www.revistageintec.net
ISSN: 2237-0722
revista GEINTEC
Gestão, Inovação e Tecnologias

OTTO MOTOR DINÂMICA

OTTO MOTOR DYNAMICS

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Resumo

Dinâmica de motores Otto são semelhantes em quase todos os motores de combustão interna comuns. Podemos falar então sobre a dinâmica de motores: Lenoir, Otto e Diesel. O modelo apresentado dinâmica é simples e original. A primeira coisa necessária para o cálculo da dinâmica do motor Otto, é o de determinar a massa de inércia reduzida no pistão. Ele utiliza então a equação de Lagrange. A equação dinâmica do movimento do pistão, obtida por integração da equação de Lagrange, assume uma nova forma. Apresenta-se uma nova relação que determina a constante elástica da cambota, k. O momento de inércia J_1 *pode ser determinada com uma relação inicial, bem.*

Palavras-chave: eixo de manivela, dinâmica, constante elástica, momento de inércia.

Abstract

Otto engine dynamics are similar in almost all common internal combustion engines. We can speak so about dynamics of engines: Lenoir, Otto, and Diesel. The dynamic presented model is simple and original. The first thing necessary in the calculation of Otto engine dynamics, is to determine the inertial mass reduced at the piston. It uses then the Lagrange equation. The dynamic equation of motion of the piston, obtained by integrating the Lagrange equation, takes a new form. It presents a new relation which determines the elastic constant of the crank shaft, k. The moment of inertia J_1 *can be determined with an original relation, as well.*

Key-words: crank shaft, dynamics, elastic constant, moment of inertia.

1. Introduction

In conditions which started to magnetic motors, oil fuel is decreasing, energy which was obtained by burning oil is replaced with nuclear energy, hydropower, solar energy, wind, and other types of unconventional energy, in the conditions in which electric motors have been instead of internal combustion in public transport, but more recently they have entered in the cars world (Honda has produced a vehicle that uses a compact electric motor and electricity consumed by the battery is restored by a system that uses an electric generator with hydrogen combustion in cells, so we have a car that burns hydrogen, but has an electric motor), which is the role and prospects which have internal combustion engines type Otto, Diesel or Wankel [6-10]?

Internal combustion engines in four-stroke (Otto, Diesel, Wankel) are robust, dynamic, compact, powerful, reliable, economic, autonomous, independent and will be increasingly clean [1-2].

Let's look at just remember that any electric motor that destroy ozone in the atmosphere needed our planet by sparks emitted by collecting brushes. Immediate consequence is that if we only use electric motors in all sectors, we’ll have problems with higher ozone shield that protects our planet and without which no life could exist on Earth.

Magnetic motors (combined with the electromagnetic) are just in the beginning, but they offer us a good perspective, especially in the aeronautics industry [5].

Probably at the beginning they will not be used to act as a direct transmission, but will generate electricity that will fill the battery that will actually feed the engine (probably an electric motor).

The Otto engines or those with internal combustion in general, will have to adapt to hydrogen fuel [3].

It is composed of the basic (hydrogen) can extract industrially, practically from any item (or combination) through nuclear, chemical, photonic by radiation, by burning, etc... (Most easily hydrogen can be extracted from water by breaking up into constituent elements, hydrogen and oxygen; by burning hydrogen one obtains water again that restores a circuit in nature, with no losses and no pollution) [3].

Hydrogen must be stored in reservoirs cell (a honeycomb) for there is no danger of explosion; the best would be if we could breaking up water directly on the vehicle, in which case the reservoir would feed water (and there were announced some successful) [3].

As a backup (not too desired), there are trees that can donate a fuel oil, which could be planted on the extended zone, or directly in the consumer court. With many years ago, Professor Melvin Calvin, (Berkeley University), discovered that “Euphora” tree, a rare species, contained in its trunk a liquid that has the same characteristics as raw oil. The same professor discovered on the territory of Brazil, a tree which contains in its trunk a fuel with properties similar to diesel.

During a journey in Brazil, the natives driven him (Professor Calvin) to a tree called by them "Copa-Iba".

At the time of boring the tree trunk, from it to begin flow a gold liquid, which was used as indigenous raw material base for the preparation of perfumes or, in concentrated form, as a balm. Nobody see that it is a pure fuel that can be used directly by diesel engines.

Calvin said that after he poured the liquid extracted from the tree trunk directly into the tank of his car (equipped with a diesel), engine functioned irreproachable.

In Brazil the tree is fairly widespread. It could be adapted in other areas of the world, planted in the forests, and the courts of people.

From a jagged tree is filled about half of the tank; one covers the slash and it is not open until after six months; it means that having 12 trees in a courtyard, a man can fill monthly a tank with the new natural diesel fuel.

In some countries producing alcohol or vegetable oils, for their use as fuel (this is not a very efficient solution).

The Indians propose a Little Car driven with compressed air, (but one uses an internal engine as well, to compress the air in a tank); this solution isn’t efficiently; its low consumption is due to the small gauge of car and its load very low.

This new little vehicle isn't a real but only a quaint solution.

In the future, aircraft will use ion engines, magnetic, laser or various micro particles accelerated.

Now, and the life of the jet engine begin to end. Even in these conditions internal combustion engines will be maintained in land vehicles (at least), for power, reliability and especially their dynamics.

Otto engines design [1-5], includes and the dynamic design.

2. Determining the Inertial Mass

The first thing necessary in the calculation of Otto engine dynamics, is to determine the inertial mass reduced at the piston (1) [11-13].

$$\begin{cases} M \equiv M^* = m_t + m_{bA} \cdot \frac{r^2}{s'^2} + \frac{J_1}{s'^2} + \frac{J_2}{s'^2} \cdot \frac{\lambda^2 \cdot \cos^2 \varphi}{\cos^2 \alpha} \\ M = m_t + [(m_{bA} + \frac{J_1}{r^2}) \cdot (1 - \lambda^2 \cdot \sin^2 \varphi) + \frac{J_2}{l^2} \cdot \cos^2 \varphi] \cdot \\ \cdot \frac{1}{\sin^2 \varphi \cdot (\cos\alpha + \lambda \cdot \cos\varphi)^2} \\ M = m_t + \frac{m_1 \cdot (1 - \lambda^2 \cdot \sin^2 \varphi) + m_2 \cdot \cos^2 \varphi}{\sin^2 \varphi \cdot (\cos\alpha + \lambda \cdot \cos\varphi)^2} \end{cases} \quad (1)$$

Then it derives the reduced mass to the crank position angle (2). Were used for piston the next kinematics parameters (4). Lagrange equation is written in the form (3).

$$\left\{ \frac{dM}{d\varphi} = (M - m_t) \cdot (-2) \cdot (\frac{\cos\varphi}{\sin\varphi} - \frac{\lambda \cdot \sin\varphi}{\cos\alpha}) - \frac{2 \cdot \cos\varphi \cdot (\lambda^2 \cdot m_1 + m_2)}{\sin\varphi \cdot (\cos\alpha + \lambda \cdot \cos\varphi)^2} \right. \quad (2)$$

$$M \cdot \omega^2 \cdot x'' + \frac{1}{2} \cdot \frac{dM}{d\varphi} \cdot \omega^2 \cdot x' = k \cdot (s - x) - F_p \quad (3)$$

$$\begin{cases} s = r \cdot \cos\varphi + l \cdot \cos\alpha - l \\ s' = -\frac{r \cdot \sin\varphi}{\cos\alpha} \cdot (\cos\alpha + \lambda \cdot \cos\varphi) \\ s'' = -r \cdot \cos\varphi - \frac{r \cdot \lambda \cdot \cos(2\varphi)}{\cos\alpha} - \frac{r \cdot \lambda^3 \cdot \sin^2 \varphi \cdot \cos^2 \varphi}{\cos^3 \alpha} \end{cases} \quad (4)$$

3. Dynamic Equations

The dynamic equation of motion of the piston, obtained by integrating the Lagrange equation (3), takes the form (5).

$$x = s \cdot \sqrt[3]{\frac{k}{k - m_t \cdot \omega^2}} - c_3 \cdot \frac{\cos\varphi}{\cos\alpha \cdot (\cos\alpha + \lambda \cdot \cos\varphi)} + c_4 \cdot \cos\varphi \tag{5}$$

Dynamic reduced velocity (6) and dynamic reduced acceleration (7) are obtained by derivation.

$$x' = s' \cdot \sqrt[3]{\frac{k}{k - m_t \cdot \omega^2}} + c_3 \cdot \frac{\sin\varphi}{\cos\alpha \cdot (\cos\alpha + \lambda \cdot \cos\varphi)} - c_4 \cdot \sin\varphi \tag{6}$$

$$x'' = s'' \cdot \sqrt[3]{\frac{k}{k - m_t \cdot \omega^2}} + c_3 \cdot \frac{\cos\varphi}{\cos\alpha \cdot (\cos\alpha + \lambda \cdot \cos\varphi)} - c_4 \cdot \cos\varphi \tag{7}$$

Angular velocity ω^* is obtained through kinetic energy conservation (8-12).

$$\frac{1}{2} \cdot J^* \cdot \omega^{*2} = \frac{1}{2} \cdot J_D^* \cdot \omega_D^2 \tag{8}$$

$$\begin{cases} \omega_D = \omega_m \cdot D = \omega_m \cdot (\cos\alpha)^2 = \omega_m \cdot \cos^2\alpha = \\ = \omega_m \cdot (1 - \sin^2\alpha) = \omega_m \cdot (1 - \lambda^2 \cdot \sin^2\varphi) \end{cases} \tag{9}$$

$$J^* = J_1 + m_{bA} \cdot r^2 + m_t \cdot s'^2 \tag{10}$$

$$J_D^* = J_1 + m_{bA} \cdot r^2 + m_t \cdot x'^2 \tag{11}$$

$$\omega^* = \sqrt{\frac{J_1 + m_{bA} \cdot r^2 + m_t \cdot x'^2}{J_1 + m_{bA} \cdot r^2 + m_t \cdot s'^2}} \cdot \frac{\pi \cdot n}{30} \cdot (1 - \lambda^2 \cdot \sin^2\varphi) \tag{12}$$

Dynamic velocity (13) and kinematics velocity (14) are written:

$$\dot{x} = x' \cdot \omega^* \tag{13}$$

$$\dot{s} = s' \cdot \omega_m = s' \cdot \frac{\pi \cdot n}{30} \tag{14}$$

Dynamic acceleration (15) and kinematics acceleration (16) are written:

$$\ddot{x} = x''\cdot\omega^{*2} \tag{15}$$

$$\ddot{s} = s''\cdot\omega_m^2 = s''\cdot\frac{\pi^2 \cdot n^2}{900} \tag{16}$$

4. Notations

In the Figure 1 it presents the crank shaft [6-10].

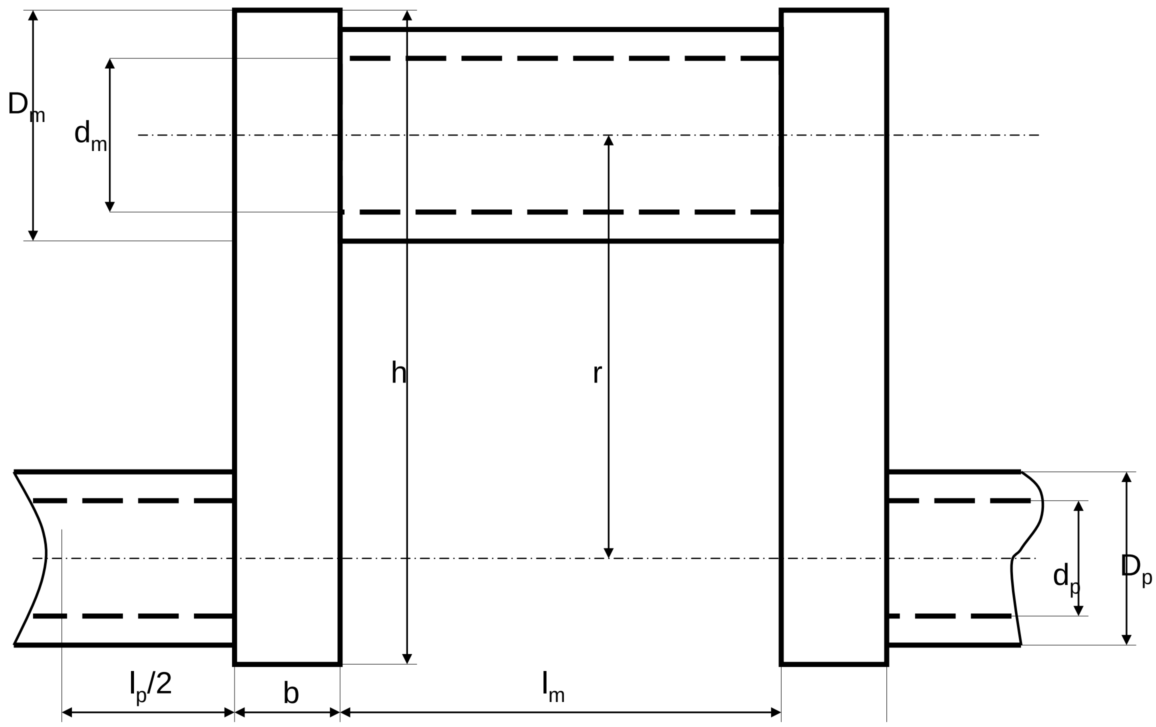

Fig. 1. *Crank Shaft*

The relation (17) determines the elastic constant of the crank shaft, k. For the masses it uses the notations (18).

λ $\Rightarrow$ the ratio between lengths of crank and rod; $\lambda = \frac{r}{l}$

m_p $\Rightarrow$ the mass of the piston, with piston bolt and segments;

m_b $\Rightarrow$ the mass of the rod;

$$k = \frac{3 \cdot \pi \cdot E \cdot G \cdot (D_m^4 - d_m^4)}{4G(l_m + b)^3 + 96Er^2 \sin^2 \varphi (D_m^4 - d_m^4)\left[\frac{l_p + .4D_p}{D_p^4 - d_p^4} + \frac{l_m + .4D_m}{D_m^4 - d_m^4} + \frac{8r - 1.6(D_p + D_m)}{b(2r + D_p + D_m)^3}\right]} \quad (17)$$

$$\begin{cases} m_{bA} = m_b \cdot \frac{l''}{l}; \quad m_{bB} = m_b \cdot \frac{l'}{l} \\ l' + l'' = l; \quad m_{bA} + m_{bB} = m_b \\ m_t = m_p + m_{bB} \\ m_1 = m_{bA} + \frac{J_1}{r^2} \\ m_2 = \frac{J_2}{l^2} \end{cases} \quad (18)$$

The parameters c1-c4 take the forms (19).

$$\begin{cases} c_1 = \frac{r}{k} \cdot \omega^2 \quad [\frac{m}{kg}] \\ c_2 = \lambda^2 \cdot m_1 + m_2 \quad [kg] \\ c_3 = c_1 \cdot c_2 \quad [m] \\ c_4 = c_1 \cdot m_t \quad [m] \end{cases} \quad (19)$$

The moment of inertia J_1 can be determined with the relation (20).

$$J_1 = \frac{\pi \cdot \rho}{32} \cdot \left\{ (l_p + 2 \cdot b) \cdot (D_p^4 - d_p^4) + (l_m + 2 \cdot b) \cdot \left[(D_m^4 - d_m^4) + (D_m^2 - d_m^2) \cdot 8 \cdot r^2 \right] \right\} \quad (20)$$

The crank length, r, and the length of the connecting-rod, l, can be seen in the kinematics schema of an Otto mechanism (see the Fig. 2) [1-2, 6-10].

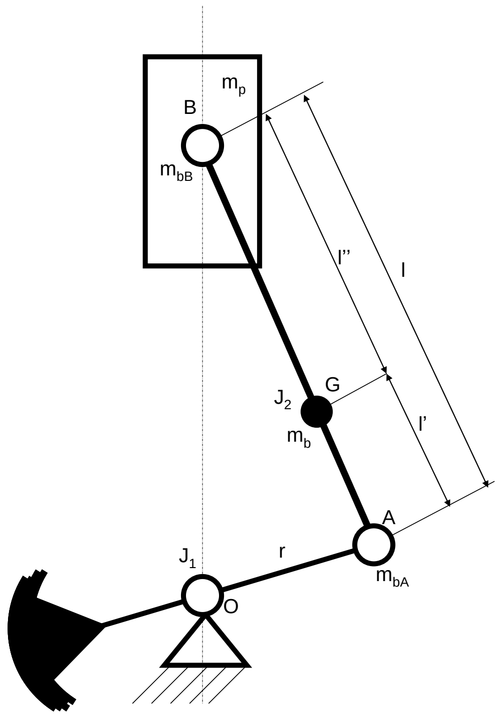

Fig. 2. *Otto mechanism kinematics schema*

5. Dynamic Analysis of the Mechanism and Discussion

When λ increases the mechanism dynamics is deteriorating. r=0.25 [m]; l=0.3 [m]; $\lambda = 0.8(3)$; For n=8000 [rpm] the mechanism is working normally (see the accelerations diagram from the Fig. 3).

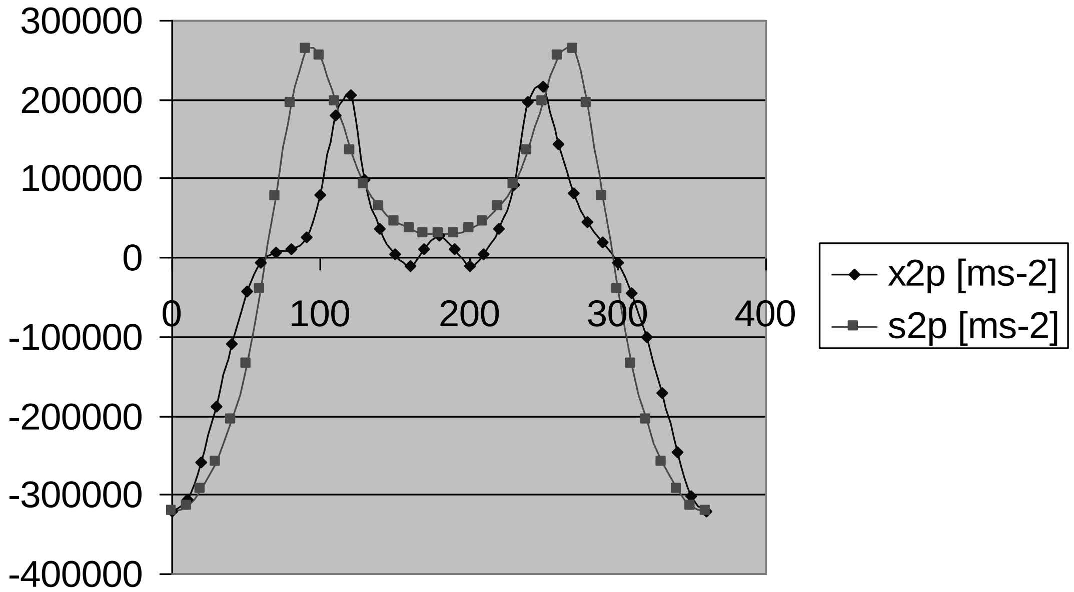

Fig. 3. *Dynamic and kinematics accelerations; n=8000 [rpm];* $\lambda = 0.83$ *r=0.25 [m] l=0.3 [m]*
$\lambda = 0.8(3)$

At n=9000 [r/m] the mechanism work abnormally (see the accelerations diagram from the Fig. 4).

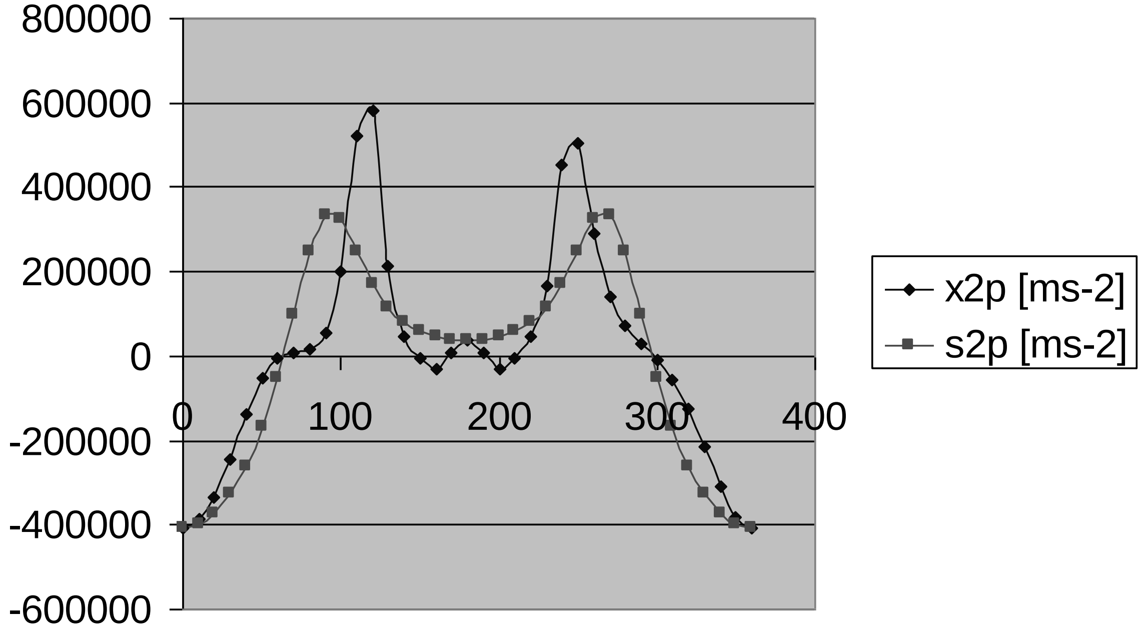

Fig. 4. *Dynamic and kinematics accelerations; n=9000 [rpm];* $\lambda = 0.83$ *; r=0.25[m];l=0.3[m]*

For a proper operation is necessary reduction of the ratio λ , especially if we want to increase the engine speed (see the next diagrams; Fig. 5-8).

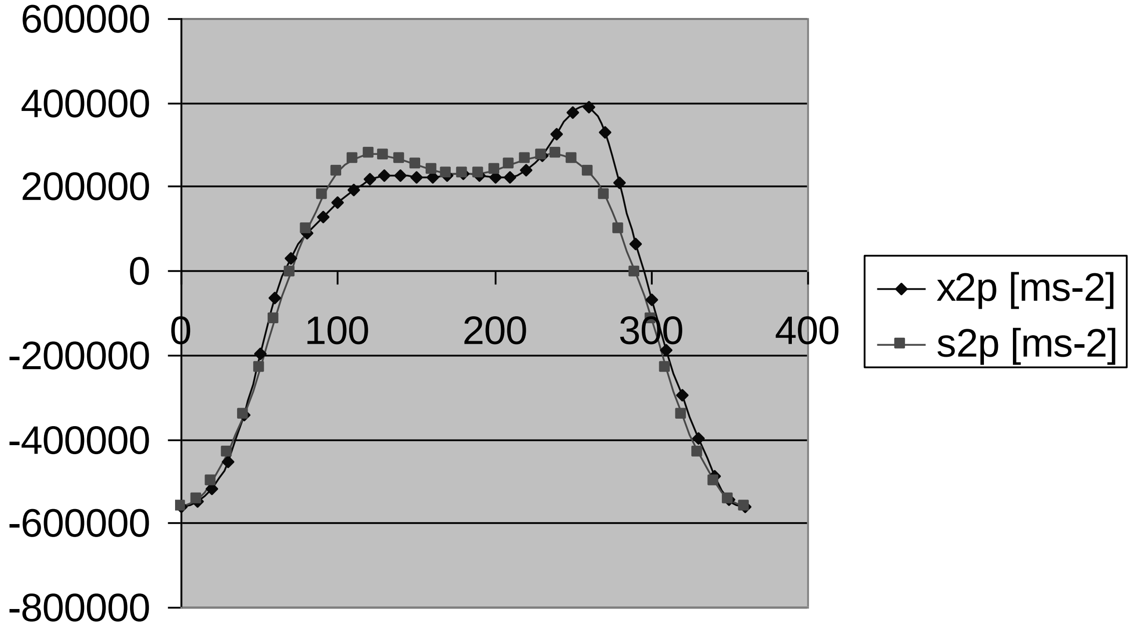

Fig. 5. *Dynamic and kinematics accelerations; n=12000 [rpm]; r=0.25[m];l=0.6[m];* $\lambda = 0.42$

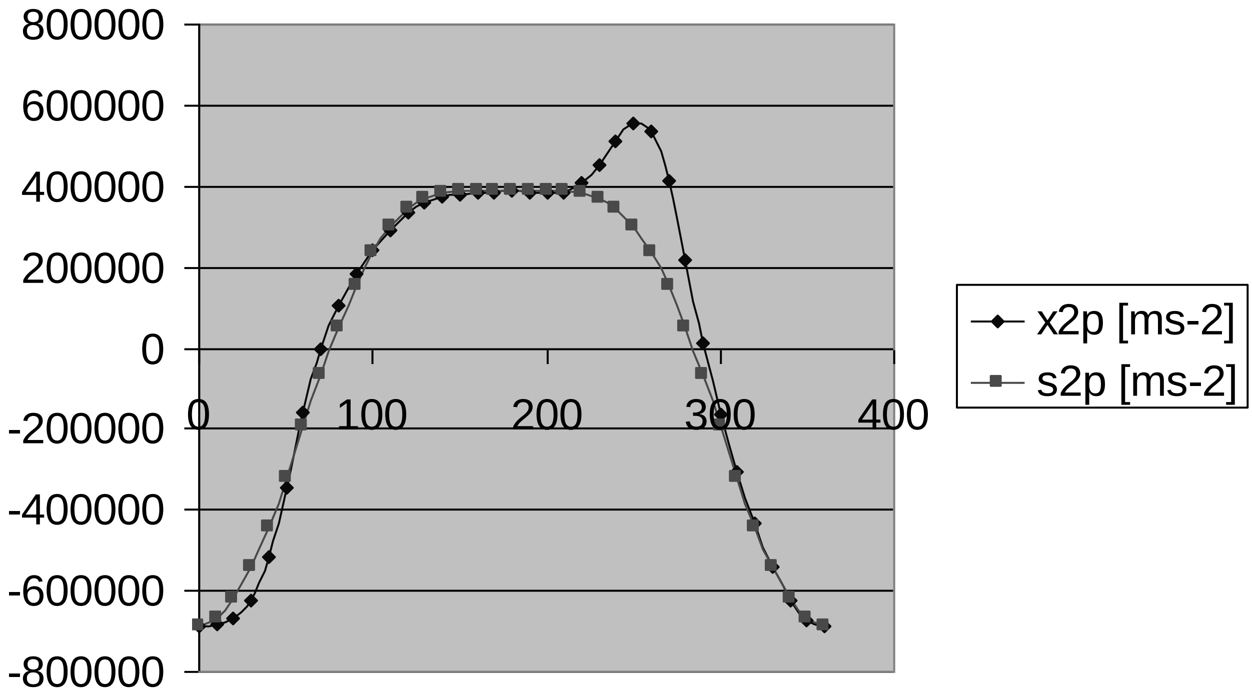

Fig. 6. *Dynamic and kinematics accelerations; n=14000 [rpm]; r=0.25[m];l=0.9[m];* $\lambda = 0.27$

We can reduce the acceleration values by reducing r and l. It can reduce the acceleration values especially if we want to increase the engine speed by reducing r and l (the lengths of crank and rod).

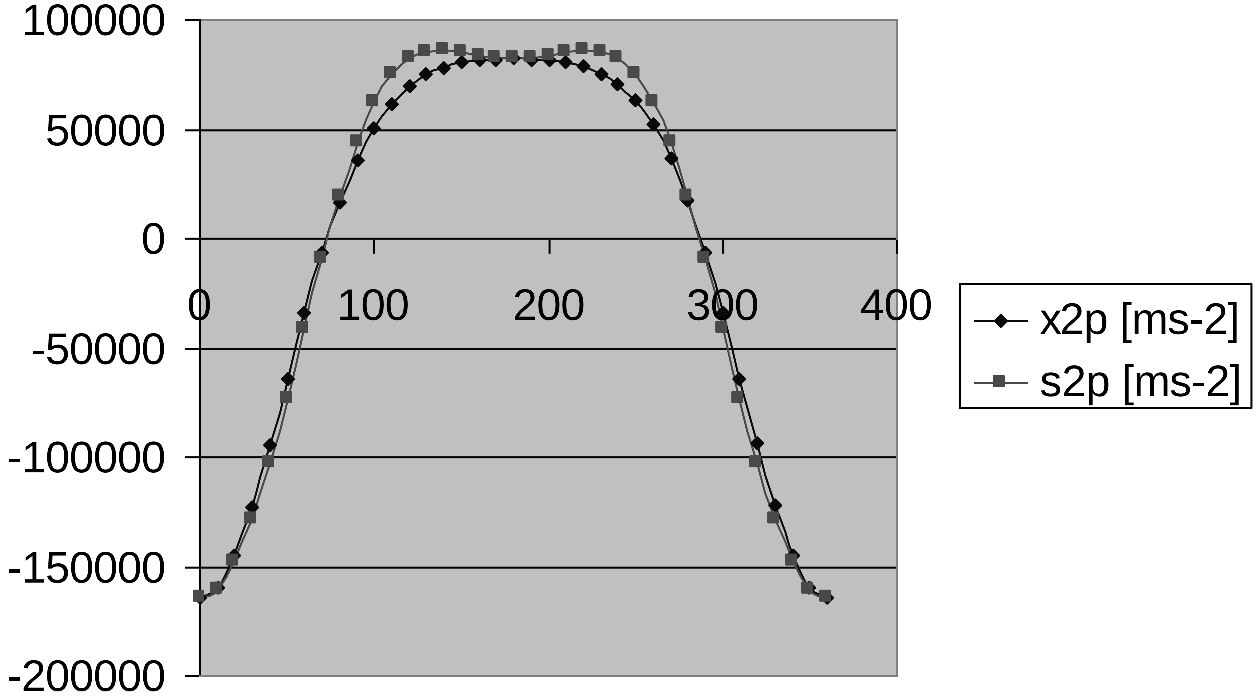

Fig. 7. *Dynamic and kinematics accelerations; n=15000 [rpm]; r=0.05[m];l=0.15[m];* $\lambda = 0.33$

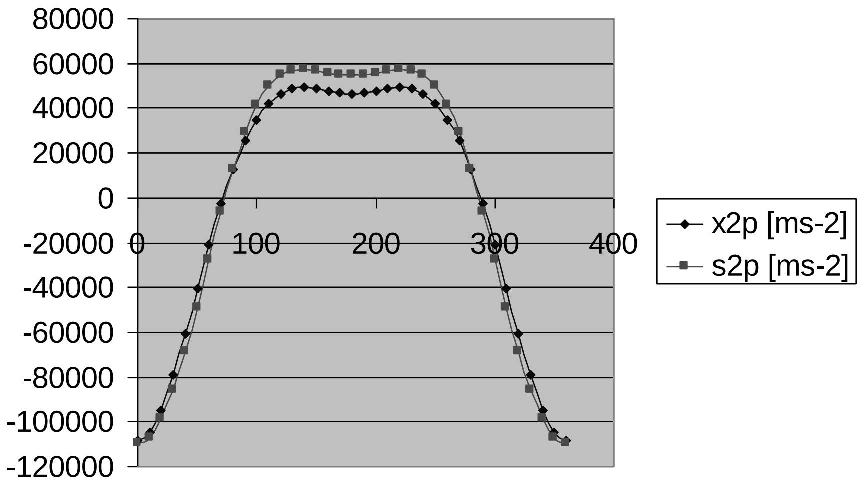

Fig. 8. *Dynamic and kinematics accelerations; n=50000 [rpm]; r=0.003[m];l=0.009[m];* $\lambda = 0.33$

6. Determining the Mechanical Efficiency when the Otto Mechanism Works Like a Steam Roller

The Otto mechanism works like motor mechanism in a single cycle (a π angle), when the piston is moving from the near dead point to the distant dead point, and it works like steam roller in the rest of the energetically cycle. At the two cycle engines, the motor works like steam roller, in a single cycle, when the piston is moving from the distant dead point to the near dead point. At the four cycle engines, the motor works like steam roller, in three cycle; two times the piston is moving from the distant dead point to the near dead point, and in one cycle (one time) the piston is moving from the near dead point to the distant dead point. By a cycle (a π angle), one understands a time, a single time, precisely a semi kinematical-cycle; a kinematical cycle has a $2.\pi$ angle. In figure 9 one can see the forces in Otto mechanism when the mechanism works like a steam roller.

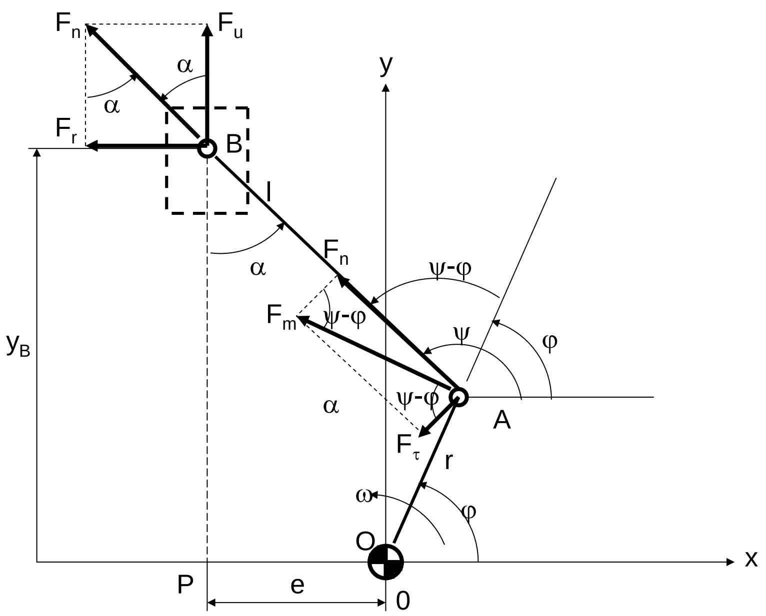

Fig. 9. *Forces, when the piston works like a steam roller*

The input force (the consumed motor force), F_m, perpendicular in A on the crank OA (r), is divided in two components: 1. F_n–the normal force, which is the active component, the only components transmitted from couple A to joint B; 2. F_τ–the tangential force, which can give a couple, and can rotate the connecting-rod, or bend it, [11-12]; see the system (21):

$$\begin{cases} F_n = F_m \cdot \sin(\psi - \varphi) \\ F_\tau = F_m \cdot \cos(\psi - \varphi) \end{cases} \tag{21}$$

In joint B, the transmitted force, F_n, is divided in two components too: 1. F_u – the useful force; 2. F_r – a force normal at the guide axis; see the system (22).

$$\begin{cases} F_u = F_n \cdot \cos\alpha = F_n \cdot \sin\psi = F_m \cdot \sin(\psi - \varphi) \cdot \sin\psi \\ F_r = F_n \cdot \sin\alpha = -F_n \cdot \cos\psi = -F_m \cdot \sin(\psi - \varphi) \cdot \cos\psi \end{cases} \tag{22}$$

The utile power can be written in form (23) and the consumed power can be written in form (24).

$$\begin{cases} P_u = F_u \cdot v_B = F_m \cdot \sin(\psi - \varphi) \cdot \sin\psi \cdot \dfrac{r\omega \sin(\psi - \varphi)}{\sin\psi} = F_m \cdot r \cdot \omega \cdot \sin^2(\psi - \varphi) \end{cases} \tag{23}$$

$$P_c = F_m \cdot v_A = F_m \cdot r \cdot \omega \tag{24}$$

The momentary mechanical efficiency when the piston works like steam roller, can be calculated with the relation (25).

$$\begin{cases} \eta_i = \dfrac{P_u}{P_c} = \dfrac{F_m \cdot r \cdot \omega \cdot \sin^2(\psi - \varphi)}{F_m \cdot r \cdot \omega} = \sin^2(\psi - \varphi) = \\ = \dfrac{[\sqrt{l^2 - (e + r \cdot \cos\varphi)^2} \cdot \cos\varphi + (e + r \cdot \cos\varphi) \cdot \sin\varphi]^2}{l^2} \end{cases} \tag{25}$$

7. Determining the Dynamic Mechanical Motor Efficiency

Dynamic velocities of joints are aligned along of the forces directions. Because of this, the dynamics efficiency takes the expression (26) [11].

$$\begin{cases} \eta_i^D = \frac{P_u^D}{P_c} = \frac{F_m \cdot v_m \cdot \sin^2\psi \cdot \sin^2(\psi - \varphi)}{F_m \cdot v_m} = \\ = \sin^2\psi \cdot \sin^2(\psi - \varphi) = \eta_i \cdot D \\ motor: \quad \eta_i = \sin^2\psi, \quad D = \sin^2(\psi - \varphi) \\ steam \quad roller: \quad \eta_i = \sin^2(\psi - \varphi), \quad D = \sin^2\psi \end{cases} \tag{26}$$

In both regimes, dynamic yield takes the same expression, but the dynamic coefficient (D) makes the castling with mechanical yield [11].

The dynamics angular velocity of the drive shaft is [11]:

$$\omega^D = \omega \cdot D \tag{27}$$

Through a computer program, dynamic velocities and accelerations are determined for different types of heat engines [11].

Figure 10 presents the diagram for two-stroke engine (Lenoir); may be observed the dynamic accelerations [13-15].

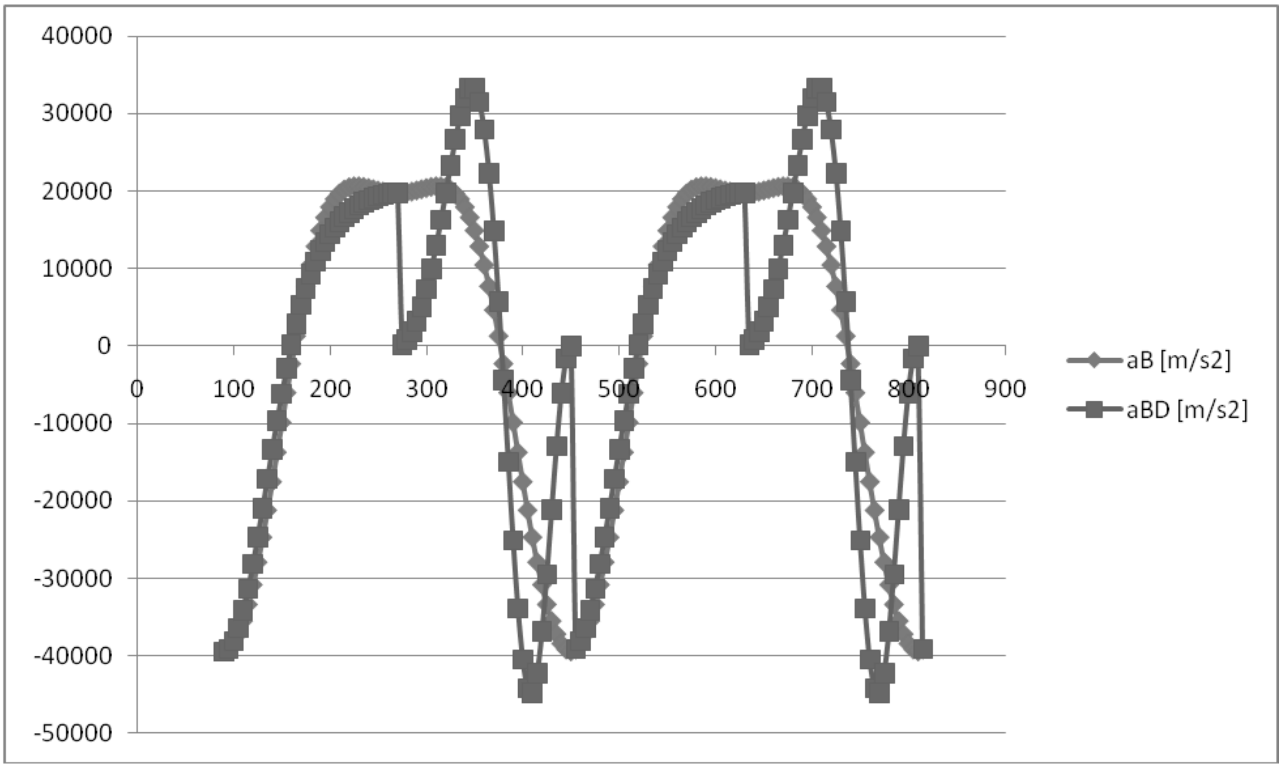

Fig. 10. *The dynamic accelerations to a Lenoir engine*

Figure 11 presents the diagram for four-stroke engine (Otto or Diesel); may be observed the dynamic accelerations.

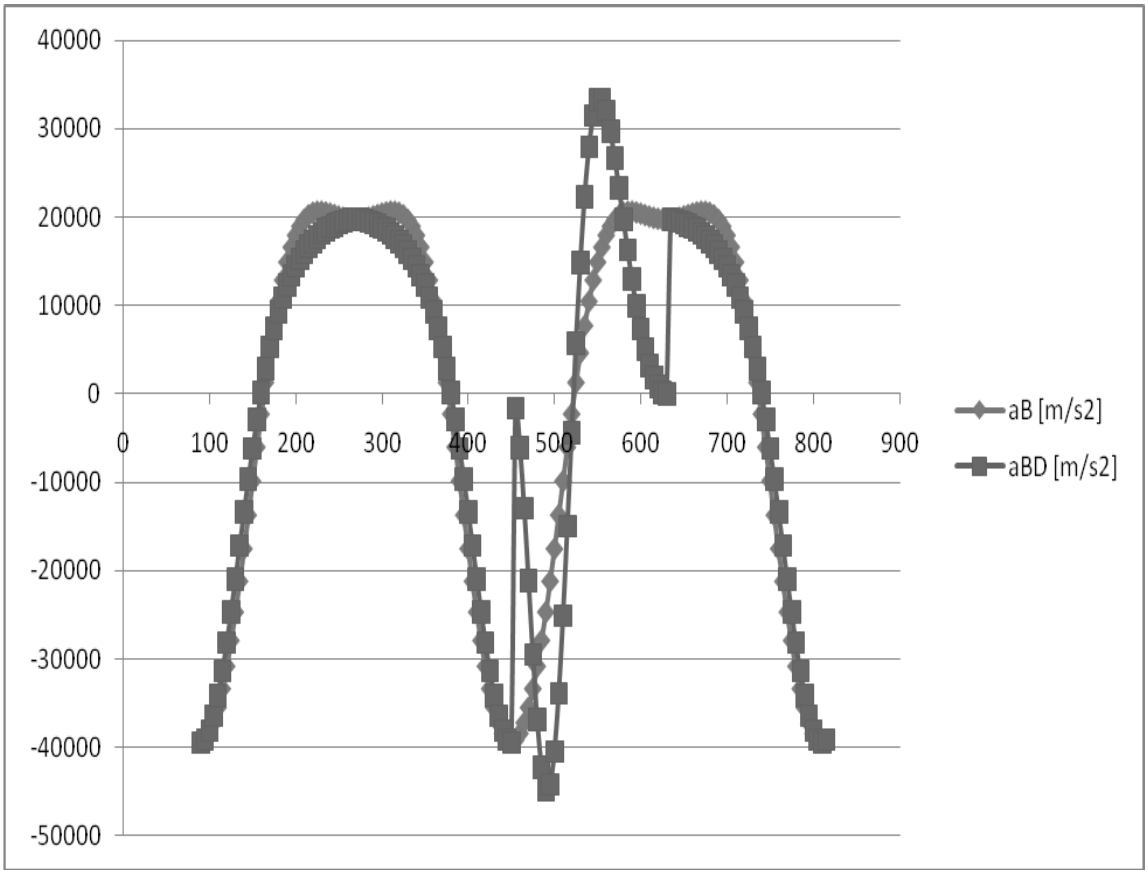

Fig. 11. *The dynamic accelerations to an Otto or a Diesel engine*

At four-stroke engine (type Stirling, Watt), all times are motor, so that we can see dynamic accelerations which have shocks, vibration and noises (to follow the diagram in Figure 12) throughout the range.

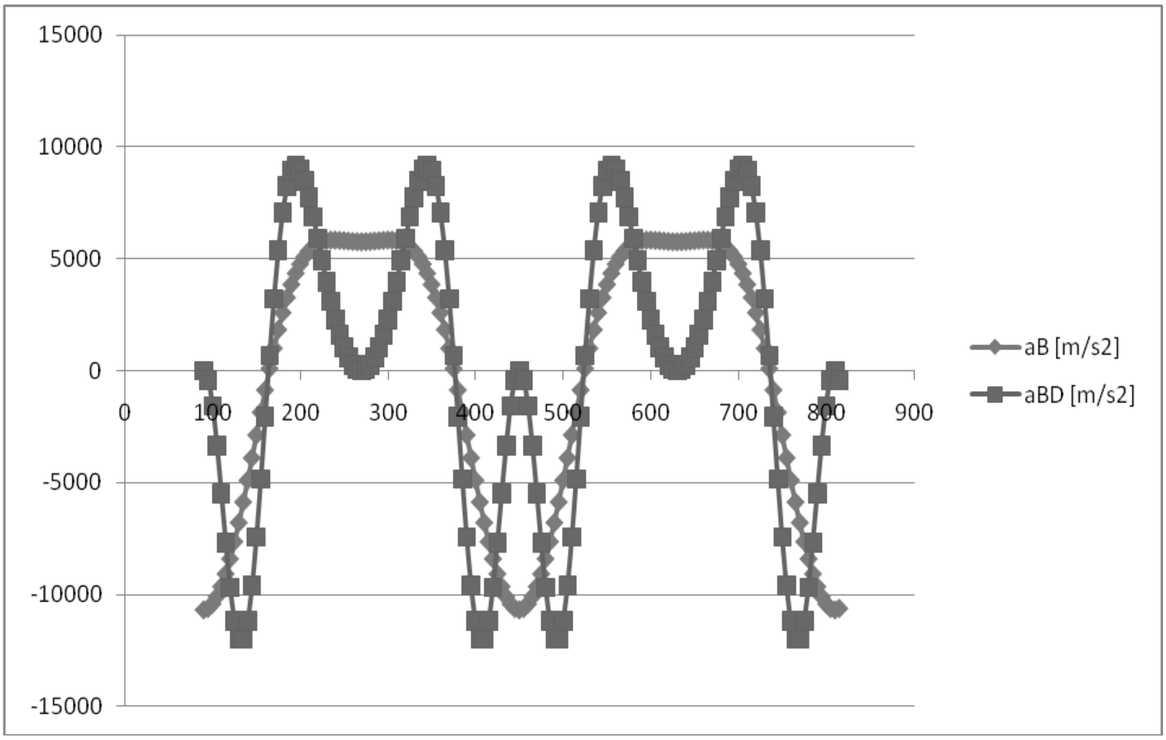

Fig. 12. *The dynamic accelerations to a Stirling or Watt engine*

Conclusions

The momentary mechanical efficiency when the piston works like steam roller (25), is different that the efficiency when the piston works like motor. Generally the steam roller efficiency is lower that the motor efficiency. The steam roller efficiency is approximately 50% or a lower value and the motor efficiency can be 60-99%, in function of the constructive parameters, e, r, l.

The motor efficiency increases when the ratio, $\lambda=r/l$, decreases. For a $\lambda<0.33$, the motor efficiency is high enough. One must calculate three types of efficiency for the four cycle engines, and one should calculate two ways of efficiency for the two cycle engines. The mechanical efficiency for the four cycle engines can be 60%, and for the two cycle engines can be 73%, with e=10 [mm], r=20 [mm], l=90 [mm]. The two cycle engines can give us a 13% more mechanical efficiency.

The Otto mechanism may be improved for giving a better efficiency and a minimum value for the maximum acceleration. Constructive, one must adopt a lower stroke and a greater bore. The radius of crank r, must be shortened. The piston should take the aspect of a pot (a frying pan). Dynamic velocities of joints are aligned along of the forces directions.

At four-stroke engine (type Stirling), all times are motor, so that we can see dynamic sharpened speeds. Dynamic accelerations have shocks, vibration and noises (to follow the diagram in Figure 12) throughout the range [11].

In addition, there must be considered and the thermal efficiency of the engine, which also reduces the final yield value [4].

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Recebido: 13/03/2014

Aprovado: 05/08/2016