INFLUENCE OF THE VOLUME RESONATOR VARIABLE IN THE PERFORMANCE OF AN INTERNAL COMBUSTION ENGINE

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Abstract: *The intake manifold of an internal combustion engine was modified with the goal to increase the quantity of inlet air mass, inserting a variable volumetric resonator. The experiments were performed on a Flex Fuel 1,3 liters engine. The tests were performed in a Bench Flow and one engine bench dynamometer; with this equipment it was able to modify the load and the engine speed. The alternative movement of the intake valves and the piston produces pressure waves that propagate through the intake manifold. Those waves, can be used to increase the quantity of inlet air mass, its can improve the engine performance. The device that permits to use those pressure waves to increase the inlet air mass on specific engine ranges, it is a fix volumetric resonator. In this work, a variable volumetric resonator is studied to increase the inlet air mass flow in all engine range. With this objective, was able to have the pressure and the inlet air mass on the intake manifold with the volume variation of the resonator. The results can be compared with one intake manifold without a resonator. The results with the present of the resonator shows that the gain of the inlet air mass for all the resonator volume. The increase of the inlet air mass flow, direct influence on the engine mean effective pressure, increasing the torque and the power engine, reducing the specific consumption. This way, the idea of using a variable volumetric resonator can be useful to increase engine performance in all range.*

Keywords: Ressonator, Internal Combustions Engine, Flow Bench, Intake Manifold.

1. INTRODUCTION

Even so the Brazilian automotive industry is increasing and the huge vehicle commercialization with small internal combustion engine with flex fuel system, it is necessary to study the performance parameters of those engine focuses on the reduction of fuel consumption. Nowadays, has been propose, many different alternatives to improve the engine performance, include the use of turbo-charge, blowers, direct fuel injection and reducing the size of the powertrain, trying to achieve more flexibility in intermediate loads. To achieve those characteristics on the intermediate loads, those engines must be designed with higher power and with a total synchronization of the fuel injection system, variable valve time, the intake manifold pressure and the spark ignition control (Cunha *et al*, 2000).

One of the alternatives used to achieve the performance gain and reduce vehicle noise is the use of fix volumetric resonator, which permit to improve the engine volumetric, mainly when the engine are working under lower and intermediate loads. With the objective to get these profits of the volumetric efficiency over all engine functionality range, this work aims at to study the influence of volumetric variable Helmholtz resonator insertions on the intake manifold system. The experimental studies were performed on a Bench flow (Hanriot, 2001) and one dynamometer bench. The air mass flow and the pressure of the intake valves movements were analyzed over several engine speeds, for different resonator positions and volumes.

2. BIBLIOGRAPHICAL REVISION

Some studies Hanriot, 2001, Hanriot *et al*, 1999, Benajes *et al*, 1997, Winterbone and Pearson, 1999, Winterbone and Pearson, 2000 had been carried through with intention to search improvements in the volumetric efficiency through alternatives for the manufacture of the mechanism of variation of the resonator volume in the intake manifold system of internal combustion engines, considering the fluid dynamics phenomena that occur during the air induction. The internal combustion engine is a thermal machine in which the gas is inlet and outlet through the valves that work in alternative way. The main function of the intake manifold is to lead atmospheric air until the intake valves. In the interior of the pipes, over to the movement of air, pressure oscillations also appears. As consequence of these waves, the movement of the gas is transient, that is, its speed and pressure change in the time

The gas movement is determined by the difference pressure between the intake manifold and the cylinder. The oscillations of pressure in the pipes occur due to the movement of the valves and the piston (Hanriot, 2001).

The resonance frequency of Helmholtz resonator is gotten theoretically without considering no restriction or load loss, independently of the form of the device. In such a way, for one given opening of the neck, the important variable is the volume not or form. The dimensions of the resonator and the neck open area it is considerably less than the wave length. The resonance frequency, independently of the form of the resonator, is given by (Kinsler *et al*, 1980):

$$2\pi f = \left(\frac{c^2 S}{l_{eq} V} \right)^{1/2} \tag{1}$$

Where:

l_{eq} = equivalent neck length (m);
S = resonator neck area (m^2);
c = sound speed (m/s);
V = resonator volume (m^3);
f = resonance frequency of the Helmholtz resonator (Hz);

Morse *et al,* 1938, they had been one of the first to show the influence of the effect of the production of pressure pulses in the intake manifolds caused by the alternative movement of intake valves. The authors had evidenced that the exploitation of such fluctuations of pressure can be used to increase the engines volumetric efficiency. For the definition of the resonator format in the intake manifold, that makes possible the variation of the internal volume, (Panton and Miller, 1975) suggests a form cylindrical, where the resonance frequency is given by:

$$2\pi f = \left(\frac{c^2 S}{l_{eq} V + \frac{1}{3} l^2 S} \right)^{1/2} \tag{2}$$

Where the equivalent neck length is considered as:

$$l_{eq} = l + \Delta o + \Delta i \tag{3}$$

Where:

Δ_o= Correction factor $8a/6\pi$;
a = intake diameter (m);
Δ_i = correction factor is given by:

$$\Delta_i = \frac{8r_o}{3\pi}\left(1 - 1{,}24\frac{r_o}{R_r}\right) \quad \text{for } \frac{r_o}{R_r} < 0{,}4 \tag{4}$$

Where

R_r = Cylindrical resonator radius (m);
r_o = Neck radius (m).

The bibliographical revision show that has the necessity to get experimental data that allows to better evaluate the transient effect of pressure generated by the alternative movement of the valves and pistons. A referring experimental data base to this type of phenomenon is of great value in the development of internal combustion engines, making possible a reduction in the fuel consumption (motor of lower piston displacement) and reduction the pollutants emissions values (Dutary, 2006).

In the intake manifold system, the pulse of rarefaction is originated by valves and that it is dislocated for the entrance of the intake manifold systems and finds a point of the system where it is reflected in return in direction to the cylinder. This place where the pulse is reflected is a particular interest place for the project of the intake manifold geometry. In a mono cylindrical configuration, the signal of pressure near the intake valve is characterized by a fast increase in the closing of the valve. From this increase of pressure and posterior the closings of the valve, typical stationary waves pressure of resonance of ¼ wave (Hanriot, 2001). The pressure waves are the main physical phenomenon of practical interest in the transient flow in the intake manifolds system. The behavior of the average mass flow is related with the excitation frequency (in the case the frequency of the aspiration valve) and with the natural frequency of the pipe.

3. EXPERIMENTAL APPARATUS AND METHODOLOGY

In this work had been evaluated the effective torque, the effective power and the specific consumption (in the engine range operation), since these are the parameters normally used to characterize the performance of a automotive engine of internal combustion. The first stage of the experiment was carried through in a Flow bench at PUC Minas of Engines Laboratory, that allow to simulate the conditions of the intake manifold and exhaust of an internal combustion engine. The system produces a constant differential pressure between the atmosphere and a great chamber of tests that pulls atmospheric air for inside of the cylinder. The depression is generated through a big blower and the movement of the valves is produced through a connected electric engine to the command valves axle, by means of an dentated leather strap. The bench flow, as shown in the figure 1, allows the study of the permanent or transient flow regimen. The mass flow variable, pressure and temperature in the intake manifold and cylinder, beyond the camshaft speed, can be gotten.

The equalization tank which the section of tests is connected has capacity of 350 liters and is used to attenuate the pulses of pressure produced by the admission valves. For the execution of the experimental tests was used an engine of normal production of 1368 cm^3, with four cylinders on-line and 8 valves.

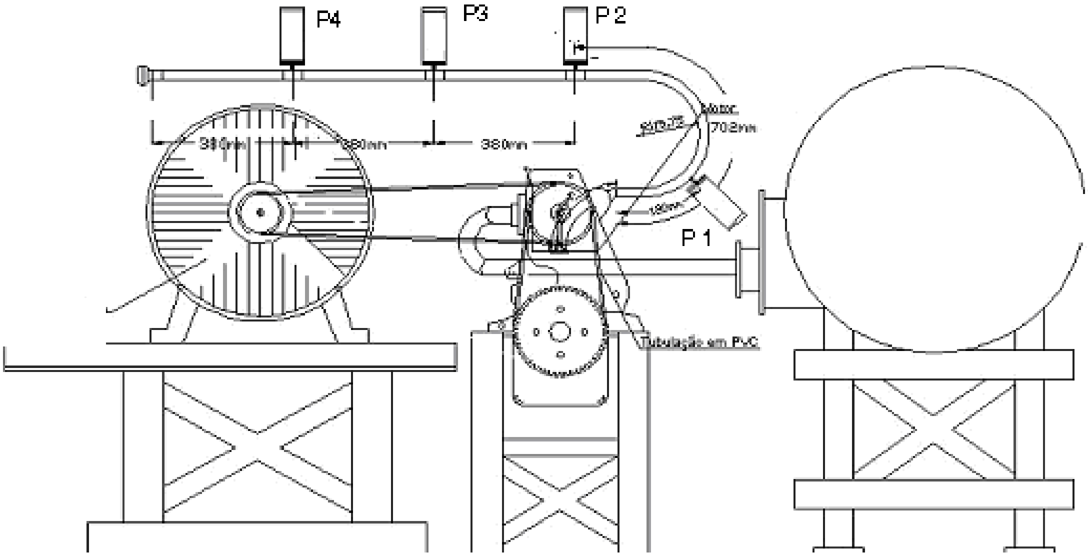

Figure 1: Esquematic drawer of the flow bench.

The experiment was carried through for same length of the intake manifold, however with the resonator in four distinct positions, P1=180 mm from the intake valve, position P2=720 mm and the others distances points 380 mm from the position P2. The resonator stroke was fixed in 100 and represents a volume of 1.76 liters, and represents the frequency answer in 72.23Hz. The figure 2 shows the bench flow and the volumetric variable resonator model that was used.

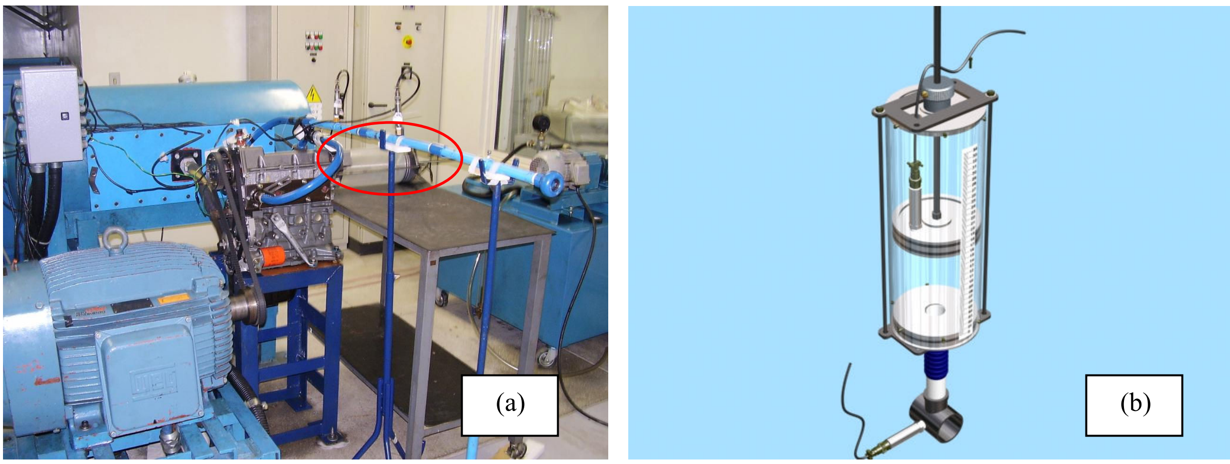

Figure 2: Photo of the Flow Bench with the resonator in the position P1 (a) and model of the variable cylindrical resonator (b).

The second stage of the experiment was performed in a dynamometer bench from PUC Minas Engine Laboratory, where had been gotten the characteristic curves (ABNT, NBR 1585, 1996) and the engine performance map.

The definitions of the engine speed and the corresponding volumes of the resonator to reach the resonance frequency were based on the rotation of more frequent operation in the vehicles. These engines, has working range between 1000 and 6000 rpm, for the most part of the time in road and urban traffic the engine works between 1000 and 3000 rpm. These engine speed and resonator frequency response are present in table 1. In such a way, tests had been performed to identify the influence of the volume of the resonator in the variation of the engine performance indices. Dynamometer pictures and the resonator and the insertion point are showed in the figure 3. The figure 4 shows the resonator being use with the variable volume mechanism.

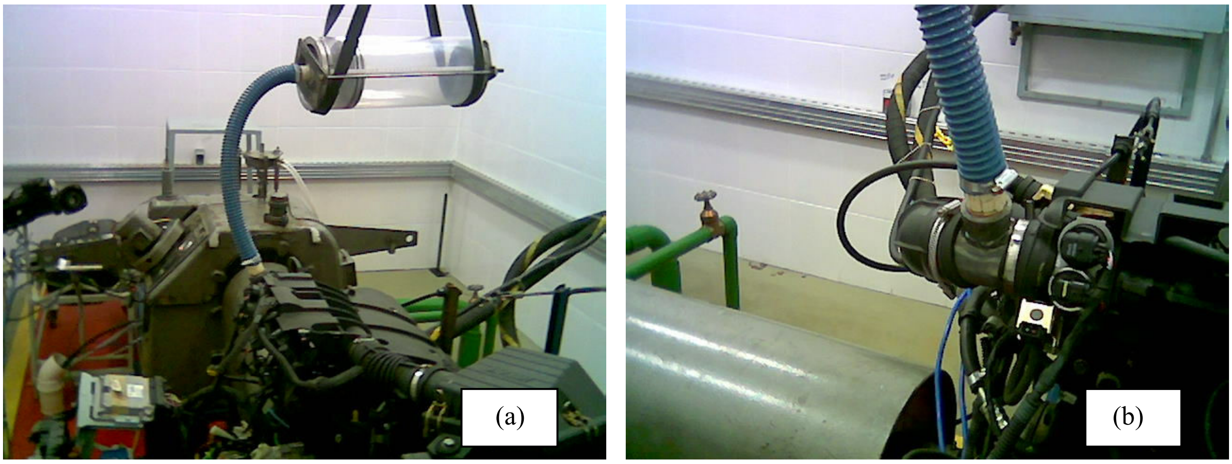

Figure 3: Bench Dynamometer picture with the engine and the resonator (a) and in detail the intake manifold insertion point (b).

Table 1: Resonator characteristic in the dynamometer test

Resonator Piston stroke (mm)	Volume (m^3)	Volume (liter)	Frequency (Hz)	Speed Camshaft (rev/min)	Speed Crankshaft (rev/min)
50	0.00088	0.88313	102.15	1532.32	3064.63
100	0.00177	1.76625	72.23	1083.51	2167.02
150	0.00265	2.64938	58.98	884.68	1769.37
200	0.00353	3.53250	51.08	766.16	1532.32
250	0.00442	4.41563	45.68	685.27	1370.55

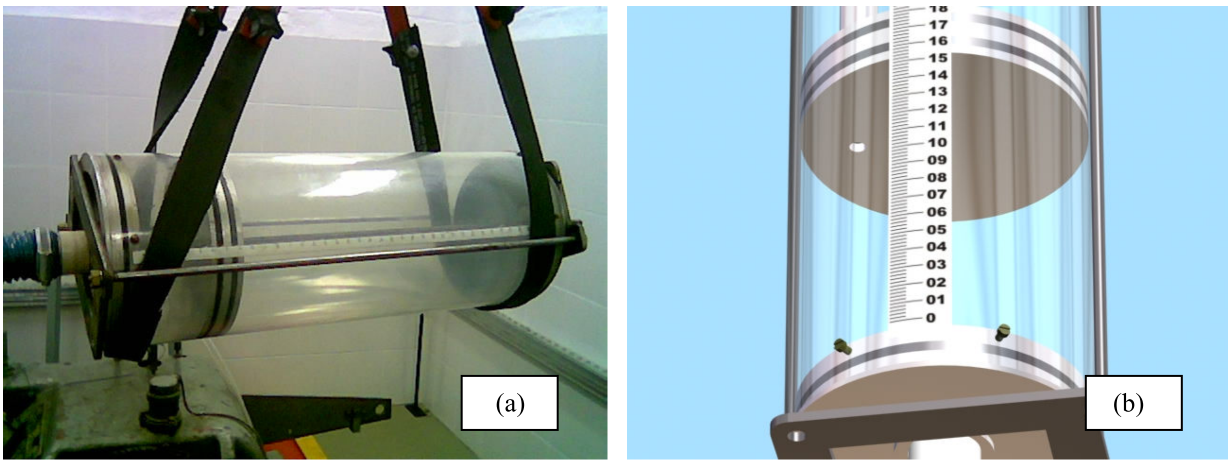

Figure 4: Picture of the resonator setting with the volume 1,76 liters (a) Resonator stroke of l50 mm (b).

4. RESULTS

The first step of experiment had the objective to define the best position of the resonator in the intake manifold. From these tests, the mass flow analysis define that the more efficient resonator position is near the intake valves. The results of the mass flow for the four different resonator positions the fix volume of 1.76 liters (stroke 100 mm), in function of the camshaft speed, are presented in Figure 5. It is important to evaluated in this experiment, the intake manifold pipes are straight and also is consider the constant differential pressure between the equalization tank and the atmospheric. However, those model physics simplifications in this step of the experiment no influence on the results (Pires *et al*, 2003). The figure 5 shows the mass flow with the engine without the resonator and with the resonator on the four different positions describe before, being that which position represents a distance between the intake valve of the engine. Notice that the frequency that happen the high efficiency of the resonator it is near the 1100 rpm. Notice a mass flow gain on others two different positions nearest the valves and a reduction of the mass flow when it is far the valves.

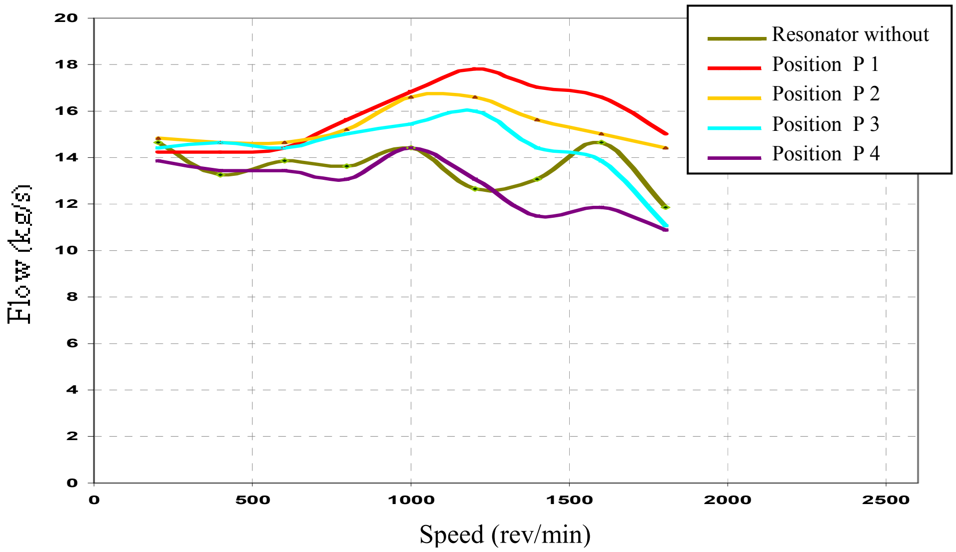

Figure 5: Mass flow behavior in the four positions of the resonator and without the resonator with the 100mm of stroke.

The second step of the experiment was done on the bench dynamometer, where measures the engine performance curves and was were evaluated the torque, power and fuel consumption parameters with the resonator in the position P_1. For the same conditions were evaluated the mean effective pressure, that characterize the work done by the engine (Heywood, 1988). On the all cases, the reference conditions

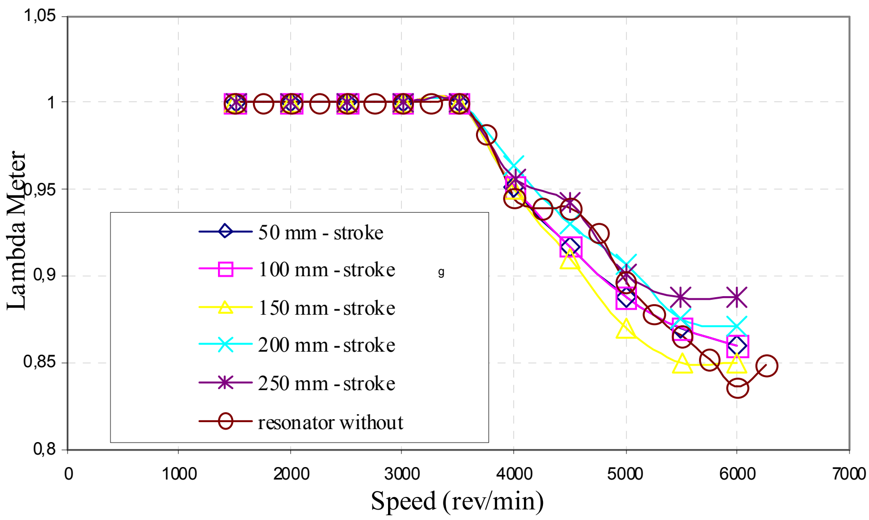

Figure 6 : Lambda values in functions of the resonator volume for the engine speed range.

In all the cases, the reference condition represents the condition without the insertion of the resonator. For all the cases, the air/fuel relation was monitored by the lambda, being that up to 3500 rpm was possible to keep the stoichiometric condition. For higher speeds, an enrichment mixture was necessary to reduce the catalyst temperature. Figure 6 shows the monitoring of the lambda factor for all the analyzed cases. The behavior of this factor must reflect in the brake specific fuel consumption for each case. In such a way, it can be foreseen that the variations in specific consumption can happen more intensive over 3500 rpm.

The figures 7 and 8 show the torque and power curves of engine, respectively, for the diverse presented displacement of the resonator in Table 1, in function of the crankshaft speed.

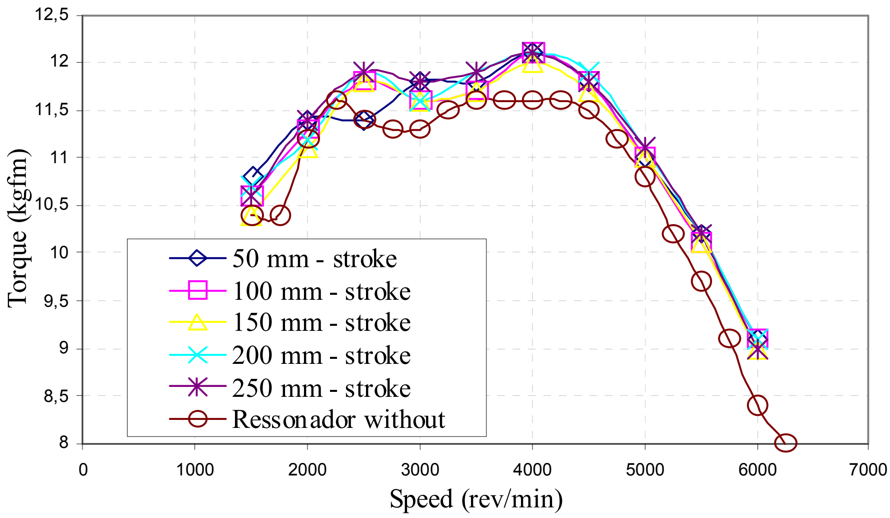

Figure7 : Torque in function of the resonator volume for all the engine speed range.

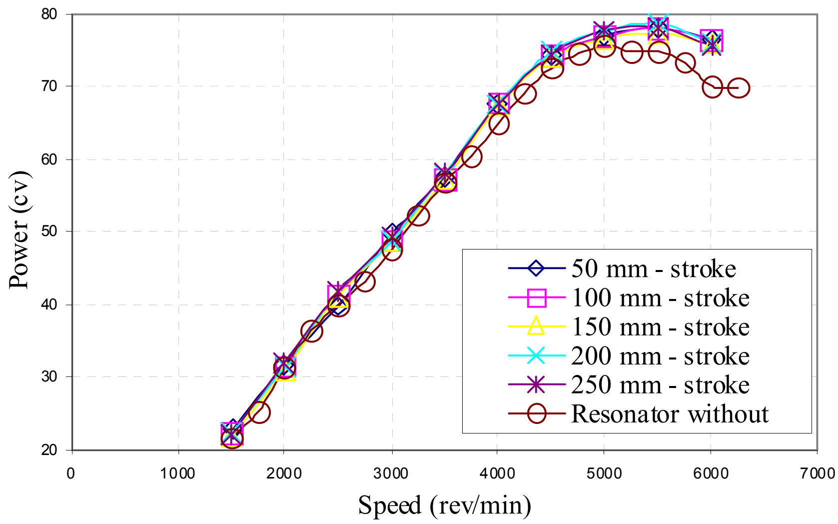

Figure 8 : Power in function of the resonator volume for all the engine speed range.

It can be observed that the torque and power results with the resonator presence show gains for all the resonator volumes, those gains are bigger to speed of 2000 rpm. Higher gains for the torque are observed, presenting lower differences for the power. For speeds over 5000 rpm the gains in the power tends to be bigger. Figure 9 presents the results gotten for the specific consumption. A reduction of the specific consumption with the insertion of the resonator in almost engine range speed. As demonstrated through the analysis of the lambda facto, the reductions of specific consumption are more representative to speed over 3500 rpm, being still bigger for higher speeds.

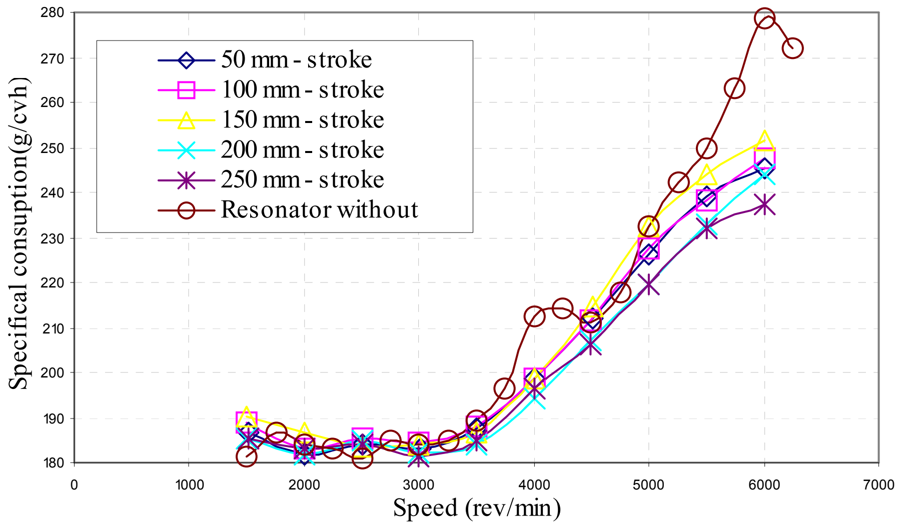

Figure 9 : Specific consumption in function of the resonator volume for all the engine speed range.

Figure 10 presents the results of the brake mean effective pressure for the analyzed volumes. Notices an increase of this pressure for all the analyzed volumes, in practically all the engine speed range. The gain of brake mean effective pressure is practically equal for all the volumes over 3500 rpm.

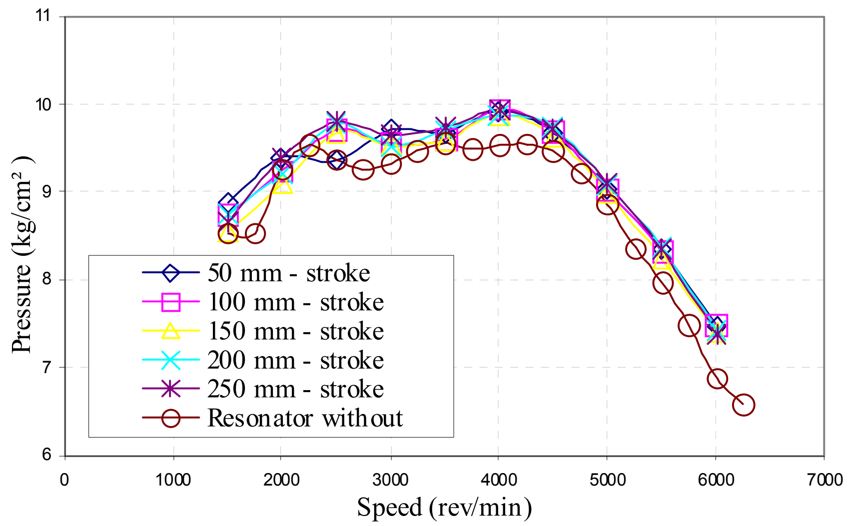

Figure 10 : Break mean effective pressure in function of the resonator volume for all the engine speed range.

5. CONCLUSIONS

The present work evaluates, by the experimental tests in flow bench bank and Dynamometer bench, the effect of variable volumetric Helmholtz resonator insertion in the performance of an internal combustion engine. The references studies, verify the optimum position of the resonator in the intake manifold, to obtain the higher mass flow gain inside de cylinder. The results had shown that the position most adequate of the resonator is that near to the intake valves, independently of the form and the volume of the device. It was also possible to show that one definitive position, more far away from the intake valves, the resonator effects is practically null. For intermediate positions of the resonator, the gain in the intake mass flow depend on the corresponding volume to the resonance frequency, but, one way, represent gain in the mass flow

It was also verified, in dynamometer test, that the variation of the resonator volume influences the engine performance curves in all engine speed range. The variation of the volume allows to adjust the resonator for each engine frequency, in way to get the maximum possible performance for each speed. The resonator optimization for each speed depends on the tuning of the pressure waves with the intake manifold, being able to be adjusted this tuning only with the volume variation.

The results show to be useful the use of an electronic resonator that allows, for each engine speed to adjust the tuning with the pressure waves in the intake manifold, in a way to get the gains profits in performance for all engine speed and load .

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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