

Compressed-air Conversion of Piston Engines for Zero-Carbon Emissions: Exploring the Applicability of Modification

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Abstract: - Electric mobility is widely featured as a solution to zero-carbon transportations. Nevertheless, this approach poses two major problems internationally; the first one is the cost of replacing the vast number of internal combustion engines globally; the second one is that efficient electric motors require a substantial amount of Neodymium, which is a rare earthy material, especially considering the first problem. Therefore, regarding zero-carbon transportations, a technically feasible and economical solution would be the conversion of existing internal combustion engines in order to function with zero-carbon emissions. Accordingly, two such historical cases are reviewed, the compressed-air conversions of existing piston engines and the inert gas chambers, while the mechanical process of converting a small two-stroke engine is presented, to explore the applicability of such modification.

Key-Words: - Internal Combustion Engine, Piston Engine, Reciprocal Engine, Compressed Air, Inert Gas, Air Plasma.

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1 Introduction

This paper presents research and methods on how non-combustible gases, as a form of energy, can contribute to the transition from polluting hydrocarbon consumption to clean and sustainable forms of energy, through the conversion of existing internal combustion engines. In this respect, electric mobility is widely featured as a solution to zero-carbon transportations. Nevertheless, this approach poses two major problems internationally; the first one is the cost of replacing the vast number of internal combustion engines globally; the second one is that efficient electric motors require a substantial amount of Neodymium, which is a rare earthy material, especially considering the first problem. Therefore, regarding zero-carbon transportations, a technically feasible and economical solution would be the conversion of existing internal combustion engines in order to function with zero-carbon emissions.

As a proof-of-concept, in this research, a low-power engine was converted to operate with compressed air. The construction uses a 60cc motor, which has been manufactured and is used in mopeds or small motorcycles, while the study also includes some technical measurements after the conversion. The scope of this conversion was to explore the applicability of the modification process, especially in the premises of a machinery-shop by a small team of technicians, which is the standard process for Liquefied Petroleum Gas (LPG) or Compressed Natural Gas (CNG) customized fueling conversions. Although the comparison of performance issues is well addressed by other studies (see subsection 2.1.4. Current Trends, and chapter 4. Discussion) in theoretical/mathematical and technical details, the technical applicability of such modification is rarely discussed.

2 History

Attempts to convert existing internal combustion engines to use non-combustible gases have a history of almost a century, with patents as early as 1936, namely that of Bob Neal [1]. This is a piston engine that, while operating, constantly maintains its own compressed air tank at full capacity (Figure 1), according to the inventor's claims.

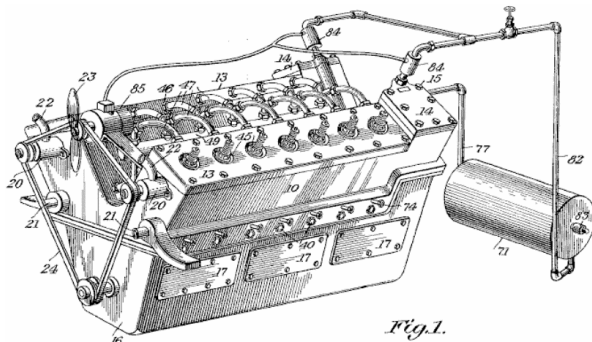


Fig. 1: Bob Neal's compressed-air engine [1].

The engine acted as a heat exchanger. Neal developed a valve that allowed to put low-pressure air into a high-pressure tank (Figure 2), and designed his engine in such a way that any previous air that entered was compressed again to a higher pressure. The tank in which the pressure was accumulated was designed so that it could retain the heat of recompression.

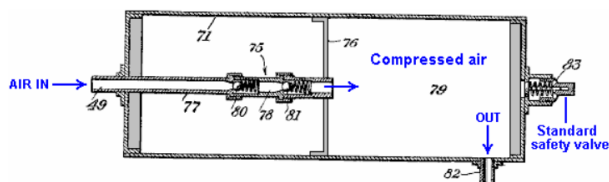


Fig. 2: A vertical longitudinal cross-sectional view of the air storage tank that includes the equalizer [2] (p. A-737).

This patent was awarded [3], however, no commercial engine was ever built, but it historically delimits the usage of compressed air in common liquid-fueled reciprocal engines, compared to other types of engines (rotary, external combustion or hybrid ones). Details of implementation are openly available at [1, 2].

2.1 Compressed-air Reciprocal Engines

Even after 50 years, we still didn't know how Bob Neal's engine worked. Then, an inventor named Leroy Rogers presented a similar patent, while later on, in 2009, Scott Robertson, using modern materials and technologies, built what Bob Neal had created with much more primitive tools a long time ago. Even

commercial proposals for a French-designed car that's propelled by compressed air appeared at about the same time. Interest in this particular category of engines remains strong today, due to the environmental pressures for cleaner forms of energy. More details of implementation are openly available at [2], with the exception of the Air Car (subsection 2.1.3).

2.1.1 The Air-System of Leroy Rogers

Inventor Leroy Rogers presented a patent on converting a conventional reciprocating engine to run with compressed air [4]. According to the description of the patent's abstract, the device consists, among others, of:

"A supercharger for delivering supercharged air to an engine, comprising a shrouded axial compressor, a radial compressor which is located downstream of the axial compressor and a housing. The housing is comprised of four sections, including a section which is a highly converging, 'frustoconical' transition duct which favourably directs the discharge of the axial compressor to the inlet of the radial compressor and a hollow, highly convergent, exhaust cone section immediately downstream of the radial compressor which converges into the exhaust port of the supercharger. An annular flow deflector is provided for directing the discharge of the radial compressor into the exhaust cone" (Figure 3).

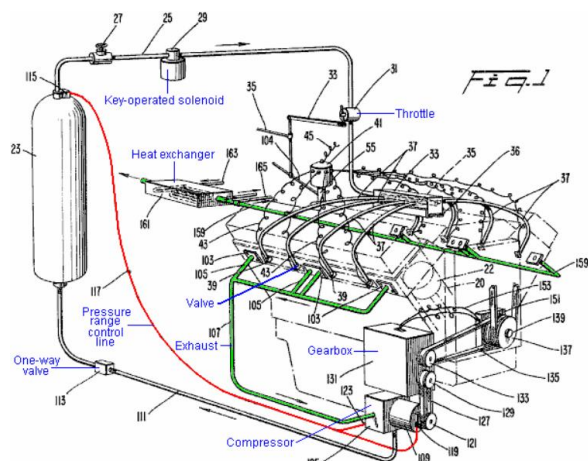


Fig. 3: The adapted engine of Leroy Rogers [2] (p. 8-8).

This patent presents detailed drawings for manufacturing crucial devices for this conversion that include the supercharger, the bearing supports, the axial compressor and the radial compressor. In addition, there are commercially available components, like the roller bearing assemblies.

2.1.2 The Compressor of Scott Robertson

This installation initially includes a standard air motor that operates on compressed air from a pressure tank. The motor expels the cooled compressed air into the atmosphere as it operates. The motor powers two compressors, which work together to maintain a supply of compressed air from the tank (Figure 4).

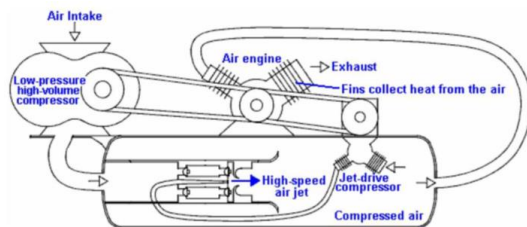


Fig. 4: The overall construction of the engine of Robertson's compressor system [2] (p. 8-4).

The initial compressor is like a leaf blower, which produces a large volume of low-pressure air. The low-pressure air is then directed into a low-pressure area, where a metal cap separates it from the high-pressure area. This cap has a ring of five one-way air valves, which allow the low-pressure air to enter the high-pressure area, due to the creation/jetting of high-speed air produced by the "Jet-drive" compressor (Figure 5). The high-speed air is directed through a specially designed nozzle ("High speed air jet"), to create a low-pressure zone around the nozzle. There, one-way non-return valves allow the low-pressure air to pass into the low-pressure area. The high-speed air produced by the "Jet-drive" compressor then presses the air into the high-pressure area. The rapid movement of the ejected air creates a vortex, causing the formation of a low-pressure circuit, before the high-pressure area. In this way, we can achieve the transfer of large quantities of low-pressure air into a tank containing high-pressure air. Thus, we have the construction of a machine with 100 psi air intake to the engine at $0.56 \text{ m}^3/\text{min}$, where this pressure is increased to such an extent that allows it to utilize the same input volume, but with a self-feeding pressure, which is 8-12 times higher than the initial input value. Therefore, with the valve that allows the low-pressure air to pass into the high-pressure air compartment, the tank can be filled and the engine can rotate in parallel. The machine costed 7,500 dollars to build and managed to have a continuous production of about 45-48 kilowatts of power, in closed-loop mode, without any input from the user [5].

2.1.3 The Air Car

We will now look at the production of a French-designed car (Figure 5) that was designed to run on compressed air, and it is claimed that it could reach speeds of over 100 km/h. While production was planned to begin in 2008, the technology's capabilities were questioned by scientists, and it was never completed. They argue that although compressed air produces zero emissions, it will not offer enough range or speed to appeal to the general public.



Fig. 5: The MiniCat compressed-air car [6].

The company, Motor Development International (MDI), worked for many years to bring this car to market, partnering with the Indian-based Tata company, which invested \$30 million USD in the development of the car. In 2010, the first designs for the car included a four-piston engine, powered by compressed air, which is stored in high-pressure tanks. The tanks are lightweight and made from a thermoplastic container enclosed in a carbon fiber shell.

To propel the vehicle, compressed air is channeled from the tanks into a small chamber, where it expands and cools. This expansion drives the piston down. However, as the ambient temperature begins to reheat the air in the chamber, this air will be channeled into a second, adjacent chamber, where it will expand again to drive the piston up. Using ambient heat helps improve efficiency and extends the car's range.

The main problem with this technology is that air heats up when compressed, so, much of the energy consumed goes into raising its temperature. Then, although the autonomy of the vehicle could reach 200 kilometers when moving in an urban environment, this range is reduced to 80 kilometers when the car moves at speeds higher than 100 km/h. Then there is the difficulty of building compression stations, as today's gas stations are not capable of supplying such quantities of air. Of course, if the compressors at the stations were able to compress and store air only during off-peak hours or when solar and wind energy are in abundance, then we would have sustainable transportation, without the need for fossil fuels.

The Air Car appeared to have prospects only as a short-distance vehicle, due to its short range, for use only in urban environments. It could be addressed to environmentally sensitive owners, but not to the general public. Also, the major car manufacturers did not show interest in building it. So, the plans to have a car running on air never came to fruition.

2.1.4 Current Trends

The MiniCat (Figure 5) reached the prototyping stage. Despite its commercial failure, the interest in compressed-air engines didn't decreased, due to the increasing concern on the acute environmental conditions, especially the human-made pollution and the climate change [7]. In this respect, proper material (e.g., for the air-tanks), features, advantages and disadvantages of compressed-air engines are studied and commented [8]. Extensive theoretical/mathematical analysis, modelling of components and studies on performance are conducted [9]. Various designs are studied that also include rotary engines and/or hybrid power systems (e.g., coupled with natural gas or electric motors) [10]. Notably, other working fluids have been proposed, besides compressed air, for converting a reciprocal engine, as well [2] (pp. 8-25 – 8-37).

2.2 Other Working Fluids

The proposals for other working fluids, besides compressed air, for converting a reciprocal engine, include inert gases, air-plasma and other non-combustible gases. Details of implementation are openly available at [2].

2.2.1 Conversion to Inert Gas Engine

Josef Papp, an inventor of Hungarian origin, originally converted an existing 4-cylinder, 90 HP Volvo engine to run on a mixture of inert gases that contained by volume a fixed amount of 17% argon, 13% krypton, 36% helium, 26% neon, and 8% xenon. According to his unverified claims, the engine generated a constant output of 300 HP at 4,000 rpm, during a 35-minute test in a closed room. The patented modification (Figure. 6) has no air intake, no exhaust, no inlet or exhaust valves. These components are removed and the engine head is replaced with his devices. The control system drives the pistons down to the cylinders by expanding the contained mixture of inert gases, and then suck the pistons back up the cylinders by contracting it, having so zero pollution emissions. Interestingly, this type of engine is quite capable of operating under water [2] (p. 8-25).

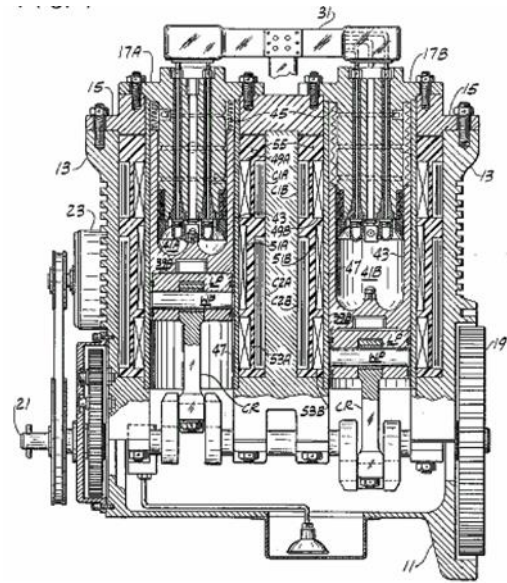


Fig. 6: A cross-sectional view of the inert gases' engine [11].

2.2.2 The Plasmic Transition Process Motor

Inventor John Rohner, a well-known new-product design engineer, expanded the idea of Josef Papp, previously, in PlasmERG Inc., as a "Plasmic Transition Process" (Figure 7). Two motors for "Own-Equipment-Manufacturers" were designed: a 2-cylinder 120 cubic inch engine, producing 300 HP, and a 6-cylinder 360 cubic inch engine, producing around 1,500 HP. A single inert gas charge allows over 3 months of continuous operation of a motor, while the gas re-charge is estimated to cost less than US \$50 [2] (pp. 8-26 – 8-27).

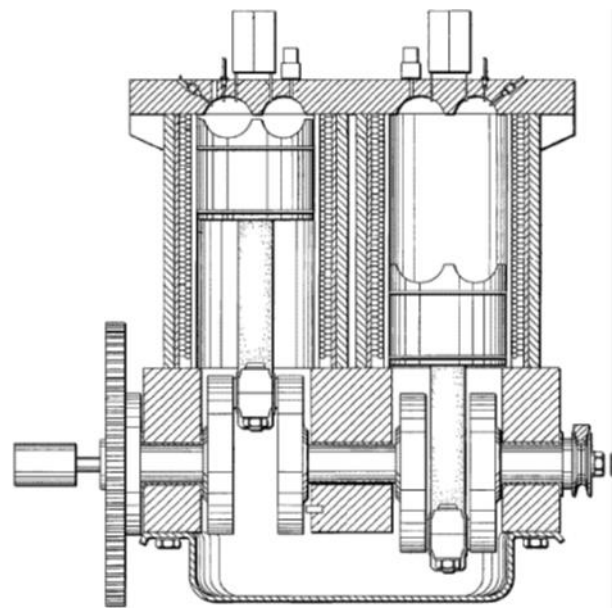
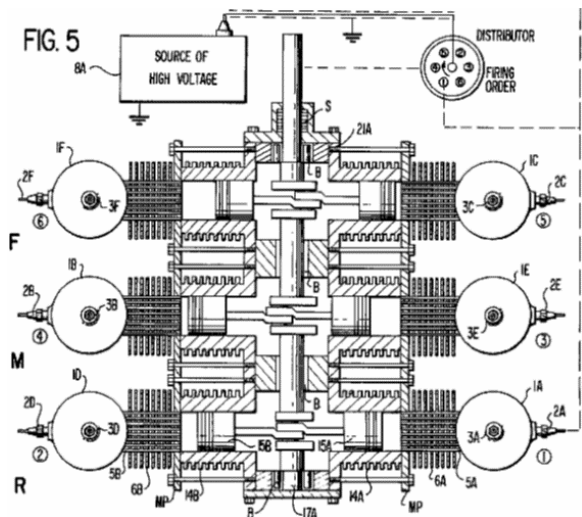


Fig. 7: An example of a 2-cylinder PlasmERG motor [12].

2.2.3 The AEROPS Engine

Inventor Robert Britt designed an inert gas motor, very similar to that of Josef Papp (Figure 8). This motor can be replicated by using a Chevy “Monza” 6-cylinder engine or a Volkswagen 4-cylinder engine [2] (p. 8-28). According to the abstract of AEROPS engine [13]: “An engine is provided which will greatly reduce atmospheric pollution and noise by providing a sealed system engine power source which has no exhaust nor intake ports. The engine includes a spherical hollow pressure chamber which is provided with a reflecting mirror surface. A noble gas mixture within the chamber is energized by electrodes and work is derived from the expansion of the gas mixture against a piston”.



motorcycle of the time, the Honda C50, for which we have the official characteristics [16, 17], we will see that our engine has many similarities in the performance and the top speed it offers, and confirms the sellers' claims on horsepower. The engine is lubricated by adding oil to the gasoline, which pass together into the combustion chamber and burned. As a result, it causes further pollution, a strong suffocating smell, and reduced visibility due to the white smoke produced by the combustion of the oil, and is emitted from the exhaust. We also know that the engine weighs about 8 to 9 kilograms, has satisfactory power for its weight, perhaps it is the advantage of the two-stroke engine, but it is characterized by its high consumption in relation to its horsepower. The article in [18] refers to the 50% greater consumption of the two-stroke, but in our case, the difference is even greater, due to the older design and the loss of the return that leads the unburned, unused gasoline back into the atmosphere.

Having described the engine we have to convert, and having understood its operating principle, and with experience in both use and maintenance, we can think of a way, a method, that this particular engine could operate with compressed air. It is worth mentioning that although there are various applications on the internet that may refer to similar conversions, none of them concern this particular engine. Its choice was made purely due to its pre-existing use, its repair and operation experience, as a means of transportation. The method followed was discovered after experimentation and dealing with emerging difficulties, as there were no steps or guides for construction. However, in this text we will describe the steps we followed to convert an engine that was designed to run on gasoline, in order to run on compressed air, as we will also refer to the difficulties we faced, and how we finally overcame them. Thus, the next section concerns the conversion of the engine.

3.2 Implementing the Conversion

In order for a piston engine to work, we must have a sequential rise and fall of the piston [19]. To achieve this, we must now design the new times, the new processes that will drive the piston up or down. With gasoline we had the ignition that drove the piston down, with enough force to produce work, rotate the crankshaft, and be able to compress the new mixture so that it can be ignited again at top dead center. In our case there is no ignition, but just as ignition gives energy at top dead center, so we must supply air under pressure to force the piston down, producing energy, while we must stop supplying air when the piston has descended, because it will stop at bottom

dead center, and we will not have engine rotation. In fact, in the first tests we did by giving compressed air to the engine, we observed exactly this. The piston would go down and stay there, since the air continued to push against it, as the piston tried to go up, and prevent so the crankshaft from turning.

So, the solution to our problem is a construction that will allow compressed air to enter the cylinder and push the piston down, but will cut off the air supply when the piston goes down, so that it can now move up and complete its rotation. The two new strokes are the first, when the piston goes down and we have the energy production, which will rotate the crankshaft, forcing the piston to go up in the second stroke from the rotation of the crankshaft. Specifically, in the first stroke, and as the piston passes top dead center and goes down, the air valve will open, driving the piston down. As the piston goes down, it will pass through the scavenge-fill and exhaust ports, opening them. Once these ports are opened, the air will come out of them. It is at this point that force stops being exerted on the piston, as we will have a release of the pressure that drives the piston downwards, because the compressed air will pass into the atmosphere, either through the exhaust valve, or through the scavenge-fill ports that lead to the crankcase, to which we will have an exit from the carburetor port.

From the first time we can see that our construction must supply air from the point where the piston passes the top dead center, to the point where the ports in the cylinder open. In the second time, that is, from the point where the piston passes the bottom dead center, until it rises, the energy exerted on it comes from the first time, that is, the force exerted on the piston to go down. However, as it rises, it will again pass through the cylinder ports, closing them. At this point, the air inside the cylinder and in the tube leading from the head to the air gun will be slightly compressed, as the available space decreases, due to the rise of the piston, and the air gun valve and the cylinder ports have closed. So, the air has no outlet, cannot be channeled to/from anywhere, and will be slightly compressed, adding a small, negative work to the engine. The reason we mention a small negative work is because of the choice of a long tube connecting the head to the air gun, thus giving the air enough space to compress, which means a lower degree of compression, therefore less negative work and less power loss.

The construction logic that we used, after experimentation on this particular engine, is that we fixed an air-gun on the engine body, at a point where the gun-valve can be mechanically pressed by an "almond" (shaped piece), located on the crankshaft

extension. The *almond* is designed to press the gun-valve to open, as soon as the piston passes top dead center, and to close it as soon as the piston passes the point where the engine's scavenging-filling and exhaust ports are located.

In piston engines, the position of the crankshaft determines the position of the piston in the cylinder and vice versa, as there is a mechanical engagement of these through links [19]. In our construction, we will note the position of the crankshaft that is immediately after the top dead center, and the position of the crankshaft where the piston passes the scavenging-filling and exhaust ports of the cylinder. Knowing these positions, we can place and design the *almond* appropriately, so that it presses and releases the gun-valve at the right time. So, in the first stages of construction, the steps we followed to fix the air-gun, near the crank extension, are described, in order for the *almond* that we will place on the crank extension to be able to open the air-gun-valve. After many parameterizations and changes, the result is shown in the image below (Figure 10).



Fig. 10: The position of the air-gun, attached to the engine body (yellow arrow), and the almond that is screwed onto the crankshaft extension (red arrow) [3].

As shown in the photo above (Figure 11), the air-gun is placed on a metal plate, and is clamped and immobilized on it with two metal clamps that hug and fasten it. To make the base, we used a pair of scissors for cutting metal. Then we placed the base near the engine, and drilled the places where the metal clamps will pass. Since we have now immobilized the air-gun with the metal clamps, we marked the places to drill them, placing the plate over the screws. Then we made the *almond* as follows:

- We took a washer and a wire.
- Then we bent the wire, so that the two bent sides touch the ends of the washer.

- Using an electric soldering iron, we glued the two metals, the wire and the washer.

To complete the *almond*, we had to cut off the extensions, as shown in the left photo, below (Figure 11a). Thus, we have completed the construction of the *almond*, but it remains to place it on the crankshaft extension. To place it we took a long screw and tightened the almond between two countersunk nuts, as shown in the right photo, below (Figure 11b). Then we tightened the screw where the almond is located on the crankshaft extension.



(a)



(b)

Fig. 11: Making the almond: (a) The wire and the washer glued together; (b) The almond tightened between two countersunk nuts on a long screw [3].

The spark plug was removed, which in gasoline mode was the NGK bp8hs, while we removed the head in the first stage to configure it, placing an air-fitting on it. Then, we removed the cylinder to remove the springs that seal the piston, because we noticed more power in the engine after their removal, in air mode. The next photo on the left (Figure 12a) shows the placement of the cylinder, as it passed through the piston, and the long screws of the engine body. In the next stage, we place a flange between the cylinder and the head. By the way, in this particular engine we do not have guides between the cylinder and the head, as we have observed in the past in other engines. In the last stage, to complete the mechanical construction and install the air, we pass a tube, in black, as shown in the right photo below (Figure 12b), to connect the air-gun to the head. There, we see the black tube connected, as well as the gray tube that we have connected to the compressor, which we have set to 100 psi, and are feeding the air-gun.

Finally, to complete the engine conversion, we need to time it. To achieve this, we need to let the compressed air pass into the cylinder, as soon as the piston passes top dead center, and stop supplying air when the piston passes through the cylinder's scavenging-filling ports and opens them. To achieve this, we need to rotate the *almond* in relation to the crankshaft extension. Here, we know that the position

we chose to place the *almond* may not be the right one or may not offer the greatest efficiency. So, we tried rotating the *almond* slightly in relation to the crankshaft, and we noticed that when we rotated it clockwise, so that the *almond* presses the valve earlier, we observed greater efficiency. There, we tested it several times, each time rotating the *almond* with a very small step, until we reached a point where whether we rotated the *almond* counterclockwise or clockwise, the engine's performance would be less. The observed efficiency during this trial-and-error phase was measured as explained in the next section (3.3. Evaluation of Performance).

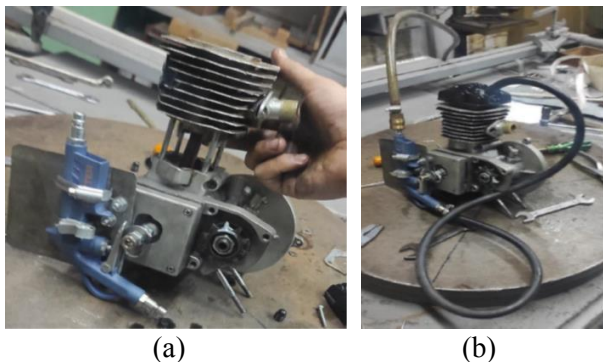


Fig. 12: The completed mechanical construction: (a) The placement of the cylinder; (b) Connecting the air-gun to the head [3].

At this point, we have officially completed the conversion of our engine, and we let it rotate long enough to identify any damage or problems in its operation. The engine seems to be operating normally, nevertheless, it is not known at this stage how these modifications affect long-term engine durability, compression leakage, or internal friction. These aspects require long-term monitoring of the engine's function, which is planned for the near future. So, we are ready now to continue to the next section, which is the power measurement, that is, to measure its operation in air mode, with the aim of testing the functionality of the mechanical parts (pistons, *almond*, connections, etc.). Any evaluation regarding applied thermodynamics issues was out of scope at this stage of the research project, scheduled though for next stages.

3.3 Evaluation of Functionality

In this section we will explain how we dynamized the engine in air mode. We clearly have not mounted it on a vehicle to know the top speed or acceleration, but we made torque measurements at the corresponding rpm, to find the power in HP or kW.

According to [20], to find the horsepower of an engine, we need to know the rpm it is rotating at and the torque it has at that rpm. Then we find the power, using the formula:

$$H = (T \times \text{RPM}) / 5252 \quad (1)$$

where "H" is the horsepower, "T" is the torque in pound-feet (lb-ft), "RPM" is the engine's revolutions per minute, and "5252" is a constant used in the equation ("formula H").

In [21], we can see that vehicle manufacturers declare the maximum horsepower at the crankshaft, which, according to [22], is not objective, and the power at the wheel is recorded in the vehicle's dynamometer. By the term maximum horsepower, as we can conclude from the graphs in [23], we mean the maximum value that is distinguished in the power-torque graph, which results from the vehicle's dynamometer. So, we will have to measure torque and rpm. For rpm, the solution we thought of is to videotape the engine as it rotates and then play this video at a lower playback speed, so that we can measure and record the rpm at a specific time. Recording the torque was clearly more difficult. We had to use a device that would controllably "brake" the engine, forcing it to produce work, while at the same time recording this work, without stopping the engine. The solution we used is the clutch, which in gasoline mode allowed us to isolate the engine's operation, so that its operation was not transferred to the wheels. Thus, by analyzing the operation of the clutch [24], we applied a technique that allows us to obtain an indication of the torque in the engine. Initially, we took a torque wrench, a tool that can measure torque, and placed it on the engine's drive gear, as shown in the following photo (Figure 13).



Fig. 13: Measuring torque [3].

Here, when the engine exerts torque on the output gear, the torque wrench will be able to record this torque, after taking many measurements. Then, with the ability given to us by modern technology, we can record video with many frames per second [25], so that when we play the video at a lower speed, we can clearly see the rotations of the crankshaft and record

them accurately (Figure 14). It is worth noting that in all the measurements we recorded, the tank pressure is set to 100 psi. So, the best measurement we recorded for the engine in air mode is with 564 rpm on the crankshaft, while on the gear it is: $564/4=141$ rpm.

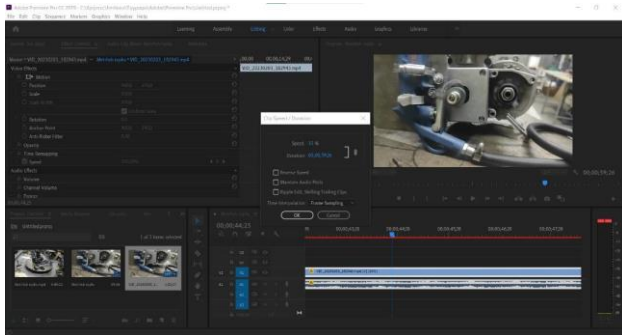


Fig. 14: Video recordings [3].

The maximum torque we recorded, if we zoom in 400% on the video, is close to 10 N.m, while if we observe the video, we will see that the torque momentarily reaches 10 N.m. To find the power, we will apply the H formula (1). Initially we have recorded 141 rpm on the gear and 10 N.m of torque. Since the formula refers to lb-ft units, we will have to do the conversion. So, for the torque we will have:

$$T = 10 \times 0.73756214927727 \text{ N.m} = 7.3756214927727 \text{ lb-ft} \quad (2).$$

The horsepower that the engine can produce after the conversion is:

$$H = (7.376 \times 141)/5252 \text{ HP} = 0.198 \text{ HP} \quad (3)$$

that is, 0.2 horsepower.

To also find the power (P) in kW, and since we have the power in HP, we will multiply this power by the factor 0.73549875 [3]. So, the power in:

$$P = 0.2 \times 0.73549875 \text{ HP} = 0.14709975 \text{ kW} \quad (4)$$

therefore, the engine produces a power of 0.2 HP or 0.15 kW.

It is worth noting that the indifferent results of performance that we obtained (i.e., the 95% reduction of power, from the initial 4 HP to 0.2 HP) from the improvised measurement were as expected, given the very low performance of the compressor connected, merely for experimental purposes. Namely, the compressor connected was a commercial model for painting or cleaning duties and not a dedicated for this purpose tool (see next section), while its usage meant to test the functionality of the modification, regarding both the standard and the fabricated mechanical parts (pistons, *almond*, connections, etc.).

4 Discussion

The presented herein experiment proved the relatively easy engineering process of converting an internal combustion piston-engine that burns gasoline to run with compressed air. The technical focus in this case is on the compressed air storage technologies. Recent developments in compressed air energy storage have reached 3.6 MJ/m³ and 2.7 MJ/kg, which is four times the capacity factor of lithium-ion batteries [26]. In 2020, a compressed-air vehicle prototype, developed in Ontario Tech. University (Oshawa), incorporates a novel compressed air system of low-pressure air tanks, exhaust air recovery and materials for heat recovery purposes. The performance achieved includes:

- an energetic efficiency of 59.5% and an exergetic efficiency of 51.0%;
- a maximum torque between 21 and 44 N.m and a minimum torque between 3 and 13 N.m, both with changing shaft speed from 400 to 1300 rpm;
- a supplementary battery power of 2.18 kW;
- a turbine work output of 1.25 kW;
- a total motor work consumed during operation of 18.36 kW;
- a range of 140 km (87 miles);

which is acceptable for a small-size city vehicle [27]. Yet, the overall environmental impact depends on the way that the compressed air is generated. Considering the whole energy chain, zero-carbon emissions can be achieved only if the compressed air is generated by renewable energy sources (RES).

The conversion of fossil-fueled engines to compressed-air ones, besides the obvious associated environmental concerns, addresses also some more specialized issues, regarding mission requirements and manufacturing processes. Considering the first issue, there is a global interest in the optimum design and construction of unmanned aerial vehicles that includes concerns for environmental-friendly applications [28]. In this case, very desirable operational requirements are the low-weight and low-noise vehicles. Compressed-air engines offer low-noise levels of operation, comparable to these of electric motors, yet with less weight due to the absence of batteries. Considering the second issue, i.e., of manufacturing processes, the need for making customized items for the modification of piston engines, e.g., like the *almond* (presented previously herein), can be met via additive manufacturing. Compressed-air engines exhibit considerably lower temperatures of function, which permits a more extensive usage of 3D-printed materials. This particular manufacturing trend is also of major concern for unmanned aerial and ground vehicles

[29], due to its implementational convenience and customization abilities. Such materials cover a satisfactory range of properties, like chemically resistant, composite, dissolvable, elastic, fatigue resistant, flexible, heat resistant, heated bed not required, impact resistant, rigid, soft, UV resistant and water resistant [30], while, depending on the particular application and desired features (e.g., strength, density, stiffness, etc.), include carbon fiber and metals [31].

5 Conclusion

For the present work, the conversion of a gasoline engine to operate with compressed air, we used an engine that we have used as a means of transportation for a long time. Here the first conclusion is that in order to convert the operation of an engine or to change its function, it is necessary to add or configure parts to it. To configure parts and add components, a number of tools were needed, which require protection measures and experience. Metallic parts were also needed to be reconfigured and placed in the engine. Based on the above, we can conclude that the use of compressed air can provide solutions in a massive scale, and contribute to the transition to cleaner, non-polluting forms of energy, through a modification process that is no more technically difficult than Liquefied Petroleum Gas (LPG) or Compressed Natural Gas (CNG) fueling conversions.

Our final impression from this work is that converting piston engines to run on compressed-air is worth-studying for rather low-power applications that may include small-size city vehicles [27] or anything similar, like a household generator, for storing the excess energy from RES. More power-demanding installations, as for example the compressed-air storage installations at Hundorf, Germany, require a whole different approach. There, an underground cave of 300,000 m³ volume stores compressed-air at 70 atm that may run a turbine of 300 MW for two (2) hours [32].

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) utilized artificial intelligence (AI) technologies solely for the purpose of linguistic refinement and grammatical correction. Following the application of these tools, the author(s) comprehensively reviewed, verified, and edited the resulting text. The author(s) maintain full accountability and responsibility for the accuracy, integrity, and final content of the publication.

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