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Use of the Miller thermodynamic cycle to optimize a very low consumption engine

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1. Context

Biomobile is a prototype car participating in the **Shell Eco Marathon** every year. The goal of this race is for the car to run as many kilometers as possible with only one liter of fuel. The Biomobile best current performance is for a distance of about 840 km/lt. The engine of the car is a Honda GX-25, running under the Otto Thermodynamic Cycle concept (Fig. 1a), with a standard efficiency of 12,5%. This engine has not been designed for this kind of race and needed to be optimized. To this purpose, the Miller Thermodynamic Cycle (Fig.1b) has been implemented.

3. Methodology

The aim of this work has been to implement the Miller thermodynamic cycle into a Bio-Diesel fueled Honda engine, originally operating under the Otto cycle principle, in order to improve its efficiency. The Project has been carried out into 2 main phases: (a) The design phase, where the original Honda engine has been modified into Miller cycle and (b) The test phase, where the new engine concept's operational characteristics have been optimized.

3.1 Theory

The Miller Thermodynamic Cycle concept is a practical approach for a better engine efficiency, in comparison to the Otto Cycle. It has been created and patented by Ralph Miller in 1947 [1]. Its general concept is based on an engine operating under the concepts of a thermodynamic cycle with an expansion ratio exceeding its compression ratio ($r_e > r_c$), as can be seen at Figure 3b below: the intake valve(s) remain (s) open even during the early stage of its compression phase, resulting into an increased expansion ratio compared to its compression ratio. This is, in general, the key to improve engine's thermal efficiency, also resulting into a better fuel economy and less NO_x emissions. In Otto Engines (Fig 3a) on the other hand, these two ratios are equal ($r_e = r_c$), resulting into a limited work production from the engine's pistons.

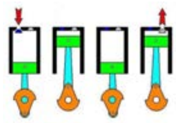


Figure 3a: The Otto Cycle engine concept

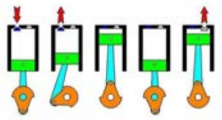


Figure 3b: The Miller Cycle engine concept

3.2 Design Phase

In order to convert the engine's operation under the Miller principle, the shape of the cam controlling the intake valve has been modified (Figure 4). On the other hand, the original Honda engine operates under the conventional Otto cycle with a compression ratio equal to: r_c = 8, which is already a quite low value. Such a change at the engine's cam, further lessens its compression ratio, which negatively affects its performance, and needed to be fixed. To this purpose, 3 new lengthened titanium connecting rods have been designed, in order to increase the compression ratio value of the engine. As a result, the new Miller engine concept operates under improved compression ratio values between: r_c =12-13, while allowing for the needed delay timing into closing the intake valve of the cylinder.

Figure 4: The designed cam for the new Miller engine

3.3 Test Phase

The 2nd part of the project has been to perform trials on the test bench of the HEPIA laboratory (Fig. 5), in order to find the optimum configuration of the engine's operational characteristics.

Figure 5: The test bench at HEPIA laboratory

After an initial characterization of the engine's carburetor operating under the Otto cycle (in order to obtain the necessary reference data), a series of tests by switching the Honda engine into the Miller cycle operating principles have been carried out. The purpose has been to increase the engine's efficiency only by using the rods, under different angle displacement configurations. The tests have been performed with 4 new cams designed for allowing a gap closure of the intake valves at 5 °, 10 °, 15 ° and 20 ° , which correspond into a delay in closing the intake valve of 10 °, 20 °, 30 ° and 40 ° of crankshaft. For each of these cams, a comprehensive series of measures has been carried out, each of them for 2 different compression rates: a maximum (15) and a lower (13) value.

2. Objectives

The goal of this project is to convert the Honda engine's operation from the Otto to the Miller Cycle, in order to optimize its resulting efficiency. The aim is to achieve the maximum distance possible with 1lt of fuel at an average speed of 30km/hr.

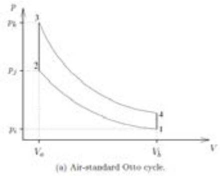


Figure 1(a): The Otto thermodynamic cycle

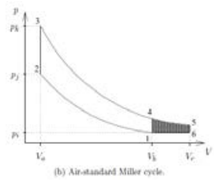


Figure 1(b): The Miller thermodynamic cycle

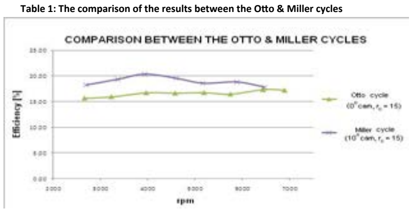
Another objective is to develop a car with each of its parts designed towards a minimized carbon footprint. To this purpose, the Bio-Gas X-41 has been the fuel of choice. As for the vehicle's cover material, a vegetal fiber has replaced the epoxy resin (see Figure 2 below). As a result, the Biomobile vehicle is one of the "greenest" cars participating in this race.

Figure 2: The Biomobile vehicle

4. Results

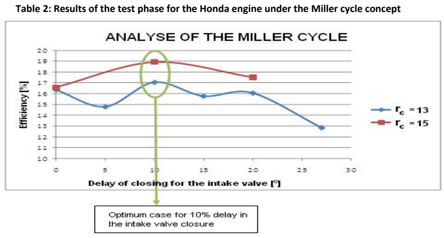
The combination of a greater compression ratio with the implementation of the Miller Cycle on the Honda engine has resulted into an increased efficiency from 12,5% to 19%.. By keeping the engine's operation under the Otto cycle concept, and increasing its compression ratio has showed also an improved performance, with an efficiency up to 16,5%. A comparison between the Otto and the Miller cycle test results showed a better performance for the Miller type configuration, with an average yield of our engine running on Miller cycle at 18,9% for a 20° delay on the crankshaft and r_c = 15 (see Table 1 below).

Table 1: The comparison of the results between the Otto & Miller cycles



In overall, the Honda engine under the Miller cycle shows the optimum performance for a combination of a compression ratio of 15 and a cam set for a 10 °closure of the intake valve, corresponding to a 20 °delay on the crankshaft (Table 2).

Table 2: Results of the test phase for the Honda engine under the Miller cycle concept



5. Perspectives

The Miller Thermodynamic Cycle concept into low consumption engines could be a promising alternative towards their further improvement: it does not require significant modifications on the engine's structure, and it can, therefore, find its place in applications that do not necessarily require a considerable power supply, but the reduction in their consumption is an important issue to be considered.

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[1]. R.H. Miller, Supercharging and internally cooling for high output, ASME Transactions 69 (1947) 453–464.