FLUID POWER ENERGY GENERATOR USING FREE PISTON ENGINE

[1]Ionut Tudor Soare[*],[1] Gheorghe-Alexandru Radu,[1]Horia Abaitancei, [1] Sebastian Radu, [1]Aron-Adrian Petric

[1]Transilvania University of Brasov, Romania,

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ABSTRACT–As conventional energy resources are diminishing and pollution is increasing especially in urban environments, the automotive industry from around the world is researching and developing new systems that reduce fuel consumption and pollutant emissions.
Hydraulic hybrid systems are an important part of hybrid technology. Hydraulic hybrid systems have the advantage of high power density and the system of recovering the braking energy is able to work at high frequencies of loading/unloading conditions. The main disadvantage of hydraulic hybrid propulsion systems is due to its lower efficiency towards mechanical transmissions. For this reason investigations are focused to increase hydraulic efficiency for example pumps and hydraulic motors with distribution controlled electronic, whose efficiency is 95%. Another direction is the primary source of hydraulic energy. Functional features of hydraulic systems allow optimized solutions for primary engine sources. A direction that needs to be researched is the free piston engine.
This paper describes simulation results of a free piston engine that generates the hydraulic energy needed by hybrid hydraulic vehicle propulsion. The method of analysis used in achieving free piston simulation is AMESIM, and the system analyzed in this paper is a free piston internal combustion engine. This paper highlights the engine thermodynamic parameters for different operating conditions.

INTRODUCTION

Large scale utilization of fossils fuels as an energy source in the transportation industry led to producing high quantities of pollutant emissions (CO, NO_x, HC) and carbon dioxide (CO_2). A lot of researches, especially on automotive industry, are done to develop different systems capable of producing fewer emissions.
After the free-piston engine concept was abandoned in the mid 20th century, it came back to the attention of researchers all over the world as free piston engines are an alternative to conventional solutions: combustion engine - hydraulic generator. Potential benefits of free piston engines include optimizing the combustion process through variable compression ratio leading to the possibility of using different fuels, reducing friction losses due to the simplistic design of the few moving parts [1].

OVERVIEW OF FREE PISTON ENGINE SOLUTIONS

The term free-piston engine is used to distinguish between linear motor and crankshaft engine. This happens because the piston is free to move and it doesn’t depend on the crankshaft position. This property gives the free piston engine some distinct characteristics: variable compression stroke, the need of active control of piston movement.

R.P. Pescara is the first that has managed to patent the free-piston engine in 1928. Since then a large number of patents have appeared describing the free-piston engine or similar systems of free piston engine. Pescara's original patent described a single cylinder spark ignited engine that was used as an air compressor, but in this patent was also included a large range of applications that used the free piston principle[1].

Free piston engines can be divided in three categories having the criteria of the piston / cylinder configuration. The fourth category is free-piston gas generators where the load is taken only by a turbine connected to the exhaust and not from a loading mechanism which is mechanically coupled to the engine.

SINGLE PISTON

This engine is mainly composed of three parts: a cylinder in which combustion occurs, loading mechanism, and an accumulator used to return the piston to initial position, which ends the compression cycle. In figure 1 the hydraulic cylinder of the free-piston engine is designed both to create hydraulic power, but also serve to restore the piston's TDC position. In other design schemes these two functions can be performed by two distinct elements. Simple design and high controllability are the main advantages of these types of engines compared to other free piston engine configuration. Using this type of system it is possible to accurately control the energy introduced for carrying out the compression and the compression ratio can be exactly controlled.

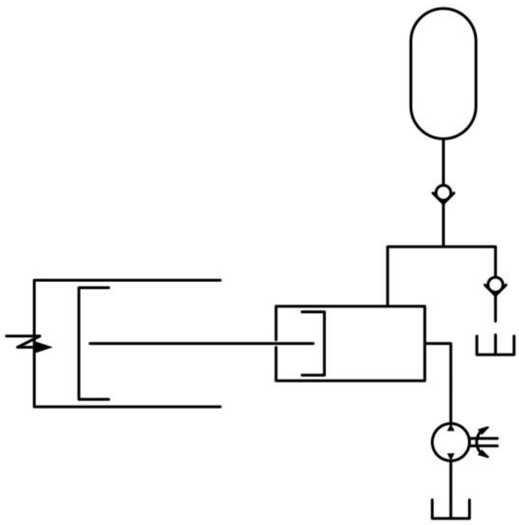

Fig.1 Single piston hydraulic free-piston engine [2]

DUAL PISTON

Dual combustion chamber engine or dual piston engine (fig. 2) is a variant of free piston engine which is studied intensively these days. A number of patents of dual piston engine have been proposed and few prototypes were created, having the output power hydraulic or electric. This configuration eliminates the need for a system to bring back the piston to the top dead centre (TDC). This solution allows developing a variant of free piston engine more compact and with a power/weight ratio much higher.

OPPOSED PISTON

A free piston engine with opposed pistons consist of two units with single cylinder with a common combustion chamber. Each piston requires a mechanism for recovering the piston to the TDC. In figure 3 is shown an opposed free piston engine having attached a synchronization mechanism of the pistons. This principle has been used almost entirely in the early development of free piston engine (1930-1960). Such engines were used as air compressors and later as gas generators in large plants. The great advantage of this type of arrangement is that the engine is perfectly balanced due to the pistons symmetry. The disadvantage of this solution is that it needs a piston timing mechanism [1].

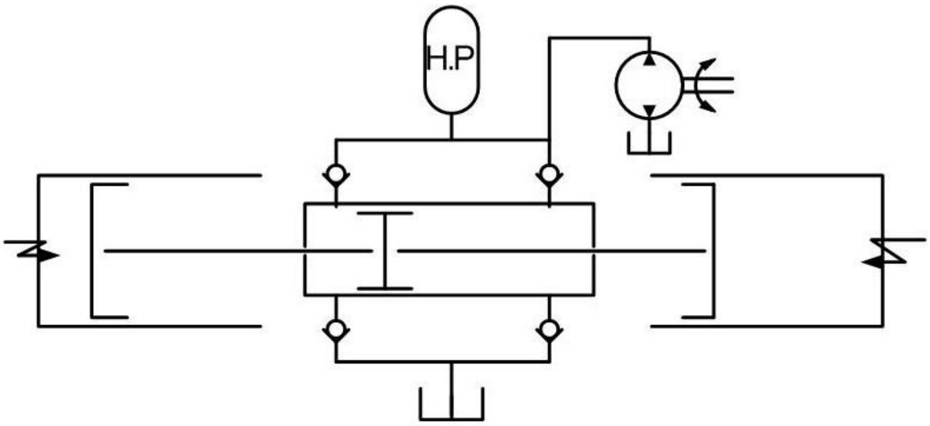

Fig. 2 Dual piston hydraulic free piston engine [3]

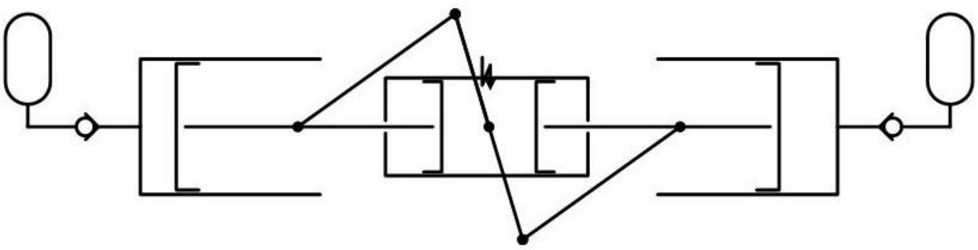

Fig. 3 Opposed piston free piston engine with
piston synchronization mechanism [1]

GAS GENERATORS

Free piston gas generators are free piston engines utilized for feeding hot air turbine. The only task of the free piston engine is to realize the supercharge of the hot air which is then fed into the turbine. Free piston gas generators were used in stationary power plants in the middle 20th century, and attempts were made to adapt the principle to vehicles. In comparison with a conventional gas turbine, free piston gas generator has the advantage of high compression ratio [1].

WORKING PRINCIPLE

Free piston engine has a number of unique features, some give a potential advantage and some are still tried to be overcome for free piston engine to become an alternative to conventional solutions.

Free piston engine is restricted to work after 2 stroke engine principle because energy in needed to compress air in the combustion chamber. Although 2 stroke engines have lower performance compared with the 4 stroke engine, researches were conducted and in recent years it is seen an increased interest in 2 stroke small engines.

The main difference between free piston engine and conventional engines is the piston dynamics. In conventional engines the piston motion is determined by the crankshaft and its high inertia makes the rotational speed of the engine constant. In the free piston engine the piston motion at any point is determined by the instantaneous force that is developed [4].

FREE PISTON ENGINE SIMULATIONS

For the simulation with the AmeSim the two – stroke engine parameters was set initially as follows:

- number of cylinders = 1
- bore 40 mm
- stroke = 39.5 mm
- connecting rod length = 120mm
- compression ratio = 14
- squish height for heat exchange = 1 mm
- piston surface for heat exchange = 1200 mm²
- cylinder head surface for heat exchange = 1400 mm²
- firing order = 1
- the shaft speed 3000 rpm

This example was well-adapted to observe the combustion development and the integrity of the whole system. The Fig.1 is presenting the chosen model and was extracted from the LMS AmeSim. Because the simulation program does not have in its libraries a two – stroke engine or a free – piston engine a serious of changes had to be applied to the four – stroke engine in order to assure a good function for the chosen solution.

For the correct functioning of the system the crankshaft is present even if the studied model is a free – piston mechanism. This compromise was adopted, because the two – stroke engine needs information’s about the crankshaft position angle to perform correctly the simulation. For the integration of the hydraulic actuation a motion sensor was placed between the connecting rod and the hydraulic cylinders piston, thus giving the motion information to the hydraulic piston, ensuring in this way a correct control for the engine piston motion.

MODEL

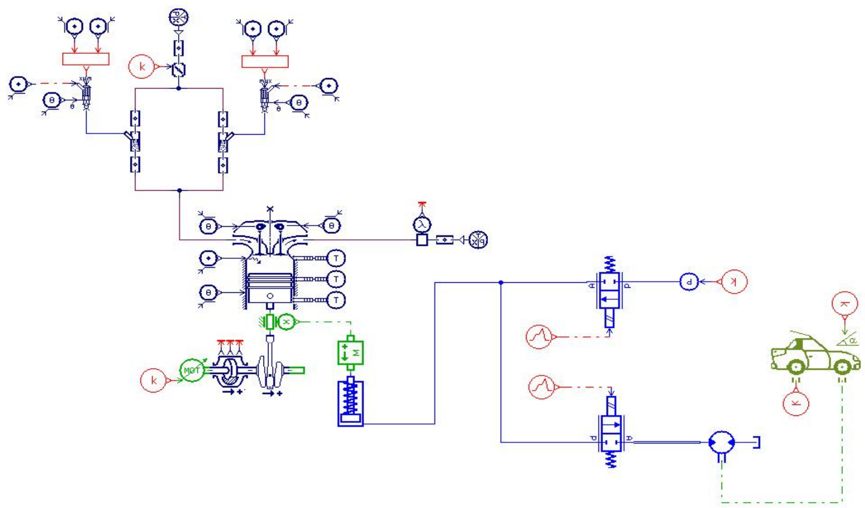

Fig. 4 AmeSim model

On this part of the article it is studied the influence of a various number of parameters over the over the two-stroke solution. Also is presented a hydraulic transmission as a type of power distribution, with its own specific control method over the piston movement.

The hydraulic transmission uses a pressurized hydraulic fluid in order to realize the movement of the hydraulic machinery. The system is composed by a hydraulic pump, driven by the free – piston engine, pipes, valves, filters to guide and control the system and the hydraulic motor needed to move the vehicle.

The piston motion is controlled by two simple hydraulic distributors, one being used for the up stroke and other one for the down stroke motion. The main disadvantage that appears for this configuration is that the distributors cannot open and close fast enough affecting the process. For accurate control of the distributors, high sensitive actuators are used. The solution with one distributor was inefficient over frequencies greater than 100Hz, were the leaks appeared. The solution with two distributors is more efficient, each distributor working at half of the engine's piston frequency.

RESULTS AND DISCUSSIONS

After running the simulation the following graphs were obtained:

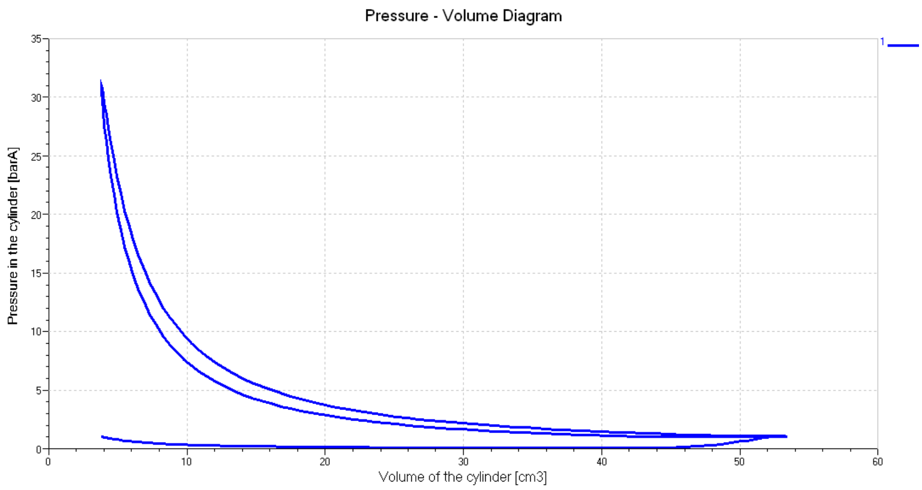

Fig. 5 Pressure – Volume diagram

In Fig. 5 illustrates the pressure – volume diagram as extracted with AmeSim plot. The maximum cylinder pressure is equal with 32 bars.

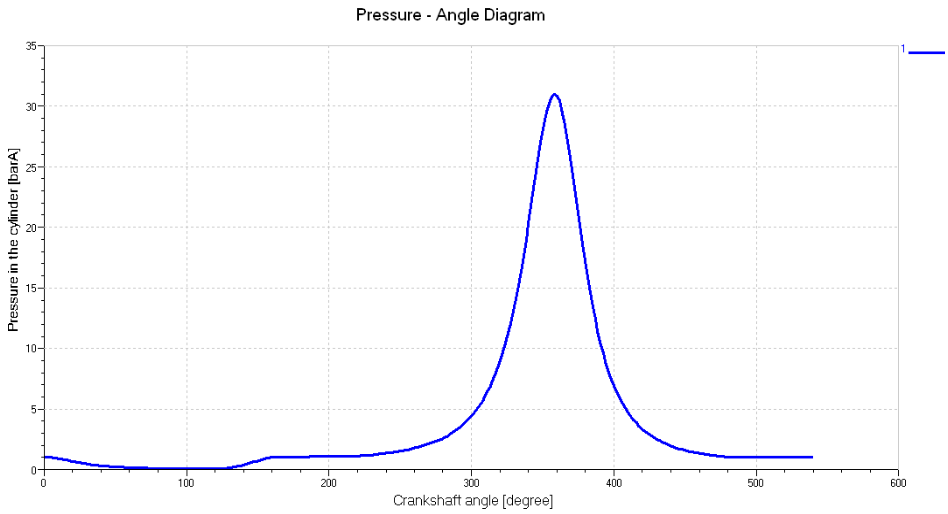

Fig. 6 Pressure – Vangle diagram

In fig. 6 is illustrated the pressure – angle diagram. The maximum cylinder pressure is obtained at 358 crankshaft angle degrees.

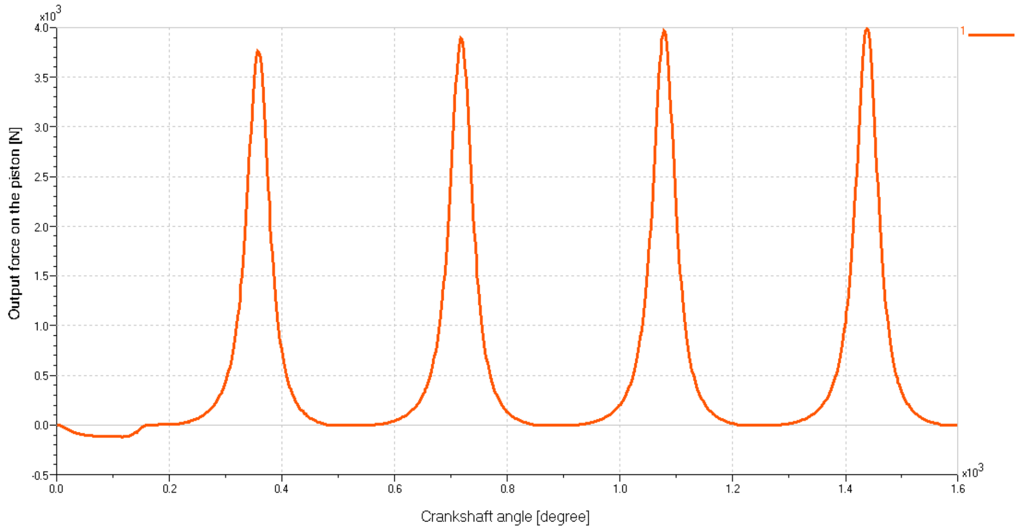

Fig. 7 Output force – angle diagram

In order to compare the effect that different changes would have on the test free – piston engine batch test were run. There will be studied the following:

- cylinder intake pressure;
- intake ports opening and exhaust ports closure;
- intake ports diameter;
- exhaust ports diameter;
- the compression ratio

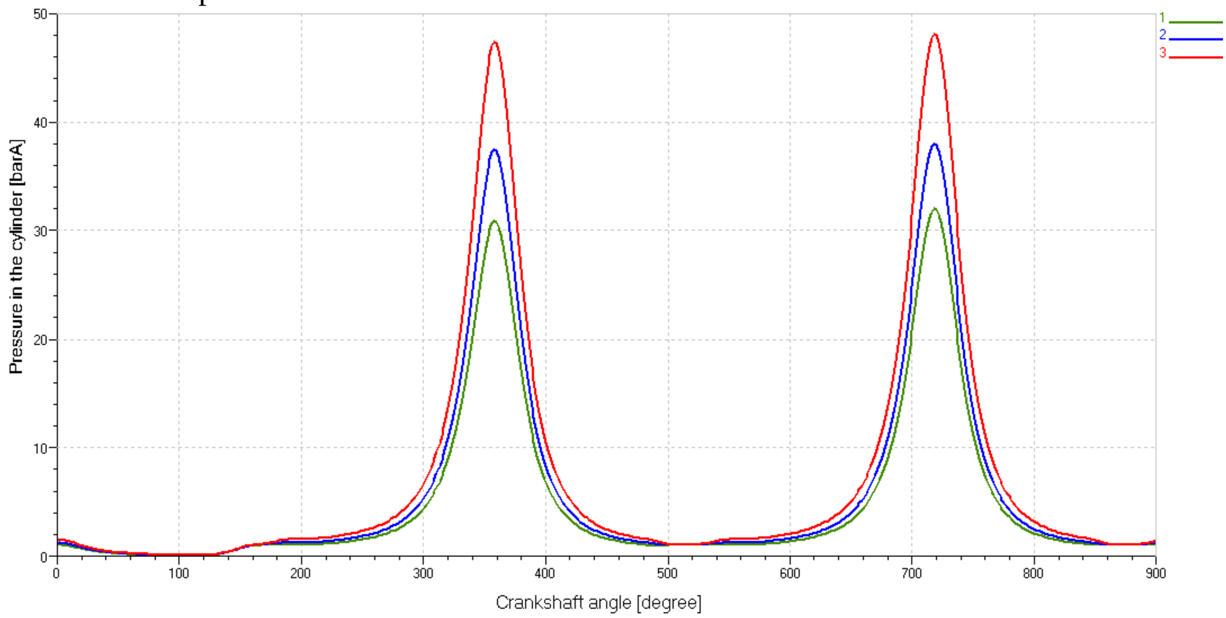

Fig. 8 Variation of cylinder pressure depending on the intake pressure

In the fig. 8 it is showed the cylinder pressure variation depending on the intake pressure. The chart is composed by three lines which correspond to three different intake pressures. First line, the green one, matches to normal intake pressure of 1.013bars. The blue and the red line correspond to the supercharged pressure of 1.2bars for the blue one and 1.4bars for the red one.

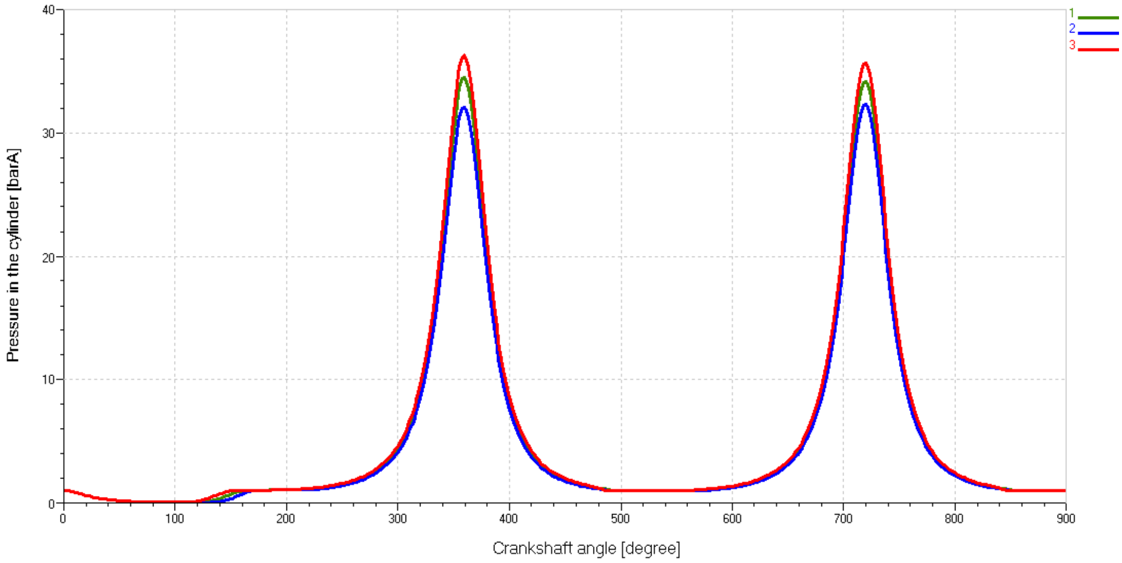

Fig. 9 Effect of the different valve timing on the cylinder pressure

In Fig. 9 is illustrated cylinder pressure dependence related to intake ports open and to the exhaust ports closure. The best solution – the red line, has a peak pressure of 36bars and it corresponds to the intake ports open of 140 degrees exhaust port closure at 230 degrees. For the green line the intake ports open is set at 150 degrees and the exhaust port at 240 degrees. Also for the blue line the intake ports open is set at 130 degrees and the exhaust port at 220 degrees.From Fig. 10 it is observed that the maximum cylinder pressure reached for the intake ports diameter of 10 mm – green line. For a diameter equal with 15 or 20mm the maximum cylinder pressure decreases around 31bars. Therefore, for a maximum cylinder pressure improvement is recommended a smaller diameter of the intake ports. Also a smaller diameter combined with a larger intake pressure gives a better mixture of the fresh charge.

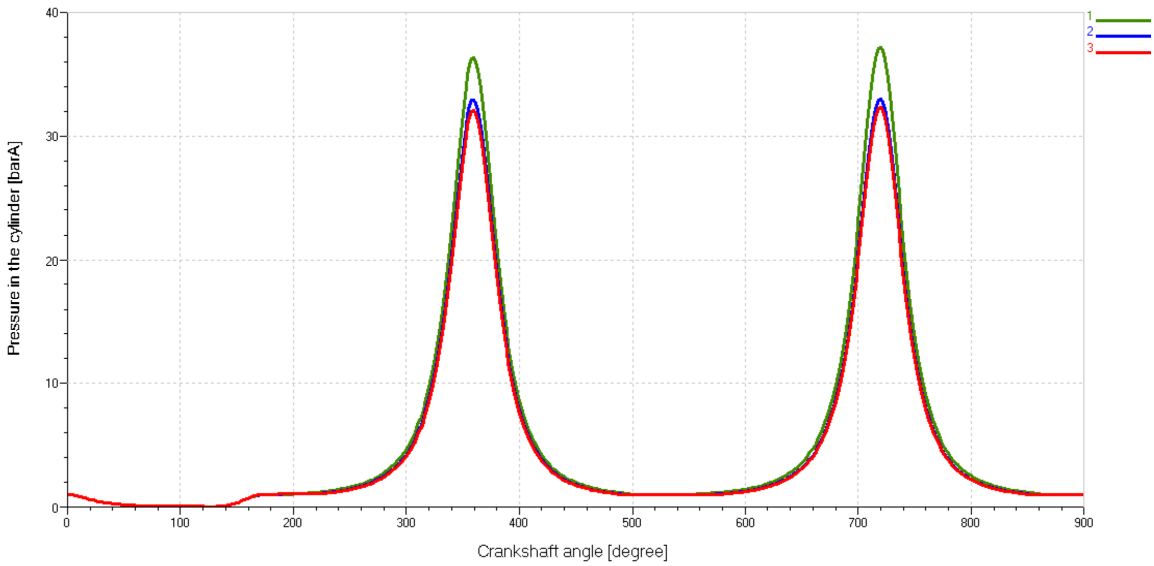

Fig. 10 Variation of cylinder pressure related to the intake ports diameter

CONCLUSIONS

The AmeSim one-dimensional analysis gives the opportunity to study different engine behaviours, to modify engine parameters in order to find the best solutions for the free – piston engine development.

Thus, the engine functioning could be optimized for best performances, by modifying the compression ratio, the intake pressure, the diameters for the intake and exhaust ports. Also the AmeSim analysis provides a good approached to the thermodynamic calculus for a two – stroke engine.

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