SCIENTIFIC BULLETIN
OF THE POLITEHNICA UNIVERSITY TIMISOARA, ROMANIA
Transactions on MECHANICS
Vol. 60 (74) **ISSN 1224 - 6077** **Fasc. 1, 2016**

PERFORMANCES ANALYSIS OF A CAM ENGINE

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***Abstract**: Improving the performances of internal combustion engines is a continuous goal. Trying by all means increasing efficiency and thus reducing fuel consumption and emissions. One tested way would be to replace crank and connecting rod mechanism with a cam mechanism. In this way it could change how the processes occurs in the engine, and in particular the combustion process. In this paper are analyzed by numerical simulation advantages that such a constructive solution would entail. The analysis is done by comparing the cam engine with the classic one from which it is derived.*
***Keywords**: internal combustion engine, simulation, cam engine.*

1 Introduction

An IC engine is defined as a device which transforms the chemical energy resulted after the combustion process in mechanical energy. Studies are made on IC engines today in order to improve the specific power of the engine and its efficiency.

The simulation of an IC engine using a simulation program can be a very powerful tool to analyze all the process that take place inside the cylinder. Also by modifying the entering parameters in the created model (like the crankshaft radius, the engine speed etc.), the processes can be improved, e.g. introduce more fresh mixture into the cylinder when the intake stroke takes place, have a complete combustion of the mixture, produce a higher pressure in the expansion stroke, minimize as much as possible the mechanical work used in the exhaust stroke to evacuate the burned gases from the cylinder.

The performances of an IC engine can be evaluated by analyzing the PV diagram.

In the present paper was analyzed a cam engine that uses a new piston motion in order to make the combustion stroke to take place at constant volume. For comparison the simulations have been performed for a classic crank rod engine and a cam engine. The two configurations are depicted in figure 1.

In the paper of Jovan Dorić "Constant Volume Combustion Cycle for IC Engines" [7] was shown that the piston movement law have a big impact on the engine performances. Volumetric efficiency, PV diagram for the unconventional piston movement have been calculated and compared to a normal IC engine.

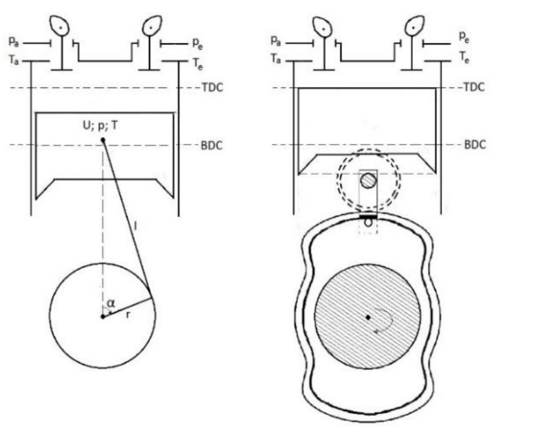

Figure 1, the two engine configurations considered for the present study

In "Efficiency of a new internal combustion engine concept with variable piston motion" [8] is presented a new engine concept with an unconventional piston movement created by a toroidal piston.

The movement of the piston is dictated by a mechanism with two pairs of non-circular gears. The results show the difference made by the piston movement law in the PV diagram on heat addition at constant volume.

2 Mathematical model

For computing the engine cycle, the first principle of thermodynamics for open systems is used.

$$dQ = dU + dL + dI_A + dI_E \quad (1)$$

For simplicity, air as working fluid with constant heat capacities was considered.

The heat exchange between the engine and the environment has to components: the heat release during the fuel combustion and the heat exchange trough the engine walls. For the present study the heat flux trough the walls is neglected, and the heat release during fuel combustion is computed considering a Vibe type burning law [1]:

$$Q = H_c \cdot m_f \cdot \left[1 - e^{-a\cdot\left(\frac{\alpha-\alpha_{sb}}{\Delta\alpha}\right)^{m+1}}\right] \quad 2$$

where the H_c is the calorific power of the fuel, m_f is the fuel mass computed based on the air mass trapped in the cylinder after the admission valve closes, a and m are the burning shape parameters, α_{sb} is the point where the burning start and Δα is the combustion duration.

The enthalpy of the incoming and outgoing fluid is computed based on the fluid temperature, respectively the fluid quantity:

$$dI = dm \cdot c_p \cdot T \quad 3$$

The fluid mass that enters or exits the cylinder is calculated considering the valves as a convergent nozzle, and the flow area is calculated based on a valve timing and lifting. For that we consider polidin cames [2]

The internal energy can be rewritten as:

$$dU = c_v \cdot (T \cdot dm + m \cdot dT) \quad 4$$

and the mechanical work:

$$dL = pdV \quad 5$$

Now, by solving the equations 1, the temperature inside the cylinder is obtained and based on the thermal equation of state the pressure can be calculated.

The above mentioned model is solved in the present work with Matlab/Simulink using the Runge-Kutta solver with fixed computational steps.

The purpose of the present work is to compare the performances between an engine with a crank rod mechanism and cam engine. From computational point of view the difference between the two engines is the movement law of the piston. For crank rod engine, it can be written:

$$x = l + r - r \cdot cos(\alpha) - l \cdot \sqrt{1 - \left(\frac{r\cdot sin(\alpha)}{l}\right)^2} \quad 6$$

and for the cam engine is proposed:

$$x = r + r \cdot \sqrt{\frac{1+b^2}{1+\left(b\cdot cos(\alpha+\pi)\right)^2}} \cdot cos(\alpha + \pi) \quad 7$$

where r represents the crankshaft radius (specific to the classic motion of the piston), l is the connecting rod length, α is the crankshaft position, and b is the shape parameter. The reason that the crankshaft radius is used in the determination of the new motion law is that the piston stroke must be equal in both cases, as the scope of this paper is to compare engine output for the two mechanisms.

The engine power and thermal efficiency is computed, for comparison, using the formulas:

$$P = \frac{\int_0^{2\pi} pdV}{t} \quad 8$$

where t is the engine cycle period.

$$\eta = \frac{\int_0^{2\pi} pdV}{H_c \cdot m_f} \quad 9$$

3 Results and discussions

The numerical simulations have been performed for a four stroke internal combustion engine with the characteristics presented in table 1

Table 1, Engine characteristics

Name	symbol	u.m.	value
Engine speed	N	rot/min	5000
Crank radius	R	M	0.025
Connecting rod length	L	M	0.012
Engine bore	D	M	0.06
Compression ration	ε	-	10
Admission valve opening	α_{AO}	°	700
Admission valve closing	α_{AC}	°	200
Admission valve diameter	d_A	m	0.03
Admission pressure	p_A	bar	0.8
Admission temperature	T_A	K	300
Admission flow coefficient	μ_A	-	1
Exhaust valve opening	α_{EO}	°	520
Exhaust valve closing	α_{EC}	°	20
Exhaust valve diameter	d_E	M	0.025
Exhaust pressure	p_E	bar	1
Exhaust temperature	T_E	K	300
Exhaust flow coefficient	μ_E	-	1
Start of burning	α_{SB}	°	340
Burning duration	$\Delta\ \alpha_B$	°	50
Burning parameters	a, m	-	5.6, 3
Calorific power of the fuel	H_c	MJ	43

The idea behind this study was to see what is happening if the fuel burning take place at constant volume, therefore for the cam engine was proposed a piston movement law than ensure a small variation of the volume around dead centers. In figure 1 the piston movement laws for the considered mechanisms are presented:

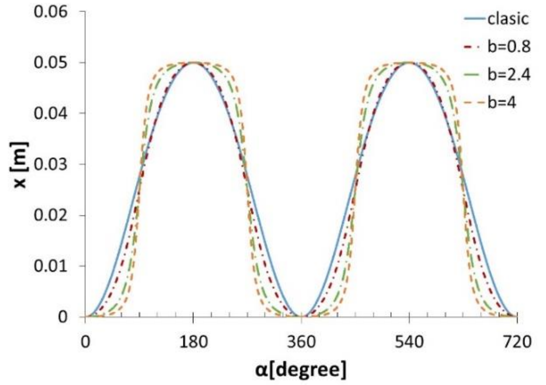

Figure 2, Piston movement for the considered mechanisms. For the cam engine different values of the shape factor was considered.

As the shape factor b is increasing the variation of the cylinder volume, around dead centers, it is kept at almost the same value for a longer time.

Although the burning can take place at constant volume this new piston movement law leads to higher values of the piston acceleration between dead points (figure 2). This means also higher inertia, which involves higher friction forces and lower mechanical efficiency, and finally the necessity of a more robust mechanism.

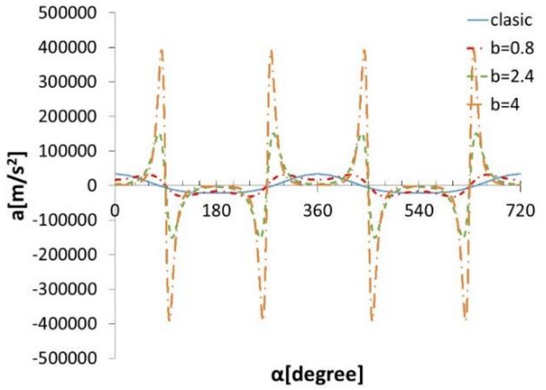

Figure 3, Piston acceleration for the considered mechanisms.

Also due to a small variation of the volume during fuel burning was expected an increase of the in cylinder pressure figure 3.

Higher pressure, which leads to higher forces, comes together with higher temperature inside the cylinder with impact on the emissions mainly on the NOx formation.

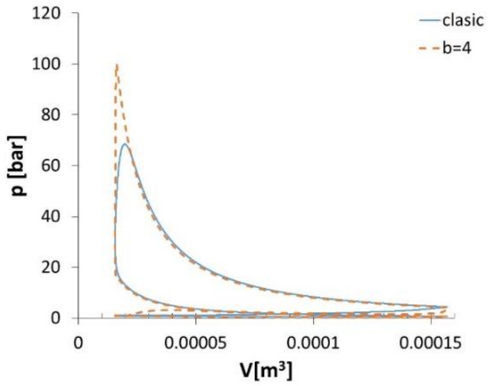

Figure 4, the p-V diagram for crank rod engine (classic) and the cam engine (with a shape factor b=4)

The cam engine, and special the one studied in this paper, besides a low mechanical efficiency due to higher forces that acts in the engine mechanism ensures a higher thermal efficiency. As presented in fugure 5 the thermal efficiency is increasing with almost 8% compared to the classical engine. The engine power presents a maximum for a b=1.6 but the overall changes are not significant

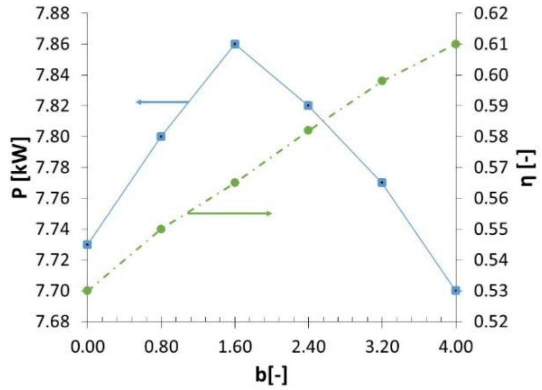

Figure 5 Power and thermal efficiency for the classic internal combustion engine b=0 and cam engines b=0.8, 1.6, 2.4, 3.2, and 4

4 Conclusions

In the present paper is presented a comparison, from the performance point of view, between a classical internal combustion engine and cam engine. The thermal efficiency can be significantly improved by using a non-conventional movement of the piston. The drawback of the cam engine consists in increasing the forces that acts in the engine mechanism and as a consequence a lower mechanical efficiency. Also due to higher temperature inside the cylinder the NOx production is expected to increase. In the present study the mechanical efficiency was not quantified therefore it is not possible to state that the overall efficiency is higher for the cam engine. A detailed analysis concerning the mechanical efficiency is required.

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ANALIZA PERFORMANŢELOR UNUI MOTOR DE TIP "CAM-ENGINE"

Rezumat: *Îmbunătăţirea performanţele motoarelor cu ardere internă este un deziderat continuu. Se încearcă pe toate căile creşterea eficienţei acestuia şi implicit reducerea consumului de combustibil si a emisiilor poluante. Una dintre metodele încercate ar consta in inlocuirea mecanismului bielă manivelă cu un mechanism cu camă. In acest fel s-ar putea modifica modul în care au loc procesele in motor si în special procesul de ardere. În lucrarea de faţă se analizează prin simulare numerică avantajele pe care o astfel de soluţie constructiva le-ar implica. Analiza se face comparativ cu motorul classic din care este derivat.*