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Experimental study on noise reduction and performance enhancement for internal combustion engines

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Abstract. As the number of cars increases and large cities become more and more crowded, noise reduction becomes more and more important. The decrease of the fuel consumption and the increase of power to the same cylindrical capacity are always current topics. This paper's aim is to bring a contribution to solving these problems. The proposed solution consists in the use of ceramic materials in the design of the combustion chamber.

1 Introduction

Although internal combustion engines were invented in the middle of the 19th century, they went on for more than half a century before imposing themselves in front of electric motors to equip onto cars. This is largely due to Henry Ford's innovative ideas put into practice in 1913 [1, 3, 5].

With global warming and the depletion of fossil fuel reserves after almost a hundred years, the debate between electrical and internal combustion cars has been resumed. On the other hand, on a larger scale, biofuel is required in fuelling internal combustion engines. The cars equipped with electric motors seem ideal at first sight as they are more friendly to the environment. According to some researchers in the field, manufacturing of electric batteries represents approx. 80% of that made by an Otto engine car. Also, recycling the batteries is still an unsolved problem due to their lack of standardization. Internal combustion engines will have a relatively long-life equipping hybrid car [2, 7, 8].

Internal combustion engines will still represent the solution for the propulsion of trucks, military equipment, ships etc [4, 5]. Improving the performance indices of internal combustion engines remains an ongoing research topic to increase the performance of internal combustion engines, the use of new materials in general and the use of ceramic materials may be a solution [3, 9].

"Advanced ceramics" represents a group of structural and functional materials, with superior characteristics to the classical variants. They are designed for special fields of use, where they offer a higher performance compared to the metallic or polymeric materials. Advanced ceramics intervene in applications where the latter classes of products reach their limits [6, 9].

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The new class of “advanced ceramic” materials, which entered the market in the 20th century includes much more pure material systems, with specially processed compounds. They were developed mainly for structural and electronic applications. Advanced ceramics are distinguished by their high chemical purity and high values of use characteristics [6, 9].

In the last 25 years, new structural materials, such as ceramics, polymers and composites, have caused revolutionary changes in the field of materials engineering. With advanced ceramics and composites, the concepts of materials and structures taken together have led to a new concept of integrated design. Each projected material consolidates the discrete and functional parts into one, multifunctional structure, which leads to the highest efficiency of material use and the lowest costs [6, 9].

The innovative technological ceramics extend their use in the engineering of applications that exploit their mechanical properties. All applications for cutting-edge technologies require components that have high mechanical and wear resistance, along with high toughness, high breaking resistance through ballistic impact. They add tenacity, chemical inertia and ability to work at high temperatures. In some cases, they may have special functions: electrical, magnetic, optical or chemical-biological [6, 9].

2 Equipment and methods

In the early 1980s, the Japanese researchers from TOYOTA MOTORS made a 100% ceramic engine. The idea was abandoned due to its modest reliability of only 250 hours of operation.

Currently, composite materials are used for building engines: they contain a metal part and a ceramic part. The metal part provides mechanical strength, and the ceramic one achieves the thermal barrier in the most thermally demanded areas. The ceramic part was made by sintering.

Ceramic coatings have been known to implement these directions: isolation chamber, isolating the exhaust path, isolating hot components. Our research focused on isolating the piston head with Al_2O_3. Since the main mechanical stress is given by the gas pressure, the technical solution chosen was adhesive bonding of the ceramic crown on the piston surface.

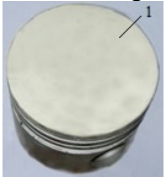
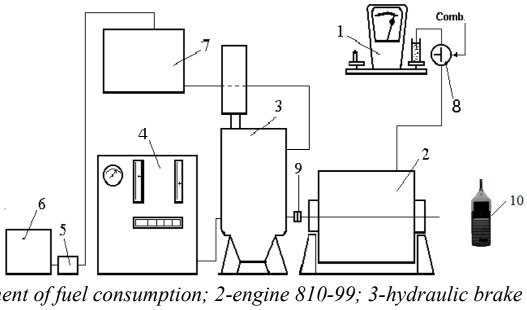


Fig. 1. Insulated piston with ceramic crown: 1-ceramic crown

The model of the experimental stand is presented in the following figure:



1-mass measurement of fuel consumption; 2-engine 810-99; 3-hydraulic brake with electromotor and analogue apparatus for determining the motor moment; 4-control block with digital display of coolant temperature, oil temperature and pressure and crankshaft speed; 5-electric pump; 6 and 7-coolant basin; 8-way three-way valve; 9-cardan coupling; 10-Digital Sound Level Meter

Fig. 2. Model of the experimental stand.

For the experimental part, an 810-99 engine was used with the following characteristics: SIE motor type; 8.5:1 compression ratio; Cylinder diameter 73mm; Piston stroke 77mm; Total cylinder 1289cm^3; Maximum power 39.72kW at 5250rpm; Maximum torque 95Nm at 3.000rpm; Number of times 4; Positioning of cylinders: Line.

The characteristic parameters and admissible measurement errors are presented in Table 1 and general conditions for carrying out the experiment are summarized in Table 2.

Table 1. Characteristic parameters and admissible measurement errors.

Parameter	*Symbol*	*Unit of measurement*	*Admissible measurement errors*
Actual motor momentum	M_e	N·m	±1%
Brake indication	F	N	±1%
Arm length from the weighing device	l	m	-
Drive shaft speed	n	rpm	±0,5%
Hourly fuel consumption	C, C_h	l/h, kg/h	±1%
Hourly air consumption	C_a	m^3/h, kg/h	±2%
Air temperature allowed	T_{aer}, T_o	K	±2K
Coolant temperature	T_{apa}, T_r	K	±2K
Oil temperature at the measuring site	T_u	K	±2K
Temperature of exhaust gases	T_{ge}	K	±5K
Fuel temperature	T_{comb}	K	±2K
Atmospheric pressure (barometric)	p_{atm}, (p_b)	bar, (KPa)	±0,1KPa
Oil pressure at the indicated location	p_u	KPa	±10KPa
Pressure or depression in the exhaust system	$p_{sist\ ev.}$	bar, KPa	±0,1KPa
Pressure drop on the air filter	p_{filtru}	KPa	±0,05KPa
Depression at the admission gallery	p_{adm}	bar, KPa	±0,05KPa
Depression of control of the advance	p_{av}	KPa	±1%
Ignition advance angle	β_s	RAC	±1%
Time	t	s	±0,1s

Table 2. General conditions.

<table>
<tr><td rowspan="2">Engine type</td><td colspan="2">Standard / Modified</td></tr>
<tr><td colspan="2">Engine: 810-99 + Carburettor: 32IRM-A</td></tr>
<tr><td>Purpose of the test</td><td colspan="2">Determining the effective power</td></tr>
<tr><td rowspan="2">Test conditions</td><td>Air temperature: 28°C</td><td>Atmospheric pressure: 740mmHg</td></tr>
<tr><td>Coolant temperature: 83÷92°C</td><td>Oil temperature: 93÷117°C</td></tr>
<tr><td>Fuel and lubricant</td><td>Petrol: PREMIUM II (STAS 176-80)</td><td>Oil: M20W40 (STAS 9171-80)</td></tr>
</table>

3 Results and discussions

The values of measured parameters (*Braking force (F)*, *Fuel mass consumed (m)* and *Sound pressure level (SPL)*) are presented in the Table 3.

3.1 Calculated parameters

Effective power (P_e):

$$P_e = \frac{F \cdot n}{13600} \quad [kW] \tag{1}$$

Actual specific consumption (C_e):

$$C_e = 3{,}6\frac{m}{\tau \cdot P_e} \quad \left[\frac{kg}{h}\right] \tag{2}$$

Actual efficiency (η_e):

$$\eta_e = \frac{3600}{C_e \cdot Q_i} = \frac{3600}{C_e \cdot 43890} \tag{3}$$

where: Q_i is the calorific value of the fuel used.

The values of calculated parameters (*Effective power (P_e)*, *Actual specific consumption (C_e)* and *Actual efficiency (η_e)*) are presented in the Table 4.

Table 3. The values of the measured parameters.

rpm	*Time of trial (τ)*	*Standard engine*			*Modified engine*		
		Braking force (F)	*Fuel mass consumed (m)*	*Sound pressure level (SPL)*	*Braking force (F)*	*Fuel mass consumed (m)*	*Sound pressure level (SPL)*
	[s]	*[N]*	*[g]*	*[dB]*	*[N]*	*[g]*	*[dB]*
1500	32	115,6	40,35	61,0	118,2	39,28	58,0
2000	30	121,0	45,38	62,0	125,3	44,53	60,0
2250	24	125,5	41,25	63,0	128,3	39,62	61,0
2625	25	130,3	52,22	64,5	133,8	50,75	62,5
3000	22	132,4	54,26	67,0	135,2	52,67	64,0
3375	19	128,1	50,33	67,5	132,0	48,75	65,5
3750	18	125,3	50,79	68,0	128,3	48,82	66,5
4125	16	121,0	47,63	69,0	124,3	45,74	67,0
4500	15	115,3	47,37	71,0	117,7	45,11	68,0
4875	15	109,0	49,82	72,5	110,0	47,64	68,5
5250	14	101,3	48,21	74,0	102,9	46,34	71,5
5500	13	91,2	44,22	75,0	94,9	43,66	73,0

Table 4. The values of the calculated parameters.

rpm	*Standard engine*			*Modified engine*		
	Effective power (P_e)	*Actual specific consumption (C_e)*	*Actual efficiency (η_e)*	*Effective power (P_e)*	*Actual specific consumption (C_e)*	*Actual efficiency (η_e)*
	[kW]	*[kg/kWh]*	*[%]*	*[kW]*	*[kg/kWh]*	*[%]*
1500	12,75	0,356	23,04	13,04	0,339	24,20
2000	17,79	0,306	26,80	18,43	0,290	28,28
2250	20,76	0,298	27,52	21,23	0,280	29,29
2625	25,15	0,299	27,43	25,83	0,283	28,98
3000	29,21	0,304	26,98	29,82	0,289	28,38
3375	31,79	0,300	27,34	32,76	0,282	29,09
3750	34,55	0,294	27,90	35,38	0,276	29,72
4125	36,70	0,292	28,09	37,70	0,273	30,05
4500	38,15	0,298	27,52	38,94	0,278	29,50
4875	39,07	0,306	26,80	39,43	0,290	28,28
5250	39,10	0,317	25,87	39,72	0,300	27,34
5500	36,88	0,332	24,71	38,38	0,315	26,04

3.2 Statistical analysis

Comparative analysis of functional parameter values of the two engines obtained in the experiment is presented below:

Table 5. Analysis of functional parameter values.

rpm	Standard engine P_e [kW]	Modified engine P_e [kW]	*Relative increase* (P_e) [%]	Standard engine Ce [kg/kWh]	Modified engine Ce [kg/kWh]	*Relative decrease* (C_e) [%]	Standard engine η_e* [%]	Modified engine η_e* [%]	*Relative increase* (η_e)* [%]	Standard engine SPL [dB]	Modified engine SPL [dB]	*Relative decrease (SPL)* [%]
1500	12,75	13,04	*2,25*	0,356	0,339	*4,78*	23,04	24,20	*5,01*	61,0	58,0	*4,92*
2000	17,79	18,43	*3,55*	0,306	0,290	*5,23*	26,80	28,28	*5,52*	62,0	60,0	*3,23*
2250	20,76	21,23	*2,23*	0,298	0,280	*6,04*	27,52	29,29	*6,43*	63,0	61,0	*3,17*
2625	25,15	25,83	*2,69*	0,299	0,283	*5,35*	27,43	28,98	*5,65*	64,5	62,5	*3,10*
3000	29,21	29,82	*2,11*	0,304	0,289	*4,93*	26,98	28,38	*5,19*	67,0	64,0	*4,48*
3375	31,79	32,76	*3,04*	0,300	0,282	*6,00*	27,34	29,09	*6,38*	67,5	65,5	*2,96*
3750	34,55	35,38	*2,39*	0,294	0,276	*6,12*	27,90	29,72	*6,52*	68,0	66,5	*2,21*
4125	36,70	37,70	*2,73*	0,292	0,273	*6,51*	28,09	30,05	*6,96*	69,0	67,0	*2,90*
4500	38,15	38,94	*2,08*	0,298	0,278	*6,71*	27,52	29,50	*7,19*	71,0	68,0	*4,23*
4875	39,07	39,43	*0,92*	0,306	0,290	*5,23*	26,80	28,28	*5,52*	72,5	68,5	*5,52*
5250	39,10	39,72	*1,58*	0,317	0,300	*5,36*	25,87	27,34	*5,67*	74,0	71,5	*3,38*
5500	36,88	38,38	*4,06*	0,332	0,315	*5,12*	24,71	26,04	*5,40*	75,0	73,0	*2,67*
Min			**0,92**			**4,78**			**5,01**			**2,21**
Max			**4,06**			**6,71**			**7,19**			**5,52**
Average	**30,16**	**30,89**		**0,31**	**0,29**		**26,67**	**28,26**		**67,88**	**65,46**	
Average increase		***2,41%***	***Average decrease***		***5,59%***	***Average increase***		***5,98%***	***Average decrease***		***3,56%***	
**** Informal values***												

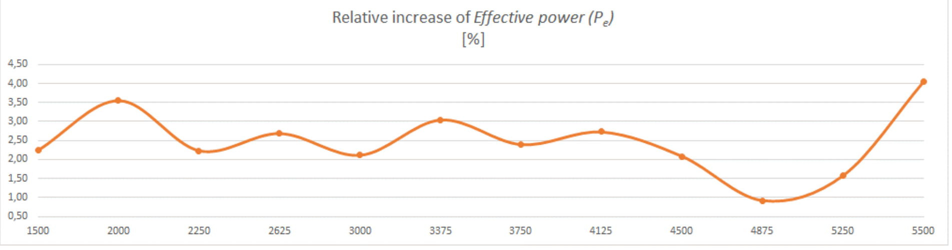


Fig. 3. Relative increase of *Effective power (Pe)*.

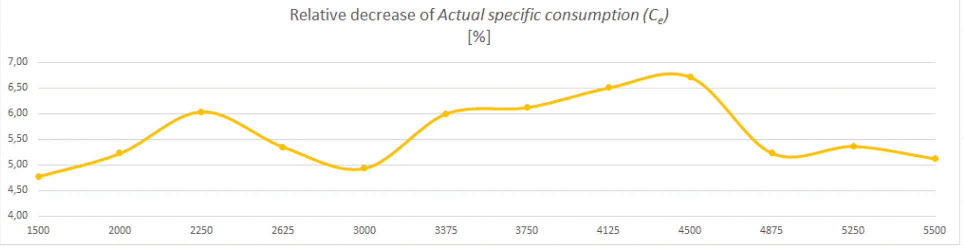


Fig. 4. Relative decrease of *Actual specific consumption (Ce)*.

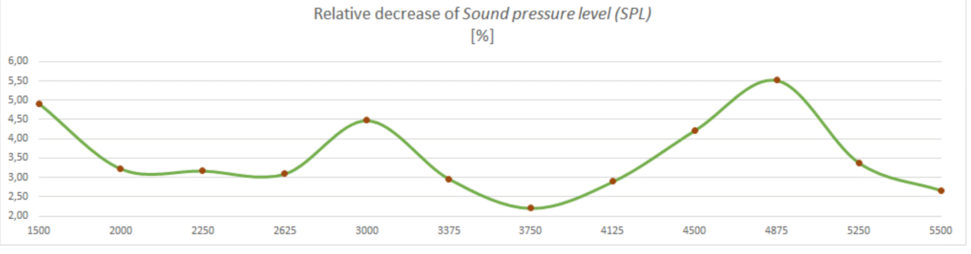


Fig. 5. Relative decrease of *Sound pressure level (SPL)*.

Results of analyse *Modified engine vs. Standard engine*:

i. Regarding the *Effective power (P_e)*, there is an increase between 0,92÷4,06%, showing an increasing in the *average value* of 2,41%;
ii. *Actual specific consumption (C_e)*, shows a decrease between 4,78÷6,71%; the *average value* of this decrease is 5,59%;
iii. The decrease of *Sound pressure level (SPL)* is between 2,21% and 5,52%, showing a decreasing in the *average value* of 3,56%.

4 Conclusion

Using the ceramic materials in the construction of the combustion chamber of spark-ignition engines seems ideal in terms of mechanical strength and functional benefits. Their main shortcoming is the fragility to shocks and vibrations which led to the successful use of composite materials. By using ceramic materials, the temperature in the firing chamber increases by 150÷200K which favours the firing process. In addition to increasing the actual power, the actual engine torque and the reduction of the actual specific fuel consumption, the noise and, not to be neglected, the chemical pollution are reduced. The replacement of metallic materials with ceramic ones leads to a decrease in the motor mass due to the lower density of ceramic materials. The next step is to redesign the cooling system by using a smaller radiator and implicitly by decreasing the volume of the coolant.

Future research will focus on redesigning the cooling system by using a smaller radiator (implicitly decreasing the volume of the coolant) and improving the current ceramic crown bonding solution on the piston surface.

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