The projective design of an engine for a hybrid vehicle

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Abstract. The paper concerns conceptual design of two-cylinder spark-ignition internal combustion engine for a hybrid car with power requirement at least 45 kW at 6000 rpm intended for use in HEV and PHEV vehicles. In the first part of the paper is presented the design of the engine and 3D CAD model, created with support of 3D CAD software. The main part shows the thermodynamic calculation of the main parameters of the combustion engine by means of special software.

1. Introduction
Emission limits, mainly CO\textsubscript{2} ones, have been reduced in the EU in regular intervals since the 1990’s. Therefore, the pressure on combustion engines manufacturers has been constantly increased so that they would invest a large amount of their financial resources especially into reducing adverse exhaust gas and fuel consumption of vehicles. The limits planned for the year 2020, when their next restriction is scheduled, are close to the physical limits of maximum combustion engine efficiency (fuel consumption 4 l/100 km for spark ignition engines and 3,6 l/100 km for diesel engines). Therefore, automobile manufacturers must search for a way in hybridization of combustion engines of vehicles, eventually in using electromobiles instead of classic vehicle drive [1, 2].

Figure 1. Required CO\textsubscript{2} reduction in the key markets [3].
Hybridization of vehicles involves increased production costs. Thus the manufacturers will have two possible ways to follow:
- Manufacturing vehicles with zero or considerably low values of produced CO₂,
- Hybridization of most vehicle production.

The first option is to manufacture several models which will considerably decrease the average CO₂ emissions of fleet. This will allow the manufacturers to sell even premium vehicles with much higher fuel consumption. Such solution can be expected at companies offering primarily premium and sports vehicles. The second option considers hybridization of most manufactured vehicles. Therefore, the manufacturer would have to offer a great amount of vehicles of, for example, a mildhybrid type. Most probably, car factories manufacturing supermini (B-segment) and compact (C-segment) cars will move in this direction.
Pursuant to this information it can be estimated that in the following several years the mildhybrid, HEV (Fullhybrid - Hybrid electric vehicle) and BEV (Battery electric vehicle) vehicle types will considerably extend. In comparison to these, the PHEV (Plug in hybrid electric vehicle) types of vehicles do not have so many advantages to be considered as a suitable way of further development. Moreover, their price is approximately the same as the price of BEV vehicles. The problem of PHEV and BEV types is the expensiveness of batteries, which currently limits the competitiveness of these groups [2].

By comparing the main concepts of hybrid vehicles – serial and parallel type of hybrid (Fig. 4) – it is possible to search for another way of development in serial type of hybrid which brings enhanced fuel saving, especially in city traffic. The paper deals with a conceptual design of a combustion engine which could be used in a hybrid vehicle in serial production, possibly in an electromobile as so called range extender.

![Figure 4. Comparison of fuel saving potential and efficiency/energy flows of serial and parallel hybrids [6].](image)

2. Design of combustion two-cylinder engine

The aim of the paper [2] was to create a conceptual design of a two-cylinder engine with the minimum power of 45 kW at 6 000 min\(^{-1}\), which is intended for being used in a hybrid vehicle. From the above mentioned reasons, the use of an engine in a serial type of hybrid (HEV, eventually BEV) has been chosen. A combustion engine intended for use in this type of a vehicle operates in predefined modes, which the engine can possibly be optimized for, and it means that its effectiveness can be increased and the minimum fuel consumption can be kept. The engine is designed as a two-cylinder spark ignition engine with an overall cylinder capacity of 500 ccm. The engine will work in steady regimes, when it will recharge the batteries of the vehicle – the mass-produced hybrid. The first regime is the regime of minimum fuel consumption, which means the engine running at 3 500 min\(^{-1}\). The second regime is the regime of maximum power (6 000 min\(^{-1}\)).

In regard of choosing the conception of parallel pistons, the combustion engine is unbalanced from inertia effects. In terms of smooth engine running and in terms of engine acoustic manifestation,
balance of inertial forces from rotating mass and oscillating mass of first order to 100% was undertaken at the combustion engine by using one balancer shaft (with mass distribution between crank shaft and balancer shaft 50:50).

The designed combustion engine has a standard conception of a lubricating system. The engine uses the way of piston cooling by spraying their bottoms. To provide sufficient cooling of oil, the system is equipped with a heat exchanger. It is placed directly under the oil filter. The engine is cooled with liquid, which circulates with the help of a pump with internal gearing, driven directly with a crank shaft. The cooling is designed in accordance with a current trend of combustion engines construction. The water area in the engine head is divided into two parts; the upper part functions mainly as a sustaining chamber, from where the liquid flows around spark plugs into the low area.

![Figure 5. Cross section of the whole combustion engine assembly; the view of crankshaft, connecting rod assembly and balancer shaft [2].](image)

3. Simulation model
The simulation model of a spark ignition engine was created in Wave software by Ricardo co., which is, in general, 0-D program for simulating the motor running cycle; however, the manifold can be modelled in 1-D way. The simulation model of the engine was created on the basis of proportions
of a combustion engine design (cylinder bore, stroke, compression ratio, proportions of intake and exhaust manifolds, parameters of fuel injection etc.) including valvetrain timing. From the simulation results, information about dependence of different parameters for example in the regime of external speed characteristics of the engine can be obtained. It is further possible to see the display of results of individual speed regimes in dependence on rotation of the crank shaft, eventually to create animation of calculated parameters.

When designing the model, several variants had been used before all requirements were fulfilled. The first simulated variant was an atmospheric (non-supercharged) engine with indirect multi point fuel injection. The last simulation model of an engine uses the direct fuel injection into the cylinder; cylinder filling is provided with a turbocharger, compressed air is then cooled with an intercooler. Performance parameters improved in this model and reached the intended result.

The simulation model of the engine work done in Wave software of Ricardo is shown in Fig. 6.

The following pictures in Fig. 7 show the calculated parameters of both simulated variants of the driving unit. When performing the individual designs, the values of input variables during the simulation were changed so that better performance and operating parameters were reached. Those adjustments were made “manually”, based on experience; the aim was to reach higher power and at the same time to keep low specific consumption of fuel at lower speed (bsfc - Brake Specific Fuel Consumption). Those parameters, for example, were gradually adjusted: valve timing, valve lifts, beginning of fuel injection, ignition advance, Wastegate etc. A simulation model in a new version of Ricardo Wave is currently being developed, where it is possible to use the HEEDS tool for automatic optimization. One of the parameters, which will be optimized this way, is valvetrain timing (it means cylinder filling and gas exchange in the cylinder). Because the engine would work only in several operating modes, it is not necessary to set the engine on optimal running in the whole speed regime, or to equip it with a mechanism for variable valve timing.
Figure 6. Simulation model of engine.
Figure 7. Illustration of chosen calculated parameters of two simulated variants of combustion engine: 
a) left – non-supercharged engine with fuel injection into inlet port, b) right – supercharged 
combustion engine with a turbocharger with use of intercooler of compressed air, direct injection (DI) 
of fuel into cylinder.
The final engine power reached 47 kW at 6 000 min⁻¹, the result exceeds the minimal required power. The engine break specific fuel consumption in the current state is 230 g/kW/h at 3 000 - 4 000 min⁻¹. The value of maximum gas pressure in cylinder is important for the construction of the engine, especially in terms of the robustness. At 6 000 min⁻¹, this value reaches 10.8 MPa.

4. Conclusion
The aim of the paper was to create a conceptual design of a two-cylinder engine of minimum power 45 kW at 6 000 min⁻¹, which is designed for being used in a hybrid vehicle. At first, a construction engineering design was created; the combustion engine was completely drawn in 3D CAD software. Then a simulation model of the combustion engine was built in Wave. From the results of the simulation the dependence between various parameters in individual operating modes can be obtained. Several construction variants of the combustion engine were simulated – the first variant was the non-supercharged engine with indirect multi point fuel injection, then the supercharging using a turbocharger was done, next the intercooler for compressed intake air was used. The last simulated variant uses direct fuel injection into the cylinder. The required result of the engine power, while the low specific consumption of fuel was kept, was reached (when comparing the first and the last simulated variants, the engine power approximately doubled while the specific consumption of fuel remained the same). A simulation model for optimization of operating and performance parameters with use of the HEEDS tool is currently being prepared. This tool is accessible in a new version of Ricardo Wave.

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