

Development of a Non-Conventional Two Stroke Small Engine for Scooter Applications

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ABSTRACT

The purpose of this work is to perform an analysis on the modifications necessary to convert a four-stroke engine into a non-conventional two-stroke engine. The first aim of this work is to reach the theoretical advantages of the two stroke engine (high torque values at lower rpm and working regularity) and, at the same time, to avoid the usual problems of the two stroke cycle (short-circuit of fresh air-fuel mixture and consequently pollutant emissions and high specific fuel consumption). The target is to develop a small engine with innovative solutions that allows to obtain high performance coupled with good mechanical and thermodynamic efficiency. The starting base engine is a 125cc four-stroke two-valves scooter engine equipped with a volumetric compressor. The idea is to convert it from four to two stroke cycle, using head valves and adding scavenge ports in the cylinder. Two different cylinder layouts were studied and evaluated: in the first, the cylinder ports are used for fresh mixture intake and the valves are used for exhaust gases; in the second configuration the scavenging process was inverted, with fresh mixture entering through the valves and exhaust gases going out through the cylinder ports.

An engine 1D model was built using a commercial code, and after some preliminary simulations, the solution with head valves for air and air/fuel mixture and cylinder ports for exhaust gases was chosen. After the 1D fluid-dynamic analysis of the whole engine, a 3D fluid-dynamic simulation was performed to investigate the gas exchange process and in particular the in-cylinder charge motion and the flow patterns during the scavenging process obtained with the chosen cylinder geometry. The 3D simulation also gave a reliable estimate of the fresh fuel amount that flows directly through the exhaust ports (short-circuit) and allowed to study in detail the fuel injection and vaporization process in the intake duct. All the analyses results were used to manufacture the first

engine prototype that, at the present time, is under construction.

INTRODUCTION

During the past years two stroke engines have had a widespread diffusion in many fields, the most important of these being the motorcycle area. The main advantages were the construction simplicity, robustness, lightness and high specific power. On the other hand, two stroke cycle main problems are related to high and hardly manageable exhaust emissions (with respect to the four stroke cycle) and high specific fuel consumption. These problems determined a progressive abandoning of the classic two stroke engine and promoted the research for alternative solutions, especially focused on the direct injection systems and combustion process optimization [1], [2], [3].

This paper is concerned with the study and the following realization of a possible solution to convert an existing four stroke engine with volumetric compressor into a two stroke engine, with the primary aim to benefit from the two stroke cycle advantages and try to avoid the typical problems connected to it. An important input of the work was to maintain as many parts as possible of the baseline engine, keeping low the whole project costs.

The most critical part in a conventional two stroke engine is related to the scavenging process in which are concentrated both the pollutant emissions production and the global efficiency losses. Consequently the authors focused the attention in that phase, adopting the strategy to maintain the four stroke cylinder head valves and the volumetric compressor in order to make the whole scavenging process more efficient.

Starting from a “blank slate”, the first step was to build a mono-dimensional engine model of the baseline four-stroke engine and to use it to test the effects of the two-stroke conversion and different scavenging strategies. Then, having established the best engine layout, a 3D fluid-dynamic simulation was performed in order to view in detail the fuel injection process and the scavenging process.

The results of the 1D and 3D fluid-dynamic analysis and the final engine configuration obtained from the study are presented in the paper.

ENGINE DEVELOPMENT STRATEGY

The four stroke engine chosen for the two stroke modification is a Peugeot Motorcycles scooter engine with the following specs:

- Displacement: 125 cc;
- Valves: 2 SOHC;
- Volumetric compressor and intercooler;
- CVT transmission;
- Declared Power: 15 kW @ 9000 rpm;
- Declared Torque: 16.5 Nm @ 7000 rpm;
- Engine-Volumetric compressor transmission ratio: 1:1.

Two stroke cycle, with a power stroke for each crankshaft revolution, allows, theoretically, to double the power output at each engine speed. In the specific case, a scooter application, this gives the possibility to run the engine at lower rpm with the same performance of the equivalent four-stroke engine. For this reason a maximum engine speed of 6000 rpm was chosen as a good compromise between maximum power and low mechanical losses.

Actually, the main problem is related to the difficulty to fill completely the displacement volume with fresh charge and to avoid the short-circuit during the scavenging process [4], [5]. These two problems lead to a poor charging efficiency:

$$\eta_{ch} = \frac{m_{air_retained}}{\rho_0 V} = \eta_{del} \cdot \eta_{tr} \quad (1)$$

where η_{del} is the delivery ratio:

$$\eta_{del} = \frac{m_{air_delivered}}{\rho_0 V} \quad (2)$$

and η_{tr} is trapping efficiency:

$$\eta_{tr} = \frac{m_{air_retained}}{m_{air_delivered}} \quad (3)$$

In the engine developed in this paper, the attention is focused on an improvement of both η_{del} and η_{tr} respect to the traditional two stroke engine values.

SCAVENGING STRATEGY ASSESSMENT

As far as the cylinder fresh charge supply is concerned, the crankcase compression of the standard two-stroke engine is replaced by the volumetric compressor [6]. This also allows to increase the delivery efficiency η_{del} because of the higher compression ratio reached by the volumetric compressor respect to the crankcase compression. At the same time, the target to increase the trapping efficiency η_{tr} is pursued using head valves.

Consequently, the first evaluation concerned with the use of head valves: two different uniflow scavenging strategies were studied. In the first configuration the cylinder ports are used for the fresh charge intake while the head valves are used for the exhaust gases; in the second configuration, the opposite strategy is followed: the cylinder ports are used for the exhaust gas and the valves for the intake. Before going into details, some problems in common with the two solutions are presented.

A critical issue related to the two-to-four stroke transformation is the camshaft speed. In the two stroke engine the camshaft needs to rotate at the crankshaft speed and so its velocity is doubled respect to the four stroke engine, while the time available for the gas exchange process is about halved. This implies a lower valve lift to maintain an acceptable mechanical stress. As a direct consequence the effective flow area is reduced. To make up for this problem, instead of the original two valves head, a four valves head (taken from the 4 valves 125cc Peugeot engine) was used in order to increase the geometric flow area.

To perform the first part of the scavenging process only with air, another problem that has to be solved is the fuel injection timing [7]. Two possible strategies can be followed in order to enter the fuel after the exhaust valves (or ports) closing:

- Direct injection;
- Timed port injection.

The first choice is probably the most effective in terms of fuel injection control, but involves higher costs for the direct injector implementation and installation.

The second option was chosen by the authors mainly for industrial realization and cost reasons: the port injection allows to maintain the original four stroke low pressure injector and not to design a cylinder head with a direct injector access.

COMPARISON BETWEEN INTAKE PORTS AND EXHAUST PORTS SOLUTIONS

The following scavenging strategies (Fig. 1) were evaluated by means of specific 1D models, built using WAVE, Ricardo Software:

1. Intake cylinder ports and exhaust valves (typical configuration for 2-stroke Diesel engine);
2. Exhaust cylinder ports and intake valves.

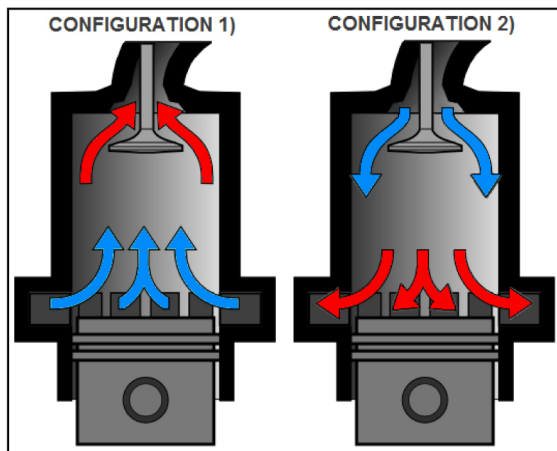


Fig. 1. Uniflow scavenging strategies.

In this initial part of the work the comparison between the two configurations is performed with other parameter being equal, and the results are valid only in comparative terms. Moreover the fresh charge entering the cylinder is considered an homogeneous air-fuel mixture, because in this preliminary phase the attention is focused only on the validity of the two different approaches in terms of scavenging efficiency.

In both cases it is possible to appreciate the advantages offered by the valves: the exhaust (or intake) process is asymmetric with respect to the BDC, leading to the exhaust closure anticipating the intake closure.

Configuration 1) has intake ports that cover the 50% of the cylinder circumference and four head exhaust valves actuated by a single overhead camshaft. In Fig. 2 is presented a possible valve diagram.

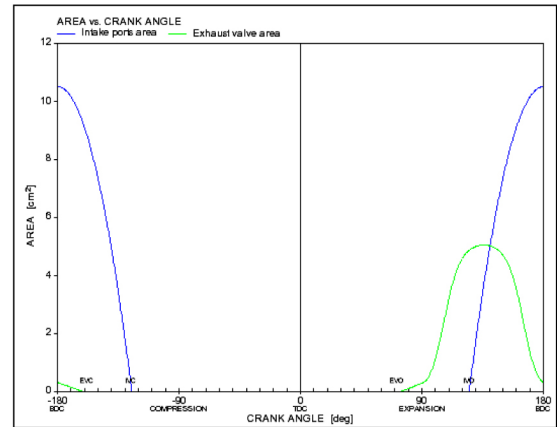


Fig. 2. Intake and exhaust passage area Configuration 1).

Configuration 2) has exhaust ports with the same passage area of Configuration 1) and four head valves used for the intake gas passage. In Fig. 3 is presented a possible valve diagram.

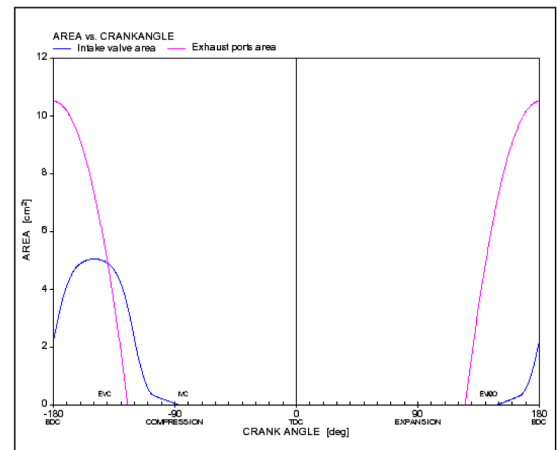


Fig. 3. Intake and exhaust passage area Configuration 2).

Charging efficiency, trapped residual gas fraction and specific fuel consumption were chosen as the most significant parameters to determine the best solution between 1) and 2). The charging efficiency and the trapped residual gas fraction take into account the phenomena related to the gas exchange process, while the specific fuel consumption is indicative of the global engine efficiency. In Fig. 4 the charging efficiency comparison between the two configurations is presented.

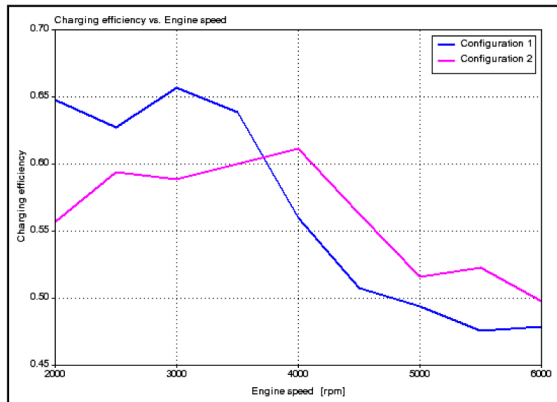


Fig. 4. Charging efficiency comparison.

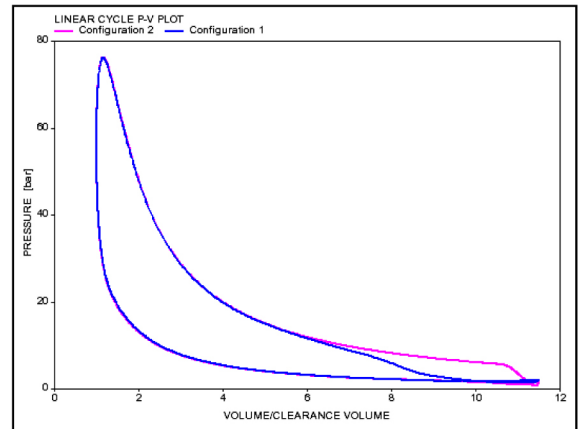


Fig. 6. p-V cycle comparison between exhaust ports and intake ports configuration.

For more than a half engine working range, the exhaust ports charging efficiency is higher than the intake ports configuration. This is mainly due to the easier way that the exhaust ports have to discharge the larger amount of exhaust gases as the engine speed increases. In confirmation of that, a lower cylinder trapped residual gas fraction of exhaust ports configuration can be observed in Fig. 5.

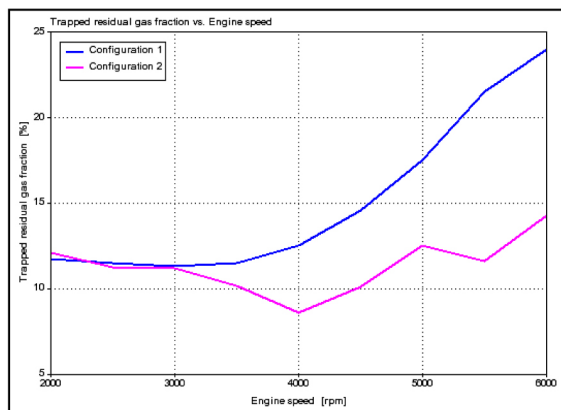


Fig. 5. Trapped residual gas fraction comparison.

The advantages of solution 2) can be summarized observing the p-V diagram (Fig. 6): thanks to the larger exhaust passage area given by the cylinder ports, it is possible to delay their opening and extend the expansion stroke. As a result, more work can be extracted from the expanding gas along with a reduction of the negative work necessary to the forced expulsion. In Fig. 6 a numeric comparison between the exhaust ports and intake ports configuration is shown, volumetric efficiency and spark advance being equal.

The specific fuel consumption simulation results reported in Fig. 7 also confirmed the exhaust ports configuration choice. This engine layout seems more promising in terms of global efficiency and it is supposed to give a maximum power close to the Peugeot baseline engine.

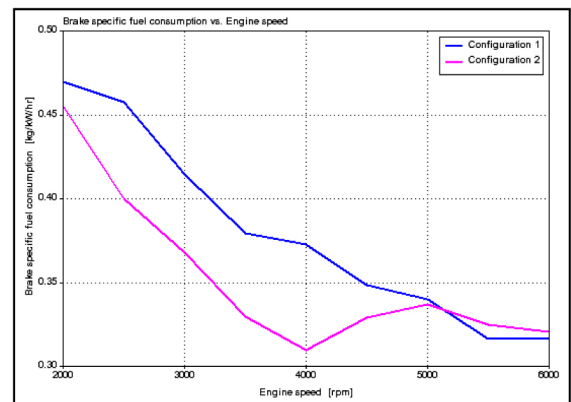


Fig. 7. Specific fuel consumption comparison.

We must underline that the scavenge process is modeled by an empiric cubic curve (Fig. 8) which relates the percentage of burned gas flowing out from the exhaust with the percentage of burned gas inside the cylinder. The imposed function has been determined by literature data for a uniflow engine [9], resulting in a typical profile for a small 2-stroke engine, and it is the same for the two configurations considered.