different needs:

- Single energy compressed air engines; and
- Dual energy compressed air plus fuel engines.

The single energy engines will be available in both Minicats and Citycats. 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. The dual 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, bio-diesel, gas, liquidized gas, ecological fuel, alcohol, etc. Both engines will be available with 2, 4 and 6 cylinders, When the air tanks are empty the driver will be able to *switch* to fuel mode, thanks to the car's on board computer.

Engine working

Approximately 90m^3 of compressed air is stored in fibre tanks in the vehicle. The engine is powered by compressed air, stored in a carbon-fibre tank at 30 MPa (4500 psi). The tank is made of carbon fibre in order to reduce its weight. The engine has injection similar to normal engines, but uses special crankshafts and pistons, which remain at top dead centre for about 70 degrees of the crankshaft's cycle; this allows more power to be developed in the engine. The expansion of this air pushes the pistons and creates movement. The atmospheric temperature is used to re-heat the engine and increase the road coverage. The air conditioning system makes use of the expelled cold air. Due to the absence of combustion and the fact there is no pollution, the oil change is only necessary every 50,000 km.

Distribution and valves

To ensure smooth running and to optimize energy efficiency, air engines use a simple electromagnetic distribution system, which controls the flow of air into the engine. This system runs on very little energy and alters neither the valve phase nor its rise**.**

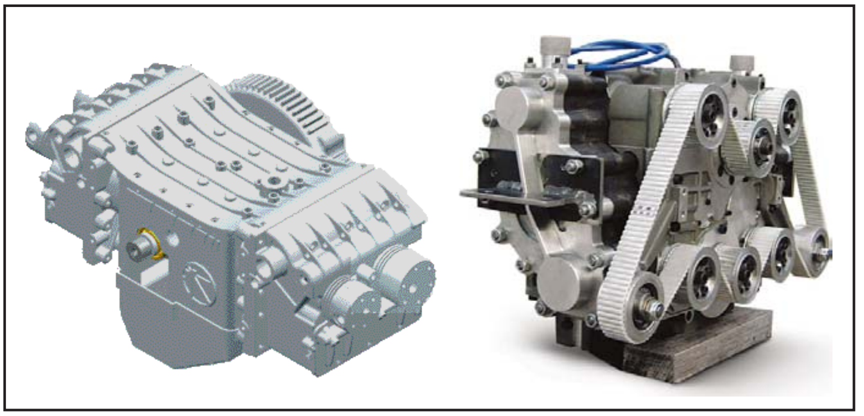
No clutch is necessary. The engine is idle when the car is stationary and the vehicle is started by the magnetic plate, which re-engages the compressed air. Parking manoeuvers are powered by the electric motor. The P04 engine is equipped with patented variable-volume butts and a dynamic variable-volume volumetric reducer. The engines can be equipped with and run on dual energies - fossil fuels and compressed air - and incorporate a reheating mechanism between the storage tank and the engine.

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, the compressor refills the compressed air tanks. The control system maintains a zero-pollution emission in the city at speeds up to 60 km/h.

Table 1: Technical specifications of a Minicat vehicle

		Mono-energy	Dual-energy 2	Dual-energy 4
Length	m	2.65	2.65	2.65
Width	m	1.62	1.62	1.62
Height	m	1.66	1.66	1.66
Number of seats	-	3	3	3
Luggage compartment volume	Dm^3	500/700	500/700	500/700
Weight	Kg	550	520	540
Engine	-	41P03	41P01	41P01/4
Power	cv	25	25	50
Max. speed	Km/h	110	125	140
Urban range (zero pollution)	Km	140/150	50	50
CO_2 emission in urban use	g/Km	0	0	0
Non-urban range	Km	80	1650	1500
Non-urban consumption (petrol)	litres	-	1.8	2
CO_2 emission in non-urban use	g/Km	0	35	40
Price (from) taxes included	• 9200			

Figure 3: Compressed air engine



Articulated con-rod

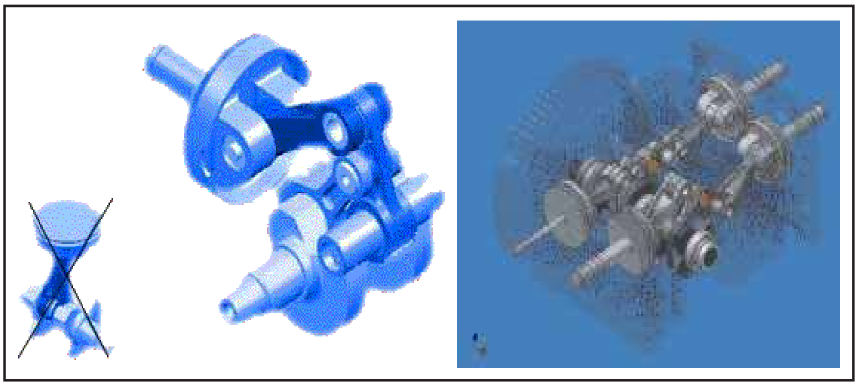
The MDI con-rod system allows the piston to be held at Top Dead Centre for 70^o of the cycle.This way, enough time is given to create the pressure in the cylinder. The torque is also better, so the force exerted on the crankshaft is less substantial. Figure 4 shows the articulated connecting rod and the drive train.

Gear box

Gear changes are automatic, powered by an electronic system developed by MDI. A computer which controls the speed of the car is effectively continuously changing gears. The latest of many previous versions, this gearbox achieves the objective of seamless changes and mimimal energy consumption. Its steering wheel is equipped with a 5kW electric moto-alternator. This moto-alternator connects the engine to the gearbox. It has many functions:

- It supports the CAT's motor to allow the tanks to be refilled.

Figure 4: Articulated connecting rod and drive train



- It starts the vehicle and provides extra power when necessary.
- As an alternator it produces brake power.

Additional features of the MDI car

- Light-weight: The vehicle has a fiberglass body, which makes it a light, silent urban car. The car's body is tubular, and is held together using aerospace technology. It can reach speeds up to 220 km/h (even though the legal limit is 120).
- It does not have normal speed gauges. Instead, it has a small computer screen that shows the speed.
- Its electric system is also revolutionary. MDI has bought a patent that is bound to reduce the importance of electrical systems in all cars. The trick consists in using a small radio signal. The system makes the car 20 kilograms lighter and considerably quieter.
- In the single energy mode, MDI cars consume less than one euro every 100 km (around 0.75 euros), that is to say, 10 times less than gasoline-powered cars.
- Its driving range is close to twice that of the most advanced electric cars (from 200 to 300 km or 8 hours of circulation). This is exactly what the urban market needs where, 80 per cent of the drivers move less than 60 km a day.
- The recharging of the car will be done at gas stations, once the market is developed. To fill the tanks, it will take about 2 to 3 minutes at a price of 1.5 euros. After refilling, the car will be ready to drive 200 kilometers. The car also has a small compressor that can be connected to an electrical network (220V or 380V) and will recharge the tanks completely in 3 or 4 minutes.
- Because the engine does not burn any fuel, the car's oil only needs to be changed every 50,000 km.
- The temperature of the clean air expelled from the exhaust pipe is between 0 and -15 degrees and can be subsequently channelled and used for air conditioning in the interior of the car.
- Advanced features such as GSM telephone systems, GPS satellite tracking systems, programmes for delivery people, emergency systems, Internet connections, voice recognitions, map presentation and traffic information can be incorporated.
- Regarding security, the seatbelt system is different from what is known. One part of the belt is anchored to the floor of the car, like traditional cars. The other part of the belt, instead of being attached to the side of the car, is also anchored to the floor of the vehicle. This helps to secure the bodies of the driver and passengers in the case of a collision.
- There are no keys - just an access card that can be read by the car from your pocket.

Safety features of the air car

The CATS air tanks store 90m^3 of air at 300 bars of pressure (four tanks have a capacity of 90 litres, and they store 90m^3 of air at a pressure of 300 bars), just like tanks already used to carry liquefied gases on some urban buses. That means that the tanks are prepared and certified to carry an explosive product: methane gas. In the case of an accident with air tank breakage, there would be no explosion or shattering because the tanks are not metallic but made of glass fibre. The tanks would crack longitudinally, and the air would escape, causing a strong buzzing sound with no dangerous factor. It is clear that if this technology has been tested and prepared to carry an inflammable and explosive gas, it can also be used to carry air.

In order to avoid the so-called 'rocket effect' (air escaping through one of the tank's extremities causing a pressure leak that could move the car), MDI made a small but important change in the design. Where the valve on the bus tanks are placed on one of the extremities, MDI has placed the valve in the middle of the tank reducing the 'rocket effect' to a minimum (Figure 5).

Air car in India

Tata Motors has signed an agreement with Moteur Development International of France to develop a car that runs on compressed air, thus making it very economical to run and almost totally pollution free. Although there is no official word on when the car will be commercially manufactured for India, reports say that it will be sooner than later. The car - MiniCAT - could cost around Rs 350,000 in India and would have a range of around 300 km between refuels. The cost of a refill would be about Rs 90. In the single energy mode MDI cars consume around Rs 45 every 100 km. Figure 6 shows the proposed air car for India. The smallest and most innovative (three seats, minimal dimensions with the boot of a saloon), it is a great challenge for such a small car which runs on compressed air. The MiniCAT is the city car of the future.

Other developments in compressed air car technology

Currently some new technologies regarding compressed air cars have emerged. A Republic of Korean company has created a pneumatic hybrid electric vehicle car engine that runs on electricity and compressed air. The engine, which powers a pneumatic-hybrid electric vehicle (PHEV), works alongside an electric motor to create the power source. The system eliminates the need for fuel, making the PHEV pollution-free. The system is controlled by an ECU in the car, which controls both power packs i.e. the compressed-air engine and electric motor. The compressed air drives the pistons, which turn the vehicle's wheels. The air is compressed, using a small motor, powered by a 48-volt battery, which powers both the air compressor and the electric motor. Once compressed, the air is stored in a tank. The compressed air is used when the car needs a lot of energy, such as for starting up and acceleration. The electric motor comes to life once the car has gained normal cruising speed. The PHEV system could reduce the cost of vehicle production by about 20 per cent, because there is no need for a cooling system, fuel tank, spark plugs or silencers. Figure 7 shows the PHEV in the Republic of Korea.

Figure 5: Position of air tanks in a compressed air vehicle

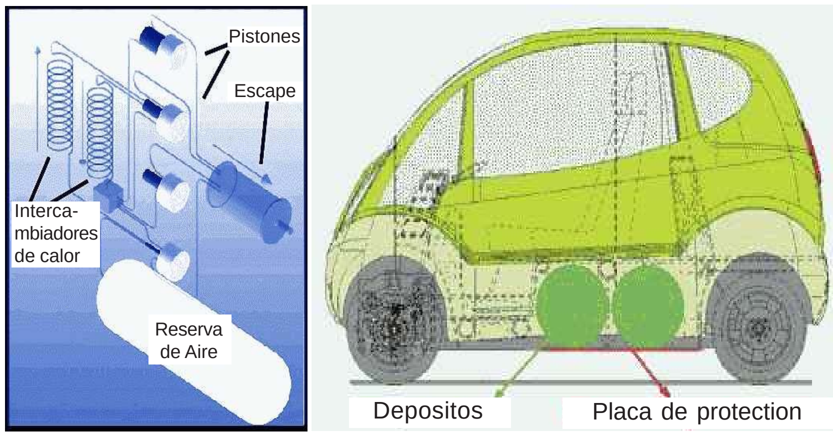


Figure 6: Compressed air car for India

Figure 7: PHEV in Republic of Korea

Well to wheel efficiency of a compressed air car

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 powertrain.

Conclusion

The technology of compressed air vehicles is not new. In fact, it has been around for years. Compressed air technology allows for engines that are both non-polluting and economical. After ten years of research and development, the compressed air vehicle will be introduced worldwide. Unlike electric or hydrogen powered vehicles, compressed air vehicles are not expensive and do not have a limited driving range. Compressed air vehicles 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 in cities. The emission benefits of introducing this zero emission technology are obvious. At the same time the well to wheels efficiency of these vehicles need to be improved.

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