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CONVERSION ANALYSIS OF A FOUR-STROKE TO A TWO-STROKE INTERNAL COMBUSTION ENGINE

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Abstract. *Nowadays, the most used engine in vehicles in the world is the four-stroke engine; however, the two-stroke engine has higher specific power, since it has fewer cycles. However, the conventional two-stroke engine exhibits a high rate of pollutants emission and fuel consumption; additionally, its lubrication is precarious, which decreases its durability. The present work proposes a change of a conventional four-stroke engine to a new version of a direct-injection supercharged two-stroke engine in a way which allows for an increase in power, characteristic of the two-stroke engines, as well as greater durability, such as of four-stroke engines. The proposal is made by altering the opening and closing times of the engine valves and adding a turbocharger. This prevents the unreacted fuel to be exhausted with the flue gases, and it allows the lubrication to be done as in a four-stroke engine. The ideal air-standard thermodynamic cycle was the tool employed to access the power gains of the two-stroke engine proposed in this paper in comparison with the four-stroke engine with the same dimensions, a 0.999-liter three-cylinder engine. The analyses demonstrated that the four and two-stroke engines power at a rotation of 6250 rpm could be estimated at 56.0 and 92.7 kW, respectively, which represents a 65.5% increase in power.*

Keywords: *Internal Combustion Engine, Two-Stroke Engine, Four-Stroke Engine, Thermodynamic Analysis.*

1. INTRODUCTION

In internal combustion engines, the working fluid burns within the boundaries of the system (Çengel, 2006). At present, automobile generally uses four-stroke engines instead of a two-stroke engine because the pollutant emissions levels, fuel consumption, and efficiency of the latter are less than the former. However, the two-stroke engine has the advantage of a higher number of cycles per unit of time, which creates a higher specific power.

These devices are thermal machines that turn heat into work. In two-stroke combustion engines, the cycle is completed with two piston strokes, or one crankshaft revolution. The most common operation idea behind the two-stroke engines is as follows: in the first stroke the ignition happens and the piston is pushed toward the bottom dead center (BDC) turning the crankshaft and at the same time compressing the air below it, present in the engine crankcase. In this downward path, the piston first allows the flue gases to exhaust into the atmosphere and then opens the inlet channel, which connects compressed air to the sump with the combustion chamber (Brunetti, 2013). In the second stroke, the piston has an upward movement, from the bottom dead center (BDC) toward the top dead center (TDC). In this movement, the piston closes the exhaust channels and creates a suction, due to a pressure drop in the crankcase, which fills the crankcase with a new air/fuel mixture. Simultaneously, the piston compresses the mixture above it.

The higher levels of pollutant emissions and fuel consumption of the two-stroke engine is because a portion of the flue gases and fresh gases (air and fuel) occupy the combustion chamber at the same time. Thus, part of the fresh gases is released by the exhaust without being burned and part of the flue gases remains in the combustion chamber (Martins, 2005). Another negative aspect is the its poor lubrication, since it must be done by spraying, once it is not possible to use the crankcase as a lubricant reservoir, which results in the lubricant being burned together with the fuel (Brunetti, 2013). However, an advantage of the conventional two-stroke engine is the elimination of the four-stroke engine valve system, since the intake and exhaust are made by openings in the cylinder (Martins, 2005).

New technologies have been developed to combine the simplicity and high power characteristics of two-stroke engines with the durability of four-stroke engines. However, research is needed to improve efficiency, economy and reduce the emission of pollutants of the two-stroke engines. According to Pocha (2011), which patented a turbocharging system for use in two-stroke engines, the use of a turbocharging system is indicated to increase the efficiency.

The present work proposes a change from a conventional four-stroke engine to a new version of two-stroke engine with direct injection and supercharging, which will allow a higher power, characteristic of the two-stroke engines, as well as the safety and durability of the four-stroke engines. The understanding of the behavior of the working fluid (air, fuel and flue gases) in this new engine version, as well as the constructive changes necessary to make the engine functional, is fundamental to enable its use on a large scale. To do so, the original four-stroke engine and the new version of the two-stroke engine thermodynamics cycles were compared.

2. METHODOLOGY

The present study is based on the work of Park (2009) who initially proposed an adaption of a four-stroke to a two-stroke engine. First, the selected four-stroke engine for the analyses was the 0.999 litters three cylinder engine VW® UP!®, which features are presented in Tab. 1.

Table 1. UP!® 1.0 engine features. Source: Available from: http://download.uol.com.br/carros/fichatecnica_up.pdf.

Displaced volume (cm^3)	999	Bottom Dead Center (BDC) (cm^3)	365
Volume of each cylinder (cm^3)	333	Median Dead Center (MDC) (cm^3)	198
Number of Cylinders	3	Maximum Power (kW) at 6250 rpm	55
Cylinder Diameter (mm)	74,5	Compression Ratio (CR) 1 BDV/TDV	11,5
Stroke (mm)	76,4	Compression Ratio 2 BDV/MDC	1,84
Top Dead Center (TDC) (cm^3)	32	Compression Ratio 3 MDC/TDV	6,25

The modification proposal consists, in a simplistic way, in change de valve control system, so the following operating sequence may happen: at the beginning of the adapted motor first stroke, the inlet valve is already open and the air entering at high pressure (due to the turbocharger). The piston, starting from the BDC, climbs towards the TDC, where in the middle of its path - when it occupies the MDC (middle dead center) - the inlet valve closes and the air is compressed towards the TDC. Immediately before reaching the TDC the fuel is injected and the spark ignites the air/fuel mixture. The pressure generated by the explosion causes the piston to goes down, starting the second stroke. During the descent, near the MDC the exhaust valve is opened causing the gases to flow out before being fully expanded and soon thereafter the inlet valve is also opened, providing an opening crossing gap which promotes a gas flushing in the cylinder. As the piston descends towards the BDC, the valves remain both open and immediately after reaching the BDC, when the piston is already starting the first time again, the exhaust valve is closed and only the inlet valve remains open, reinitiating the described process.

Second, air enters the cylinder by means of a mechanical supercharger that must be capable of supply the engine with air pressure within the cylinder at least equal to the pressure reached by the air in the original four-stroke engine when the piston is on the intermediate position (MDC). Fuel is injected directly into the combustion chamber, and not as air/fuel mixture through the inlet valve as in a conventional Otto four-stroke engine. The valve control system has been modified to overlap the expansion, exhaust and intake cycles, and intake and compression cycles.

Third, the calculations for the analysis of the thermodynamic cycles of the two engines configurations was performed with the standard Otto air cycle, in which compression and expansion were isotropic and the injection and heat rejection occurred at constant volume. For this, the gases of the cycle were assumed with the same properties of the standard air presented in Tab. 2, where c_p and c_v are the air specific heat at constant pressure and constant volume processes, respectively, and k is equal to c_p / c_v.

Table 2. Standard air properties with temperature. Source: Adapted from Shapiro and Moran (2013)

Temperature (K)	c_p (kJ/kg)	c_v (kJ/kg)	k
300	1.003	0.716	1.401
550	1.04	0.753	1.381
800	1.099	0.812	1.354
1000	1.142	0.855	1.336

The following equations were used in the modeling. For the compression ratio (CR), equation 1 was used:

$$CR=\frac{BDC}{TDC} \tag{1}$$

Where BDV is the bottom dead center and TDV is the top dead center. For the temperature variation in isentropic compression and expansion, equation 2 was applied:

$$\frac{T_o}{T_f}=\left(\frac{V_f}{V_o}\right)^{k-1} \tag{2}$$

Where, T_o is the temperature at the beginning of the process, T_f is the temperature at the end of the process, V_o is the volume at the beginning of the process, V_f is the volume at the end of the process and k is the ratio of the specific heats of the air. For the pressure variation in an isentropic compression and expansion, equation (3) was used. In even though the two-stroke version proposed in the present work includes a supercharger, the inlet pressure of both engines, two and four-stroke, were taken as 1 bar (100.000 Pa), so the thermodynamic cycle could be better compared.

$$\frac{P_o}{P_f}=\left(\frac{V_f}{V_o}\right)^{k} \tag{3}$$

Where, P_o is the pressure at the beginning of the process and P_f is the pressure at the end of the process. The temperature variation in the injection and rejection of heat was estimated by equation 4.

$$q=c_v\left(T_f-T_o\right) \tag{4}$$

Where, q is the heat transferred per unite mass and c_v is the specific heat at constant volume. For the variation of the pressure in the admission and rejection of heat, equation 5 was applied.

$$\frac{P_o}{P_f}=\frac{T_o}{T_f} \tag{5}$$

3. RESULTS

According to Brunetti (2013), the temperature of the gases in the combustion in a two-stroke engine is between 2000 and 2800 ºC, so the assumed maximum temperature set for the comparison calculations of the engine from four to the two-stroke engine was 2227 ºC or 2500 K. Figure 1a shows the *P* x *V* diagram of the Otto standard air cycle for a four-stroke engine. The work performed in this cycle is given by the difference of the injected heat and the rejected heat in processes 2-3 and 4-1, respectively. This way, the work done in each cylinder in a cycle and the power generated in the three cylinders at 6250 rpm is 837.1 kJ and 56.0 kW, respectively, with an airflow consumption by the engine of 0.067 kg/s. Figure 1b shows the *P* x *V* diagram of the standard Otto air cycle for the new two-stroke engine. The work done in this cycle is given by the difference of the heat injected and the heat rejected in processes 2-3 and 4-5, respectively. Process 1-2-5 of Fig. 1b was assumed to be identical to process 1-2 of Fig. 1a, the pressure at 5, which is 2.3 bar, is the minimum absolute pressure that the supercharger must provide to the two-stroke engine, otherwise, there will be reflux of air through the intake valve. Process 1-5 is not part of the ideal cycle of this engine; it is illustrated to facilitate the understanding of the system. In this way, the work performed in one cycle and the power generated in the three cylinders at 6250 rpm is 693.5 kJ and 92.7 kW, respectively. The airflow consumed at 6250 rpm is 0.134 kg/s.

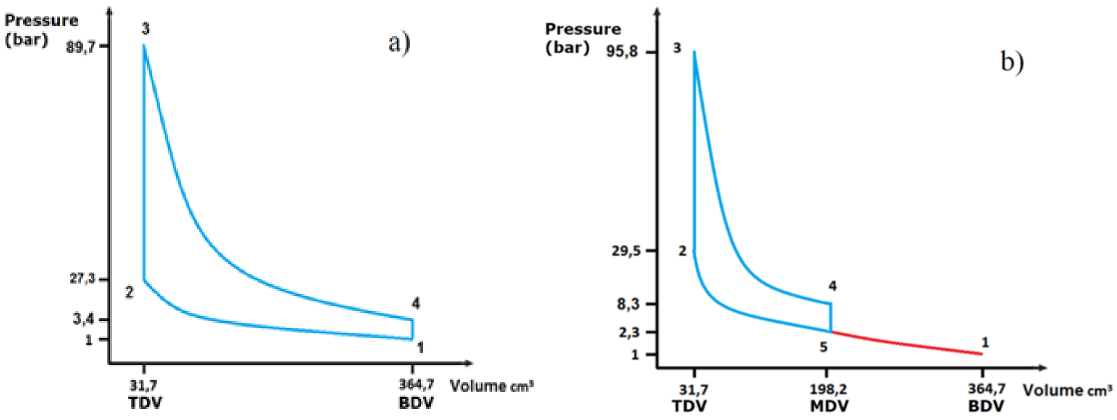

Figure 1. Ideal Otto standard air cycle: a) four-stroke engine; b) two-stroke engine.

Figure 2a shows the actual Otto cycle of the four-stroke engine. It is possible to observe the positions of opening and closing of the valves as well as the losses in the cycles at the exhaustion and admission strokes (pumping work). Figure 2b presents the actual Otto cycle of the proposed two-stroke engine. It is possible to observe the positions of opening and closing of the valves as well as the losses in the exhaust and the intake (pumping work) that are much smaller compared to the conventional four-stroke engine. To ensure that there will always be an airflow to the cylinders, even at low rotations, the supercharger must be positive displacement and be capable of delivering a flow rate of 0.134 kg/s at a pressure of 2.3 bar. Additionally, since in the adapted two-stroke engine the exhaust valve opens near the MDC, the gases are released with a greater content of specific energy than in the four-stroke engine. However, since the proposed two-stroke engine includes a supercharger, a portion of this energy may be recovered.

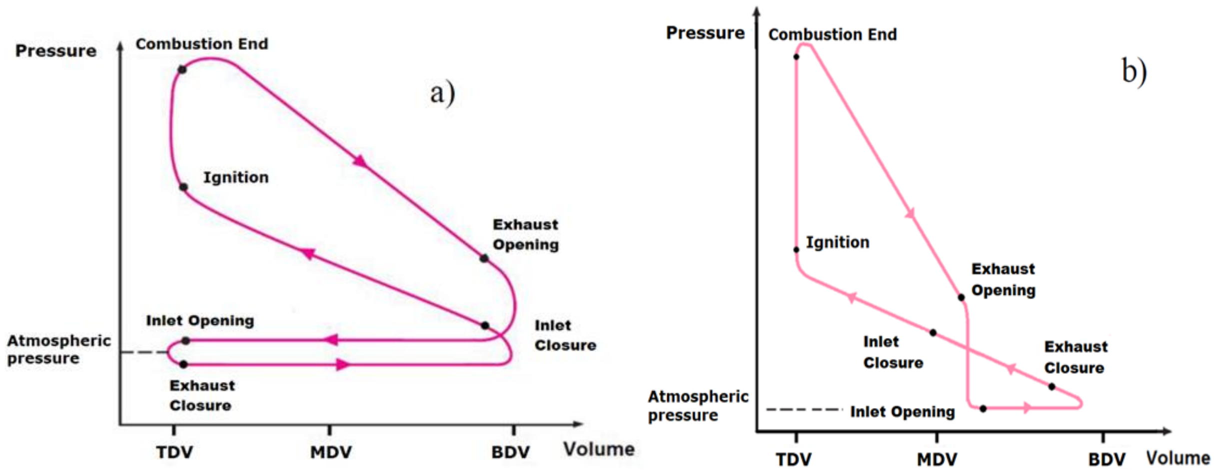

Figure 2. Real cycle: a) four-stroke engine, adapted from (Çengel, 2006). b) two-stroke engine.

Figures 3 and 4 show the operation of the modified valve control system to allow 2-stroke operation. In Fig. 4 EO is exhaust opening, IO is inlet opening, ES is exhaust closure and IS is inlet closure. The supercharger selected was the Rotrex Manufacturer's C30-64 (Rotrex, 2016) with a fixed pressure ratio. It can be seen in Fig. 5 that for the proposed conditions of use the efficiency of this device is between 60 and 65%.

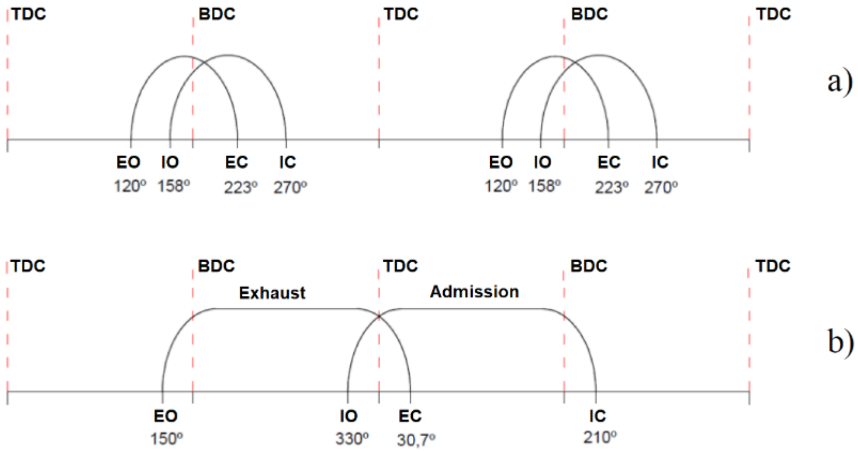

Figure 3. Crankshaft angles for closing and opening valves a) 2-stroke; b) 4 strokes.

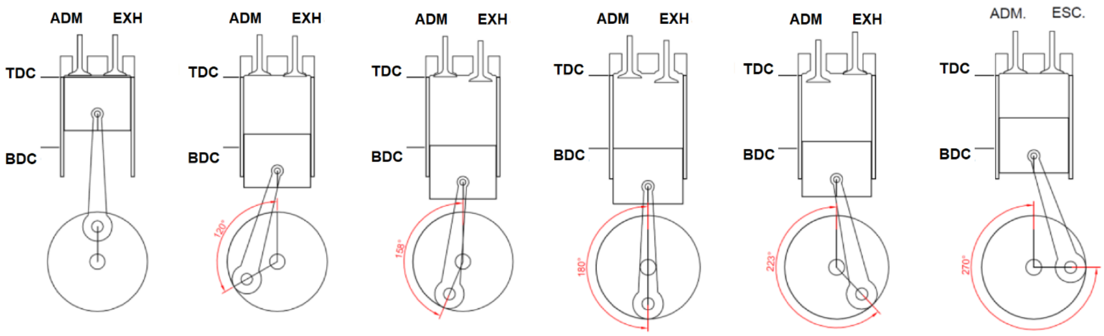

Figure 4. Position of the valves. Start on fuel ignition and gas expansion.

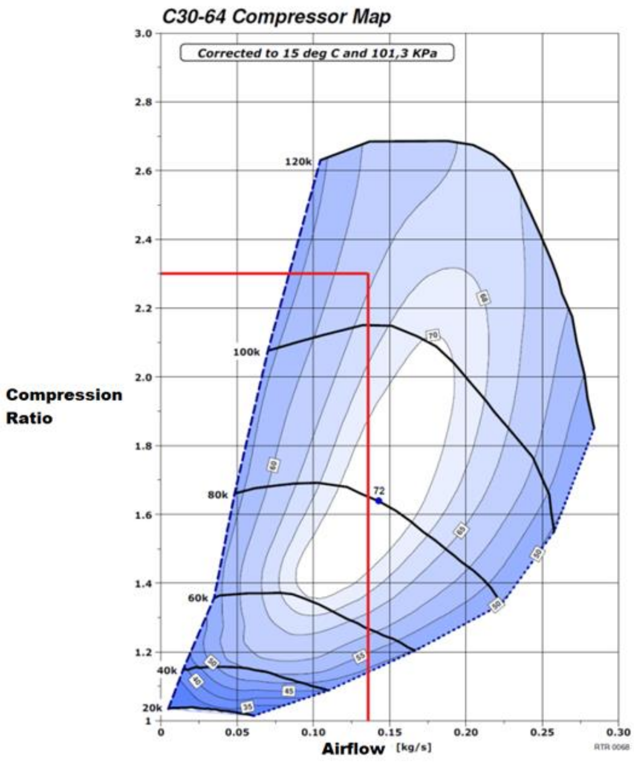

Figure 5. Efficiency map of supercharger C30-64. Adapted from (Rotrex, 2016).

4. CONCLUSIONS

Based on the results, it is possible to observe that the changes proposed in this work to transform a four-stroke engine into a two-stroke engine increase durability and power and reduce pollutant emissions through changes in the control valves system. First, since this engine uses the mechanics of a four-stroke engine, not a conventional two-stroke engine, lubrication is much more efficient, which increases its durability. Second, engine power increases by about 65.5% because the speed of the two-stroke engine cycle is twice that of the four-cycle engine, yet the two-stroke engine exhaust gases are exhausted with higher internal energy than the four-stroke engine, about 20.8% more. Third, there is a drop in the emission of pollutants because the fuel is injected after the exhaust valve closes, which substantially reduces the amount of exhausted unburned fuel. This makes the consumption of this engine less than that of a conventional two-stroke engine. This way, the analyses of the standard air thermodynamic cycle of the two engines clearly demonstrated that the an increase in power is possible only by means of a change in inlet and exhaust valves opening and closing times and the use of a supercharger.

5. ACKNOWLEDGEMENTS

None.

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