INCREASE OF THE TOTAL EFFICIENCY USING THE ATKINSON CYCLE IN THE SPARK IGNITION ENGINE

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Abstract

The paper presents the results of investigations performed on a combustion engine with Atkinson cycle included and application of variable valve timing. Investigations were carried out at constant rotational speed 2500 and 3500 RPM and at throttle opening 25% and 50%. Influence of the advance/delay angle of inlet valves closing on formation of exhaust gases toxic components such as: carbon monoxide, hydrocarbons and nitric oxides was presented. Basing on the obtained results difference of toxicity of exhaust gases before and after application of phase shifter and their concentration in places of total efficiency increments was demonstrated.

Especially The Atkinson cycle comparing with conventional Otto cycle, characteristics of the electric motor applied in Toyota Prius generation, starting and work of engines (combustion engine and electric motor) during vehicle standstill, relation of specific fuel consumption in function of rotational speed for a Toyota Prius engine, generation II, in total efficiency of engines with Atkinson cycle and Mitsubishi GDI in function of rotational speed, relative increase in total efficiency as rotational speed function, influence of intake valves opening angle on concentration in exhaust gases: carbon monoxide, hydrocarbons and nitric oxides at diferrent throttle opening values are presented in the paper.

Keywords: *variable valve timing, setting of valve timing, Atkinson cycle, combustion engines*

1. Introduction

The paper contains the results of research work using the Atkinson cycle in the Spark Ignition engine. Comparison between the Atkinson and Otto cycles is shown in Fig. 1.

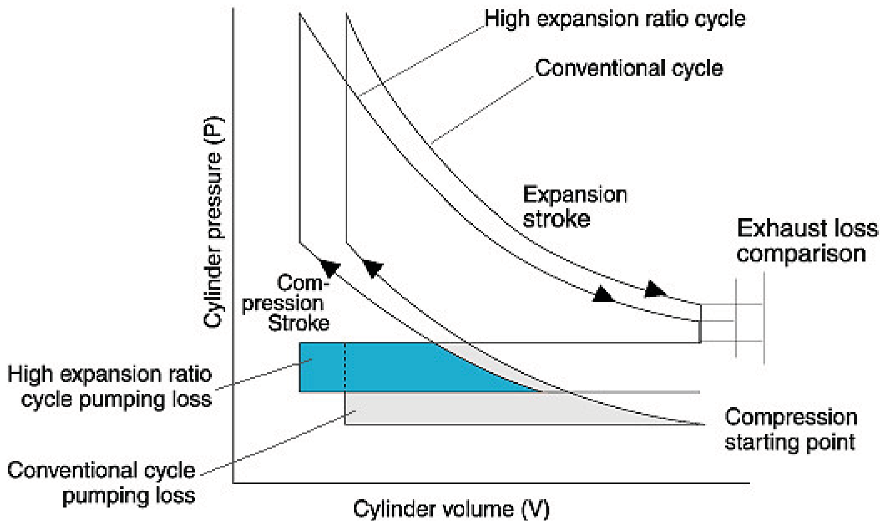

Fig. 1. The Atkinson cycle comparing with conventional Otto cycle

In the Toyota Hybrid System two applied electric motors work as synchronous machines of alternating current: motor/generator of power 15 kW and motor/generator of power 33 kW (50 kW THS II) are coupled with planetary (epicyclical, crypto) gear. With regard to their different roles they require exact computer control [1, 6]

Figure 2 presents torque and power differences related to rotational speed of the electric motor of the first and second generation [1]. Power 50 kW was obtained due to application of a power converter in a conventional system, which permits voltage increase to 500V.

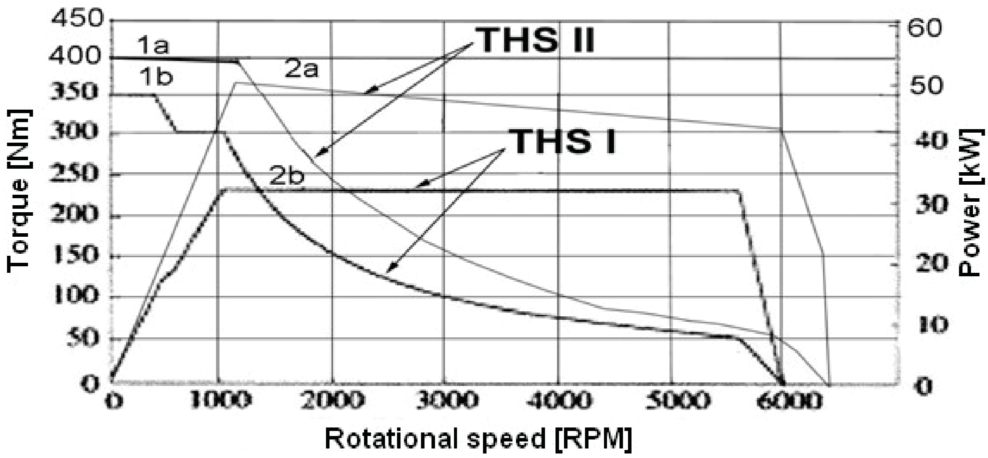

Fig. 2. Characteristics of the electric motor applied in Toyota Prius generation I and II: 1a – torque curve THS II, 1b – torque curve THS I, 2a – power curve THS II, 2b – power curve THS

While in motion the Toyota Hybrid System ensures permanent proper balancing of power between the electric and combustion units so that the rotational speed and load would correspond to minimal specific fuel consumption. Fig. 3 presents time dependent rotational speed and torque distribution (at assumed frequency 10 Hz) during starting and work on idle gear of both engines [2].

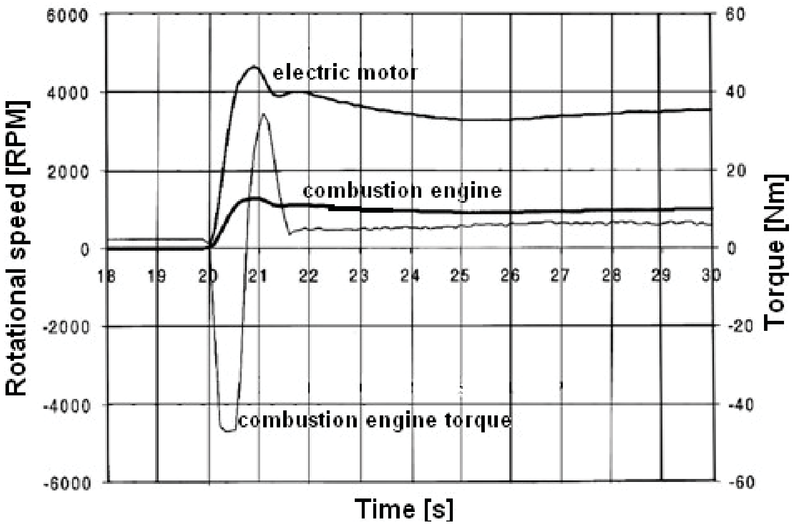

Fig. 3. Starting and work of engines (combustion engine and electric motor) during vehicle standstill [3]

Diversity of functions which are to be fulfilled by particular units are shown in Fig. 3. In order to ensure proper elasticity and economy of traveling the Toyota Hybrid System is subjected to following restrictions [3-5]:

- motor/generator 1 acts as generator/starter,
- motor/generator 2 acts within the range 1040-5500 RPM,
- rotational speed of the combustion engine is 1527 during standstill.

Tab. 1. Strategy of cooperation of combustion engine, electric motor and generator in Toyota Hybrid System [6]

Vehicle speed V [km/h]	Rotational speed of the combustion engine [RPM]	Rotational speed of the electric motor [RPM]	Rotational speed of the generator [RPM]	Power of the battery [W]
0	off	0	0	0
50	off	1733	–4504	–3.29
65	1500	2310	–608	+670
80	1800	2890	–1027	+430
100	1700	3465	–2888	–860
115	2200	4043	–2604	–1110
130	2800	4620	–1937	+430

2. Comparison of total efficiency of a combustion engine with Atkinson cycle and engine working with Otto cycle

Making use of investigation data of specific fuel consumption by Toyota Prius engines, generation I and II and Mitsubishi engine 4G93 GDI working with Otto cycle as well considering relation (1), the total efficiency was determined:

$$\eta_o = \frac{3.6 \cdot 10^6}{g_e \cdot W_o}, \tag{1}$$

where:

η_o - total efficiency [-],
W_o - fuel caloric value [kJ/kg],
g_e - specific fuel consumption [g/kWh].

Specific fuel consumption of the using engine is shown in Fig. 4.

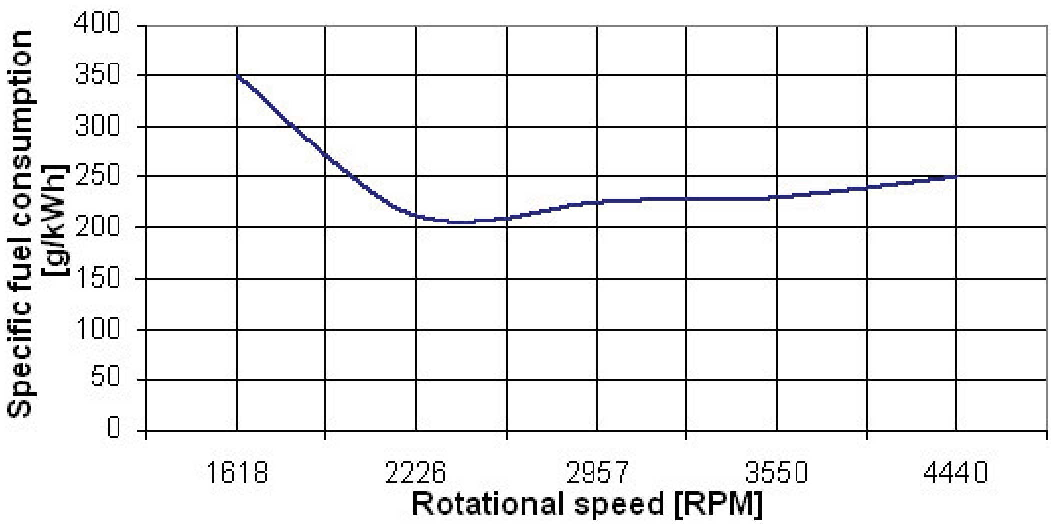

Fig. 4. Relation of specific fuel consumption in function of rotational speed for a Toyota Prius engine, generation II

Subsequently total efficiency of the engine with Atkinson cycle in hybrid vehicles of the I and II generation was compared with a Mitsubishi engine 4G93 GDI (Otto cycle) where a 18% increment of total efficiency at rotational speed at about 2300 RPM was compared (Fig. 5).

Increment of total efficiency (Δη) of the engine with Atkinson cycle working in the hybrid system generation II in relation to the engine with direct injection of fuel can be determined from Fig. 5. This is shown in Fig. 6.

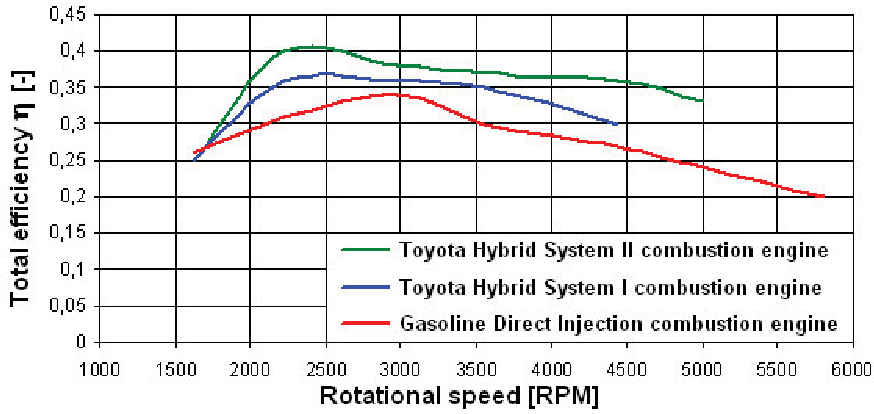

Fig. 5. Increase in total efficiency of engines with Atkinson cycle and Mitsubishi GDI in function of rotational speed at 75% throttle opening [7]

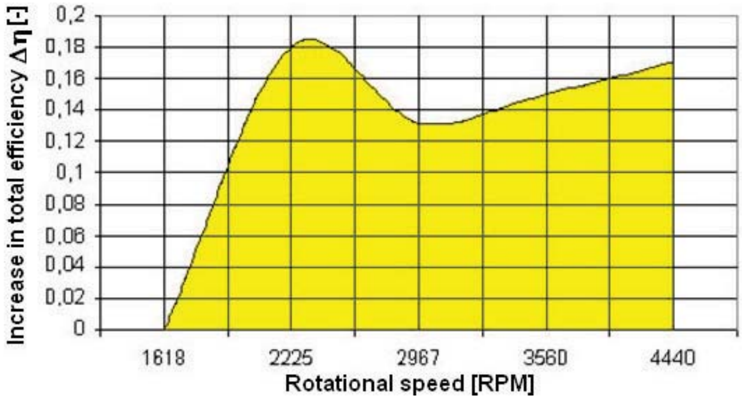

Fig. 6. Relative increase in total efficiency as rotational speed function

3. Influence of phase setting of inlet valve opening on exhaust gases composition

Investigations were carried out at constant rotational speed 2500 and 3500 RPM and at 25% and 50% throttle opening. Exhaust gases for investigation purposes were sampled from the exhaust manifold. Measurements were performed for various phase setting of valve timing of the Toyota 2SZ-FE engine in order to determine the influence of the advance/delay angle of intake valve closing on exhaust gases composition. Fig. 7 shows the difference of exhaust gases toxic components concentration for particular angles of inlet valves opening in relation to an engine working without a phase shifter for throttle opening 25%, $\lambda = 1.00 \pm 0.03$, at rotational speed 2500 RPM.

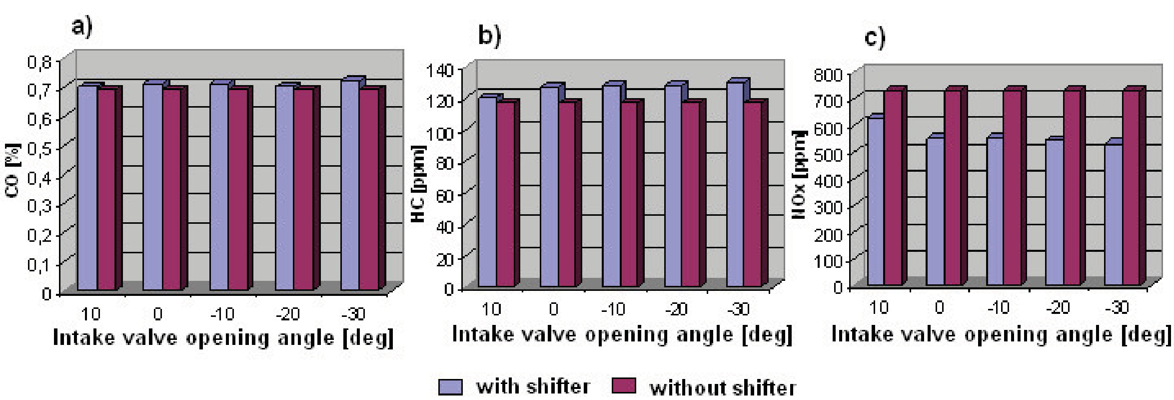

Fig. 7. Influence of intake valves opening angle at throttle opening 25% and rotational speed 2500 RPM on concentration in exhaust gases: a) carbon monoxide, b) hydrocarbons, c) nitric oxides

Figure 8 shows differences in exhaust gases toxic components concentration for particular phases of inlet valves opening angle with shifter in relation to an engine working without phase shifter for throttle opening 50%, λ = 1.00±0.03, at rotational speed 2500 RPM.

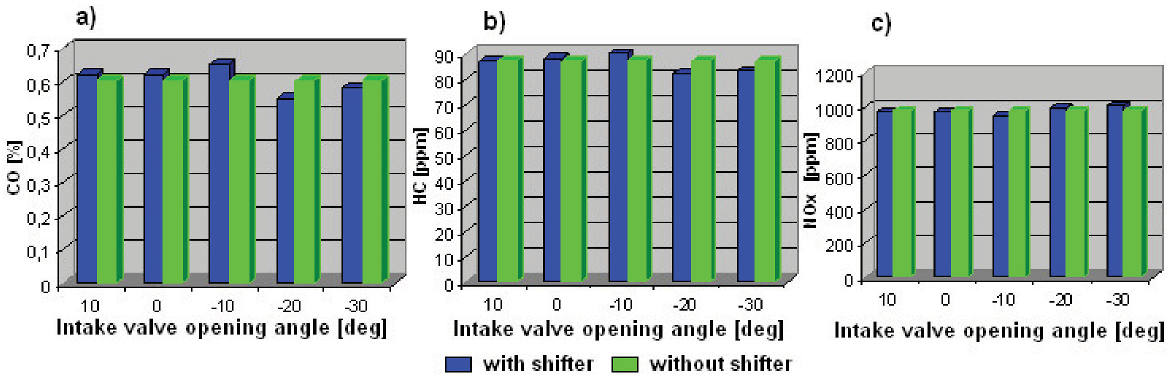

Fig. 8. Influence of intake valves opening angle at throttle opening 50% and rotational speed 2500 RPM on concentration in exhaust gases: a) carbon monoxide, b) hydrocarbons, c) nitric oxides

On the basis of the obtained results it may be stated that in the operation area of the engine, in places of maximal increments of total efficiency, at throttle opening 25% a decisive drop of NO_x concentration and slight increase of uncombusted hydrocarbons and carbon monoxide in exhaust gases takes place. With loading increase, what was illustrated at throttle opening 50%, a remarkable drop of both of the NO_x concentration value and a slight decrease in uncombusted hydrocarbons and carbon monoxides in exhaust gases takes place but only for the last two phases of intake valves opening angles (–20 and –30 deg CA).

4. Summary

1. Application of variable valve timing in a way conditioning occurrence of Atkinson cycle makes it possible to obtain some increase in total efficiency in the range of rotational speeds from 1500 to 3500 RPM in the engine operation area, of statistically highest loading density in time.
2. Application of variable valve timing in a way conditioning occurrence of Atkinson cycle makes it possible to obtain a remarkable drop of NO_x concentration and small decrease in concentration of uncombusted hydrocarbons and carbon monoxides in exhaust gases in the engine operation area, of statistically highest loading density in time.

References

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