

STUDIES ABOUT OTTO-CYCLE ENGINES: A) EFFICIENCY OF THE VARIABLE VALVE CONTROL; B) RATES OF NITROGEN OXIDE FORMATION RELATED TO EXHAUST TEMPERATURES

Fábio Jairo Dias - fabioj.dias@outlook.com

Ezio Castejon Garcia - ezio@ita.br

Thomaz Ernesto de Sousa Savio – thomaz@ita.br

Instituto Tecnológico de Aeronáutica

Divisão de Engenharia Mecânica

Praça Marechal Eduardo Gomes, 50

São José dos Campos - SP, 12.228-900, Brasil

Abstract. *The purpose of this work is to evaluate the efficiency of Otto cycle engines with fixed and variable valve timing using Diesel-RKTM simulation software. Firstly, the history of internal combustion engines of Otto cycle was made in order to improve understanding on the introduction of the mechanisms and operation of engines. Secondly, the theory revision was performed for different types of valve control, especially for operating methods that include mechanical, hydraulic and electronic engine. In the next step, the presentation and use of simulation software were made by defining the input parameters and a way to obtain the results that indicates the best and really efficient valve control. The results showed that the Otto cycle efficiency of engine equipped with a variable valve timing is superior to that one equipped with fixed valve timing. The multiparameter function used in the software ensures a considerable increase in the Numerical investigation efficiency, and it also improves assessment of the technical level of the engines. The calculation of emissions (NO_x) is carried out by the latest technology using the Zeldovich scheme (with detailed kinetic mechanism). The software also allows applications to: Fuel consumption prediction and its optimization, construction of the torque curve and engine performance, combustion and emissions analysis including low calorific fuel, evaluation camshafts, EGR analysis and conversion of diesel engines to gas.*

Keywords: *Engines, Simulation, Variable camshaft.*

1. NOMENCLATURE

η_V	= Volumetric efficiency	e	= Euler's number
P_e	= Exhaust pressure	T	= Turbine
P_i	= Admission pressure	π	= Pi
γ	= Heat capacity ratio	c	= Cylinder
r	= Compression ratio	N_2	= Nitrogen
NO_x	= Nitrogen oxide	NO	= Nobelium
R	= Constants of Gases	O	= Oxygen
P	= Pressure	ω	= Gas Flow Rate

2. INTRODUCTION

Diesel-RKTM is simulation thermodynamic software for engines. It was developed to assess the performance, rational choice of setting and constructive parameters of internal combustion engines, either two or four strokes. It also allows studying the optimization of camshafts and to project intake and exhaust valves.

The development of the Diesel-RKTM software has been started in 1981-1982, at internal combustion engine department (alternative engines), Bauman Moscow State Technical University. Since the start of software design, it comes being incremented improvements, expanding the range of possible variables and simulations in the system with particular emphasis on the operation of adequacy and speed of models, and applied mathematical algorithms. Other computational options were introduced in software to meet the demands of industrial companies, including software users, one being one of the biggest Russian engine manufacturers. In 1991, the first software version with an improved interface, was capable of calculating toxic emissions with EGR system and apply multiparameter functions.

The multiparameter function used in the software ensures a considerable increase in the numerical investigation of the efficiency, improving the assessment of the technical level of the engines. According to Meacham and Stein (1995), to optimize control in real cam time in an engine equipped with a two spindles command can reduce the hydrocarbon (HC) unburnt and nitrogen oxides (NO_x) emitted in the exhaust system. The calculation of emissions (NO_x) is carried out by the latest technology, using the Zeldovich scheme with detailed kinetic mechanism. By analyzing, the internal phenomena should be considered the oil film as a flow Couette (Fox and McDonald, 2006).

According to Taylor (1977), when the shear rate increases, occurs an increased counterforce to slip, from the oil viscosity, which explains the greater power required to overcome the friction at high speed. The software is also

provided with a code "Fuel Spray Visualization" that allows to display as an image with animation, analyze the evolution of the nozzles of fuel and its interaction with the walls of the piston head with a long format spiral. Note that to improve the energy efficiency of engines, some of these engines use pistons in which on its top, also called the head, are designed to "bowls" and or depressions for which during operation is directed to fuel injection.

For this fact takes place, in the assembly of the model in the Diesel-RKTM, there is need of correct choice of diameters of the pistons, the number of pistons, the orientation of the injection nozzles, the injection pressure and evaluation of the spiral formed during the compression stage.

3. DEVELOPMENT OF COMPUTATIONAL MODEL

Diesel-RKTM is a tool that allows the creation of a desired model by the designer, and the entered data is sent to the server in Russia where they are compiled, and then present the results. One of the most difficult processes is for simulation of the combustion process in diesel engines. This process is determined and accompanied by a number of other processes and phenomena occurring intense interaction between the movement of fuel injection and engine cylinder air flow, creating numerous other variables.

Diesel-RKTM also allows the modeling: Diesel (DI) and Gasoline Engines (SI), Gas engines, including pre-chamber systems, and engines powered by different gases: methane, propane-butane, biogas, wood gas, whether two stroke or four stroke and others, etc. The software also allows applications to fuel consumption prediction and its optimization, construction of torque curves and engine performances, combustion and emissions analysis including lower fuel heating value (LHV), evaluation of camshafts, analysis and converting EGR gas of diesel engines.

To carry out this work using the Diesel-RKTM software, it was employed all data provided from the 2.0 engine, 140 HP, and command with 16 valves. The studied engine consists of four cylinders in line with 1998 cm³ of internal volume, somewhere around 1.998 liters, four-stroke, and spark ignition, with the fuel gas. The following is a brief technical motor data sheet: the outer diameter (D) of the piston is 86.0 mm and the course (S) of 86.0 mm; the compression ratio for this fuel is 9.6: 1, wherein the speed range to be studied shall be 1000 to 6000 rpm.

We first carried out the simulation for this engine considering that it has fixed valve timing and the point of optimum ignition, respecting the rule the number of octane (90) for fuel, gasoline, whose simulation is named 1D. In this condition, the scan simulation was performed by varying the ignition timing for the main rotations (RPM): 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500 and 6000, respectively. It will also be assessed when operating at minimum speed rotation of maximum torque, maximum power rotation and final rotation, where for each speed range is admitted charges of 0.5, 0.4, 0.3, 0.2, 0.1, and 0.0 where the load of 0.5 indicates little acceleration and 0.0 charge is full throttle.

With the ignition points obtained in the fixed scanning 1D simulation, as shown in the Fig. 1, the next step is to make a 2D scanning, where is obtained the optimal values for variable valve timing controlled opening of the intake valve IVO (Intake Valve Opening), and the opening of the exhaust valve EVO (Exhaust Valve Opening).

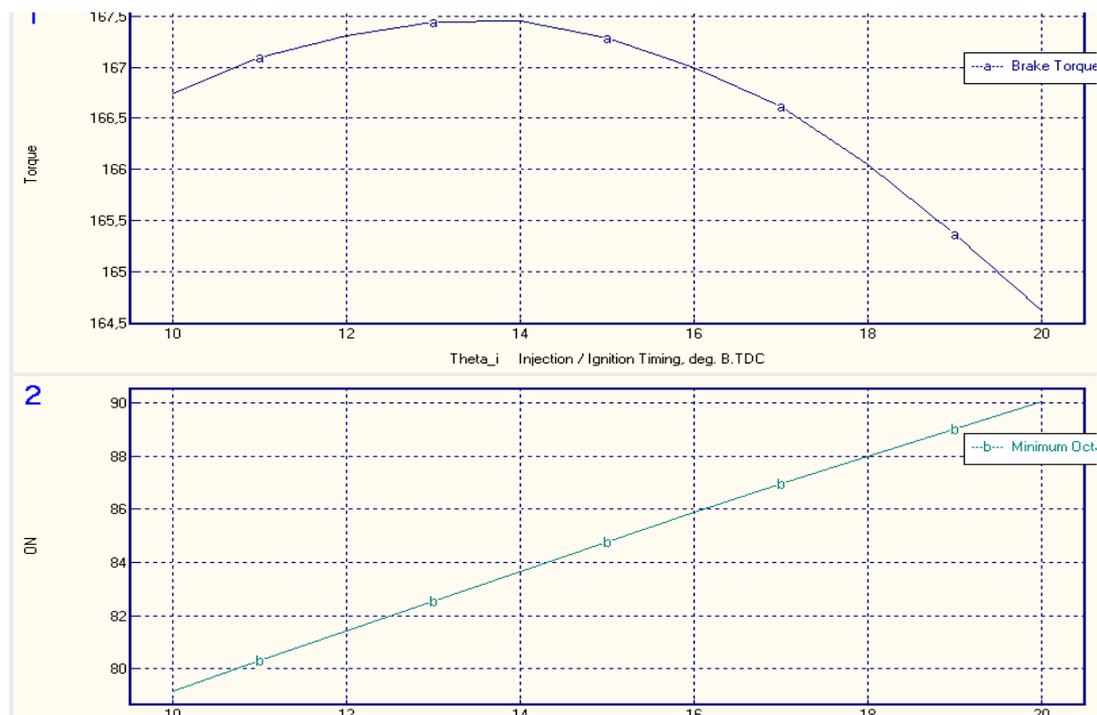


Figure 1: Obtaining the ideal ignition point.

Simulations scanning 2D allow to scan two variables combined IVO and EVO. The results of the variables define satisfactory domains for multiple control variables. Figure 2 shows the results of 2D scanning.

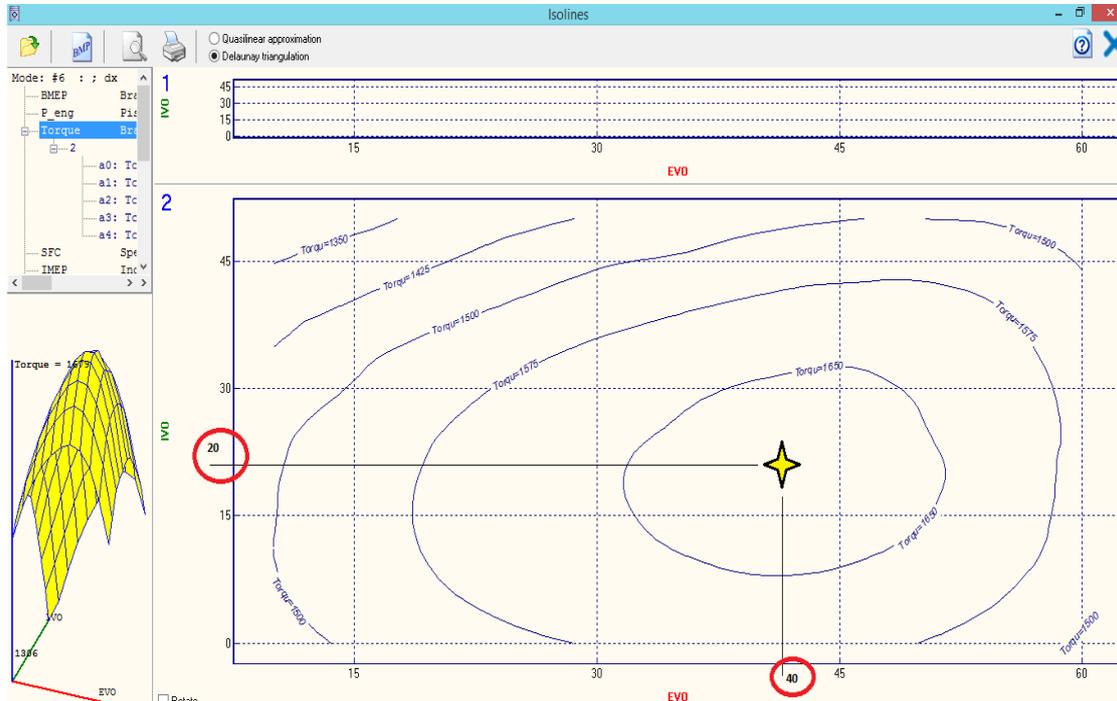


Figure 2 - 2D Scanning

Initially, the Diesel-RKTM software was supplied with engine data such as cylinder bore, cylinder stroke, working speed and compression ratio, according to the manufacturer's information to the engine with fixed valve timing. After the data entry in the software, it starts the first simulations for fixed command for the following speed ranges: 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500 and 6000 RPM, where for each range rotation was added 0.5 load values; 0.4; 0.3; 0.2; 0.1 and 0.0. With the engine simulations with fixed valve timing completed, then it was carried out simulations for engine with variable valve timing.

Firstly, the simulations have been performed to the set of EVO and IVO values, as shown in Fig. 2, for the same range of rotations used in fixed command with their proper charges. With the set of values of IVO and EVO, similar simulations were held to the engine with fixed valve timing for optimal values of point of ignition/spark. After the set of values for variable command had been applied, it was possible to generate graphics of volumetric efficiency, of power x torque curve of exhaust temperature, and for NOx for both kinds of commands (fixed and variable).

Gas parameters in cylinders and collectors for a given engine are defined by step-by-step solution of a system of equations for energy conservation and mass. Also, they are solved the equations of state and composition for open thermodynamic systems where dependencies the gas composition and temperature properties are taken into account.

The parameters of this work, in the Diesel-RK, are obtained by the following procedure:

$$\eta_V = 1 - \frac{P_e - 1}{P_i \gamma(r-1)} \quad (1)$$

$$\frac{dr_{NO_x}}{d\phi} = \frac{p \cdot 2.333 \cdot 10^7 \cdot e^{-\frac{38020}{T_{\pi c}}} \cdot r_{N_2 eq} \cdot r_{O_2 eq} \cdot \left[1 - \left(\frac{r_{NO}}{r_{NO eq}} \right)^2 \right]}{RT_{\pi c} \cdot \left(1 + \frac{2346}{T_{\pi c}} \cdot e^{\frac{3365}{T_{\pi c}}} \cdot \frac{r_{NO}}{r_{O_2 eq}} \right)} \cdot \frac{1}{\omega} \quad (2)$$

4. RESULTS

Volumetric efficiencies

With the values of volumetric efficiency, whose can be seen in Fig. 3, the behavior for both types of commands, as the increase of rotation, can be noted that the volumetric efficiency remains practically the same up to 3700 rpm for both types of commands. This is because variable control system works at higher speeds where the cam profile is aggressive due to the larger valve opening time. At 4000 rpm, the command variable has a volumetric efficiency of about 94%, while the fixed command presents a volumetric efficiency of 90%. From 4000 rpm, the volumetric efficiency for both commands tend to fall, but the variable command presents a minor fall in relation to the fixed command. This increase in volumetric efficiency of variable command in relation to the fixed command occurs due to greater opening of the valves axis command, providing variation, doing so the greater mass of air into the cylinder, and releasing more easily the combustion gases, and thus achieving a better volumetric efficiency.

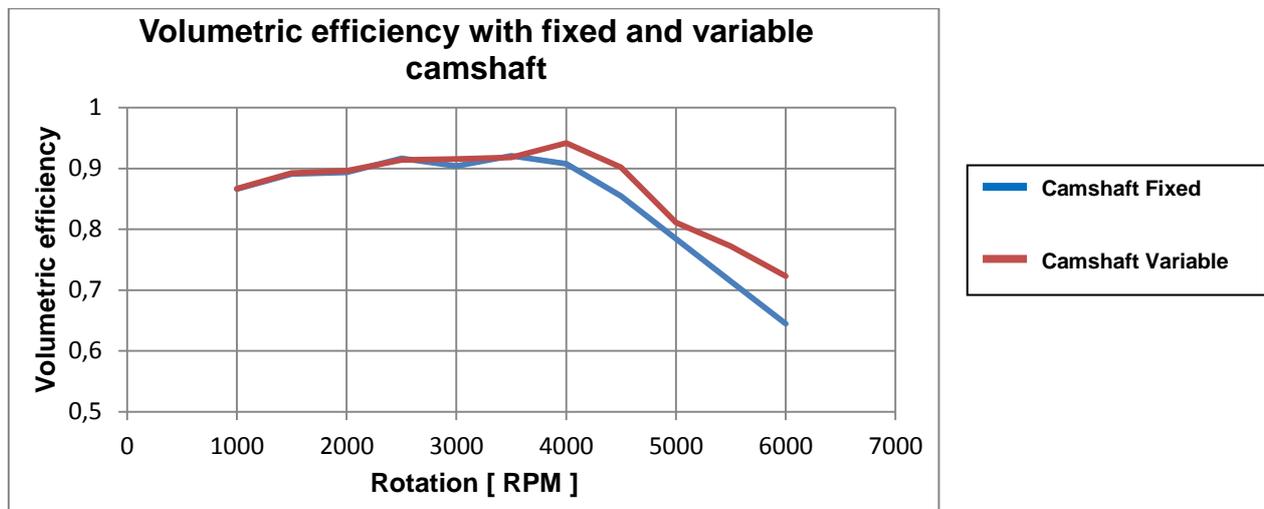


Figure 3: Volumetric efficiency with fixed and variable camshaft.

Torque x Power

It is known that the torque and power are directly connected by the rotation, since the power is the product of torque by rotation. Figures 4 and 5 show the curves of these parameters as a function of rotation. It can be seen in these figures the effect on the volumetric efficiency: the torque and power drop due to increased friction between piston and cylinder, and deficiency in intake fresh air into the cylinder.

The power loss at high speed is connected to frictional power increase; falling torque from intermediate rotations is justified by drop effect on volumetric efficiency from the same speeds. It may be noted that the maximum torque achieved at 2500 rpm begins to steadily decrease due to high rotation. The fresh air filling the cylinder becomes more difficult as the opening and closing of the valve are very fast.

The power increases from 1000 rpm to approximately 4500 rpm. From that point, it begins to fall due to frictional force between the piston and the cylinder; at the thin layer of oil which lubricates the cylinder, this frictional force increases the higher the speed.

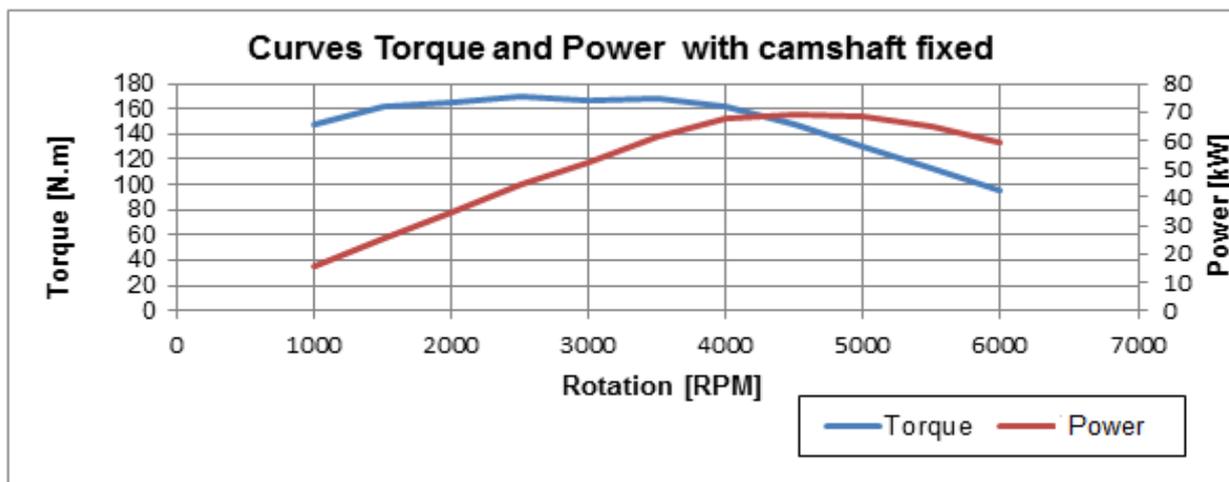


Figure 4: Curves Torque and Power with camshaft fixed.

It is also clear that the results of torque and engine power with variable valve timing are better than the engine with fixed valve timing, for the best filling effect of cylinders as shown in Fig. 5. It can be noted that the maximum torque reached 2500 rpm, and from this, begins to steadily decrease with behavior similar to fixed command. Have the power in variable command if increases from 1000 rpm to 4500 rpm which is the point of maximum power. From this, the power begins to decrease but its fall is much lower compared to fall of power with fixed command. The power, in the variable command case, increases from 1000 to 4500 rpm where it obtained the maximum point. From this, the power begins to decrease but its fall is much lower compared to fall of power with fixed command.

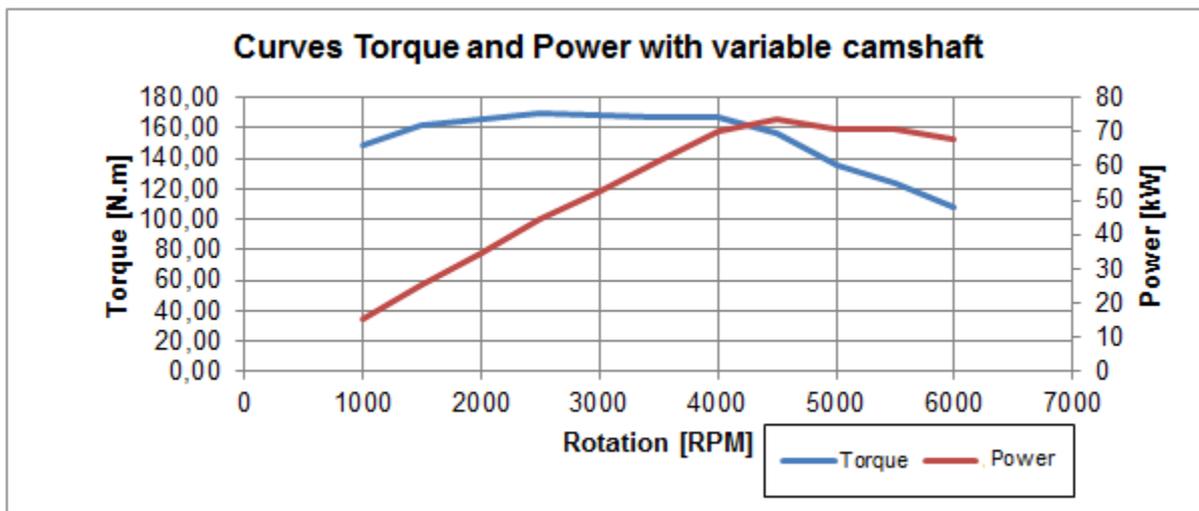


Figure 5: Curve Torque and Power with variable camshaft.

Relationship of nitrogen oxides and exhaust temperature

The results presented in Fig. 6 show a direct connection to the exhaust temperature with the formation of NO_x. To explain this phenomenon we have to look at the molecular N₂ structure: this molecule is composed of two atoms with 3 chemical bonds, highly stable. For breaking of these bonds, i.e. form a nitrogen radical, more energy is represented by temperature is required. Higher temperatures facilitate the N₂ links to rupture and then this moiety is attached to oxygen radical. Within the engine during combustion, temperatures reach levels favor NO_x formation (over 1700 K), and the higher the temperature, the greater the occurrence of the phenomenon. From the energy point of view, the mass fraction of nitrogen oxides is so low that can usually be neglected, but its study is important for the environmental problems it causes.

Figure 6 presents the NO_x increasing versus temperature for each rotation (represented by lines “Serie”) for the fixed and variable valve timing.

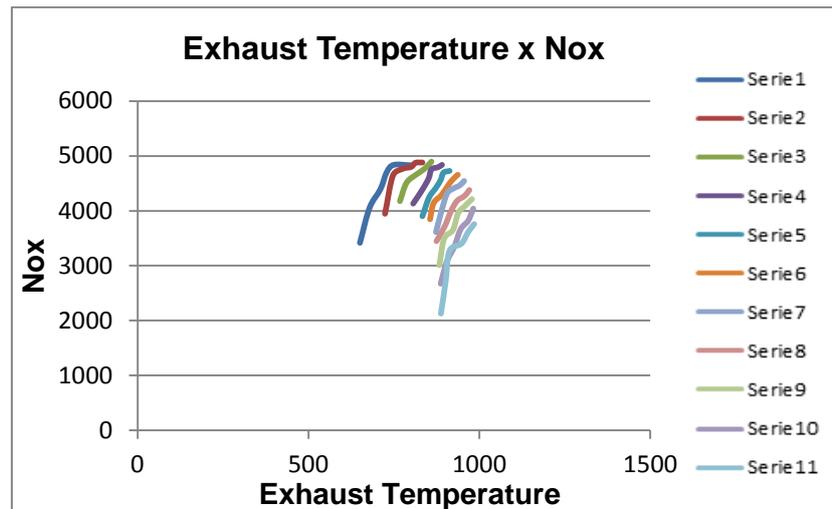


Figure 6: Exhaust Temperature versus NOx.

5. CONCLUSION

Throughout of this work, whose was performed by simulation, it is concluded that the application of variable valve timing in internal combustion engines is more efficient than the fixed camshaft, for the following reasons:

- the command variable reduces the pumping work in the gas exchange, i.e., the pressure loss in the intake air flow into the cylinder and the pressure loss in the flow of combustion products out of the engine are reduced;
- The motor volumetric efficiency is increased due to adjustments made by variable commands, in the points of opening and closing of the intake and exhaust valves, resulting in beneficial effects on cylinder filling;
- torque and engine power equipped with variable valve timing are higher than observed in the others equipped with fixed valve timing, in which this improvement is a reflection of the adjustment made by the variable valve timing in the opening of valves;
- For variable valve timing, there is greater versatility in engine tuning, that is, for each engine operating condition there is an optimum configuration of opening and closing the intake and exhaust valves;
- The specific fuel consumption showed itself with little gain, but it could be seen the variable valve timing engine as more economical when compared to the fixed valve timing engine, by reducing the pumping work, as discoursed above.

6. REFERENCES

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