Transport Research Arena 2014, Paris

Early-stage assessment of innovations for vehicle powertrains using Design Assistance System

Sergii Bogomolov[a], Jan Macek[a] , Antonin Mikulec[a] , Vit Dolecek[a] , Michael Valasek[a] *

[a]*Faculty of Mechanical Engineering, Czech Technical University in Prague, Prague, Czech Republic*

Abstract

The current uncertainty in the best solution of future vehicle powertrains calls for the advanced methods for the fast assessment of impact of intended innovations. This process is rather complicated by many interactions between a powertrain and a vehicle, considering total mass, lay-out and dimensions of a powertrain influencing vehicle driving resistances and thus road energy consumption, carbon dioxide emissions and other gaseous pollutants under unsteady operation. This assessment should be done as soon as possible during early stages of vehicle design excluding low prospective variants before devoting too much effort to them. The paper shows an application of holistic approach to ICE cycle optimization aiming at finding the limits of engine efficiency with the lowest weight of an engine.

Keywords: internal combustion diesel engine, downsizing, downspeeding, pressure boosting, peak pressure, total limits of efficiency, crankshaft, optimization

Résumé

L'incertitude actuelle sur la meilleure solution de futurs groupes motopropulseurs des véhicules fait appel aux méthodes avancées pour l'évaluation rapide de l'impact des innovations destinées. Ce processus est compliqué par de nombreuses interactions entre un groupe motopropulseur et un véhicule, compte tenu de la masse totale, lay-out et les dimensions d'un véhicule motopropulseur influençant sur la résistance d’un groupe de conducteurs et donc sur la consommation d’énergie, les émissions de dioxyde de carbone et d'autres polluants gazeux. Cette évaluation doit être faite le plus tôt possible au cours des premières étapes de la conception d'un véhicule en excluant les faibles variantes potentiels. Le document montre une application de l'approche holistique de l'optimisation du cycle de ICE visant à trouver les limites de l'efficacité du moteur avec le poids le plus faible d'un moteur.

Mots-clé: moteur à combustion interne diesel, réduction de puissance, réduction de vitesse, surpression, pression maximale, limites totales d'efficacité, vilebrequin, optimisation

* Sergii Bogomolov, Czech Technical University in Prague, Technicka 4, Prague, Czech Republic.
Tel.: +420-22435-2495.
E-mail address: sergii.bogomolov@fs.cvut.cz.

Nomenclature

bmep	brake mean effective pressure
bsfc	brake specific fuel consumption
CA	crank angle
CR	compression ratio
c s	mean piston speed
D	diameter, bore
DASY	design assistance system
delta alpha s	combustion duration (0-95% fuel burnt) in CA
eta mech	mechanical efficiency of engine
eta T	total turbocharger efficiency (virtual turbocharger surrogates the real two-stage turbocharging)
FEM	finite element method
FIE	fuel injection equipment
FMEP	friction mean effective pressure
GHG	green-house effect causing gases
HCCI	homogeneous charge compression ignition
h	width
ICE	internal combustion engine
lambda	air excess (relative air-to-fuel ratio)
NOx	sum of polluting nitrogen oxides
NVH	noise, vibration and harshness
p boost	boost pressure in an inlet manifold
PCCI	premixed charge compression ignition
PID	proportional-derivative-integrating controller
p max	cylinder peak pressure
PM	particulate matter (exhaust pollutant)
RCCI	reaction controlled compression ignition
ROHR	rate of heat release
S	stroke
SCR	selective catalytic reduction of NOx
T piston	mean temperature of piston fire surface
T t1	turbine inlet temperature of exhaust gas
TTW	tank-to-wheel
VNT	variable nozzle turbine
WLTP	world harmonized light-duty test procedure
WOT	wide-open throttle

1. Introduction

Downsizing is often referred to as a tool for increasing engine brake efficiency (due to reduction of relative thermal and mechanical losses) and improving road fuel consumption due to higher load of an engine in operation. Simultaneously, engine size and mass are reduced, which is accompanied by vehicle driving resistance decrease. On the other hand, much higher peak pressures occur, which has to be taken into account in dimensioning engine components. More robust components increase relatively the engine mass and cost. The peak pressures and inertia forces of heavier moving components impact mechanical losses in a cranktrain. In the case of any of apparently high-efficient low-temperature combustion systems (e.g., HCCI, PCCI or RCCI), efficient boost pressure charging of cylinders is required but often it is not taken into account during optimization.

Downsizing may be accompanied by downspeeding, reflected in lower cycle frequency (speed in r.p.m.). Despite all efforts, the real limits of design have not yet been found – (Eilts, P. et al., 2013) and (Hyvonen J., 2013). It is worthwhile mentioning the different level of optimism of industrial and academic R&D. Similar issues had been already addressed in the 50’s of the last century by Eichelberg and Zinner (concluded by experiments with real medium speed large-bore test engine at MAN), which was repeated by Syassen again for large bore four stroke engines in the 70’s. Recently, the same issues of truck and passenger car engines were addressed – e.g., by Curtis

E. (2013) and Reitz R. (2013). The optimum solution depends on the total effects of new design on a new product. Moreover, the described issues should be optimized for real driving conditions, hopefully reflected in test procedures, considering both fuel efficiency together with CO_2 and other GHG emissions fulfilling future pollution standards.
Up to now, no clear way to totally optimum downsized engine has been found during years of pressure charging application for ICEs. The main issue is in difficult early stage decision of a new engine design concept considering future (yet not designed) vehicle performance. The tools for doing this uneasy task and results of fully optimized downsized engine are described in the current paper as a continuation of authors' previous studies – (Bogomolov S. et al., 2011) and (Bogomolov S. et al., 2012). This first attempt to optimize both efficiency and engine mass accompanied by main design parameters estimation will be followed by powertrain and vehicle design changes including powertrain control systems in the near future.

For this preliminary study, a diesel passenger car engine has been used. Unlike in other published studies, the optimization of brake specific fuel consumption was done using minimal number of constraints to find the total optimum. The efficient exhaust gas aftertreatment system (like SCR) is assumed, which sets almost no limits to thermodynamic optimization. The low-temperature combustion modes are implicitly taken into account, as well, due to high number of degrees of freedom during optimization.

The goal of this effort is to find the optimum envelope to future real solutions. The partially optimized realizable designs with reduced flexibility of engine controlled parameters will fit into this envelope. The assessment of the distance of real design to this total optimum will help in deciding what change will be worthwhile for the next design improvement. Simultaneously, the holistic approach described below may take all significant vehicle and powertrain features into consideration even during early stage of development.

2. Main steps of new approach to ICE optimization

The authors used the previous experience and tools based on in-house development (knowledge database DASY (Bogomolov S. et al., 2011), described below, in connection with specific codes, e.g., for mechanical loss estimation (Emrich M. et al., 2011), turbocharger parameters definition (Vítek, O. et al., 2006), crankshaft safety factors assessment (Bogomolov S. et al., 2012), etc.) together with commercial software products (e.g., GT Suite or optimization code modeFrontier).

The reference diesel engine of 2 dm^3 displacement with conservative dimensions (bore of 80 mm, stroke of 82 mm) and bmep of 25 bar in the range of 1 000 – 4 000 r.p.m. was used as an initial prototype to be downsized and, if necessary, downspeeded. The initial parameters, including pressure losses, discharge coefficients and mechanical efficiency, are based on real engine tests.

Bmep has been increased up to 35 bar during the current optimization, keeping the power at different speeds equal to the initial diesel engine. The displacement was thus reduced. The stroke was kept the same, downspeeding the downsized engine in terms of mean piston speed, or it was a free parameter to be optimized in certain cases (described as optimized mean piston speed, c_s).
The peak pressure has not been limited, as well as piston surface temperature, turbine inlet temperature, etc., which is a novelty of this approach.

Other novelty of this approach, besides relatively free optimization constraints described in paragraph 4.1, is a direct coupling of thermodynamic optimum results to engine design changes, reflected by engine dimensions (dependent, e.g., on bore spacing, influenced by crankshaft dimensions fitted to peak pressures in a cylinder) and to mechanical loss estimation of more detailed cranktrain model with friction described by Stribeck curves (Emrich M. et al., 2011). The crankshaft was optimized using simple approximation of stress concentration factors in dependence of journal and web dimensions – (Bogomolov S. et al., 2012). The initial values were tested at the realized engine design. Accordingly, the dimensions of valves and manifolds were changed during the optimization in dependence on optimum engine dimensions, and the mass of the whole engine has been predicted. The inevitable tool for this approach has to link the data of different codes. The next generation of Design Assistance System DASY (Bogomolov S. et al., 2011) has been employed. A scheme of data flows with future amendments up to vehicle data is presented in Fig. 1.

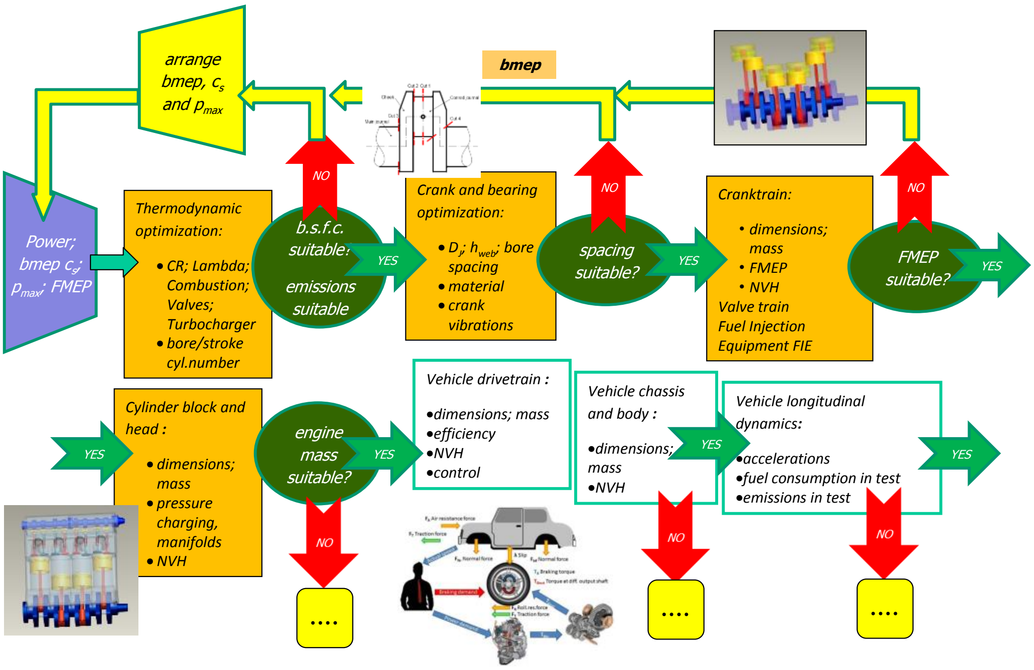

Fig. 1. Data flows during coupled thermodynamic and design optimization.

3. Design Assistance System

To automate solution process and provide integration with CAD software, the new version of Design Assistance System (DASY2 or DASY) (Bogomolov S. et al., 2012) has been developed (Hejlsberg A. et al., 2010). The system features descriptive model definition, numerical solvers and optimization algorithms (Banzhaf W. et al., 1998). Any parametric model (Motta, E. et al., 1996) in DASY is described with available knowledge, and definition of input and output parameters is separated from the model definition. This allows swapping of input and output parameters and solve both direct and reverse design tasks.

3.1. Model definition

Model in DASY2 is represented as a set of blocks linked with connections. Each block contains a set of equations, which are defining its sub-model. Sandbox approach is used for each block, which means that parameters used in equations of this block are accessible by this block only. To connect parameter of first block with parameter of second block a connection should be used. Connection provides a bridge between two separate block sandboxes. Connected parameter values are assumed to be equal. This approach allows implementation of any model with blocks, representing sub-models, and connections that will connect output state parameters of one block (sub-model) with input state parameters of another block (sub-model). With such descriptive definition one can use any knowledge about the model without strict separation of input and output parameters.

3.2. Numerical solver

Any model implemented in DASY2 is represented with blocks and connections. This allows almost effortless structural changes. However, under the cover – it is a system of non-linear algebraic equations collected from all blocks with respect to connections. Before solving this system some simplifications (like merging parameters that are connected, substituting constant parameters with numbers, or performing algebraic operations on numbers) can be done. After all possible preliminary simplifications are done, numerical solver should be used to solve this system. Two numerical solvers are implemented in DASY2:

- Descend gradient solver with variable step,
- Gauss-Newton solver with variable step.

Usually, the modified Gauss-Newton solver (Fig. 2) is preferred, because it is one of the most robust gradient-based methods. This method can be seen as a modification of Newton's method for finding a minimum of a function. The idea of Newton’s method is as follows: one starts with an initial guess which is reasonably close to the true root, then the function is approximated by its tangent line, and one computes the x-intercept of this tangent line (which is easily done with elementary algebra). This x-intercept will typically be a better approximation to the function's root than the original guess, and the method can be iterated.

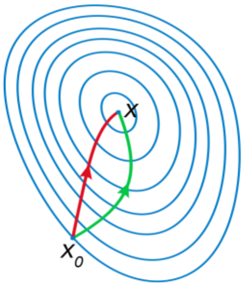

Fig. 2. Newton’s method in optimization.

3.3. Integration with CAD systems

Integration with CAD is done using special CAD system plugins. Currently, plugins to interact with CATIA and Pro/Engineer are developed. Plugin represents a communication interface between DASY and corresponding CAD system. It allows generalization of interaction with CAD and provides one convenient interface to interact with all supported CAD systems. Using this approach, it is possible to read and write parameters from/to CAD model. It is also possible to read all available inertia properties. If some parameters or inertia properties are read from CAD model, then this model will be involved in solution process, described in previous section. If parameters are only written to CAD model – it will be updated after computation is done.

CAD model in DASY is represented as a CAD block, which can be connected to other blocks using regular connections. This ensures that CAD models are always updated with the latest parameter values and allows the use of all available data from CAD models in computation and/or optimization.

4. Engine efficiency optimization

4.1. Constraints and basic boundary conditions

The thermodynamic optimization was based on calibrated 1-D model of diesel engine in GT-Power. The original 4-cylinder engine has bore/stroke 80/82 mm. All initial dimensions and loss coefficients were taken from this real engine for both aerodynamic and mechanical losses. The combustion, represented by three-term ROHR Vibe function, was characterized by the duration of main phase 0-95%. A simplified FEM model of cooled walls was used for fire surface temperature assessment. Woschni heat transfer formula was applied, up to now without correcting multipliers. Thermodynamic properties of gases, including equilibrium products of combustion, have been applied. Turbocharger maps were created for a virtual compressor (not limited by surging or choking) and turbine map derived from original one by multiplier of mass flow rate which substituted the VNT (Vítek, O. et al., 2006). They are relevant for downsized engine, in the case of significant progress in turbocharger efficiency they can be easily changed. Mechanical loss model in dependence on cylinder pressure pattern has been applied from (Emrich M. et al., 2011).

Since the task was to find the best engine for each operation condition, the optimization constraints were pushed far behind the border of real engine limits, and extreme flexibility of control was assumed. The rate of heat release was optimized as well, but considering its position and duration only, since the shape is not very important in a wide range of shape changes (Eilts, P. et al., 2013). Two optimized variants of reference length of combustion 20 and 35 degrees CA were applied amended by Woschni combustion duration dependence on speed (duration proportional to the square root of engine speed) and air excess (duration reversely proportional to the 0.6 power of air excess). Mixture strength (i.e., boost pressure), compression ratio up to 18 and all currently variable engine data (combustion timing, valve timing and a virtual turbocharger matching, surrogating two-stage turbocharger group) have been optimized as well, in dependence of engine speed and brake mean effective pressure at speed-appropriate constant power. The whole turbocharging group was replaced by a virtual turbocharger with multipliers of size and speed. The turbocharger was adjusted by multipliers to required flow rate and for demanded boost pressure at any operation point. There were two optimized variants of the total two stage turbocharger group efficiency of 50% and 60% (defined from isentropic enthalpy difference at compressor and turbine sides, including compressor side intercooling and all pressure losses). The size of valves and ports and dimensions of combustion chamber in piston were proportionally modified to engine bore.

The totally optimized engine of fixed size has required constant torque output (25, 30 or 35 bar of bmep) in the whole engine speed range from 1000 to 4000 r.p.m. The PID controller was employed to set the injection amount to reach required torque. Downsized versions were made by reducing engine displacement to keep the output parameters at same level by increasing of engine specific outputs. The engine was downsized in two steps with 30 and 35 bar of BMEP with two approaches. In the first one, the mean piston speed was kept constant and reduced was only engine bore. In the second one, the bore/stroke ratio was variable in a wide range. The optimizing software tool modeFrontier was used to search for the optimum settings of parameters listed above. The impacts of downsizing on mechanical efficiency were estimated using Stribeck curves – (Emrich et al., 2011). The genetic algorithm was applied with 72 designs in one generation and 30 generations. The bsfc was minimized to find the highest possible value of all efficiencies.

4.2. Results of cycle optimization

The fuel consumption for several optimized variants at 4 000 r.p.m. is displayed in Fig. 3. The positive influence of higher specific load can be observed if engine speed is high enough. At lower speeds, the stagnation of bsfc at speeds lower than 2 000 r.p.m. can be found. The significance of high turbocharger total efficiency is obvious. Additional reduction of fuel consumption can be achieved by optimization of bore/stroke ratio for given operation conditions. Surprisingly, the peak pressure is limited to reasonable and achievable values. In addition, the advantage of very short combustion duration is not prominent, which limits the contribution of HCCI-like combustion. This is a result of holistic approach, which takes into account the conditions for boost pressure achievement. Too low exhaust gas temperature, indicating too efficient cycle (featured by low temperature – low heat loss), creates an obstacle for reaching high boost pressure. Constant initial piston speed should be changed to optimum, which is greater at low engine speeds, as demonstrated in terms of stroke, in Fig. 4. The selected results of optimized downsized engine with optimized mean piston speed, total turbocharger efficiency 60%, reference combustion duration 35 deg and bmep 30 bar are presented as examples in
Fig. 4. The gains of extreme downsizing are not very large at full load (WOT) limit. Again, surprisingly, optimization does not call for r.p.m. reduction due to increased cooling heat transfer loss. Even the optimum stroke is reached with higher mean piston speed than that of prototype engine. The trend to long-stroke engine optimized for very low speed is changed at high speed due to the need of filling a cylinder via sufficiently large valves. The results demonstrate the limited potential of further increasing bmep at rated WOT parameters up to 5% only, which is not surprising. Power density increase reduces the relative significance of the load independent, i.e., fixed part of all losses. This effect is not too prominent, if the initial rated bmep is already high. Moreover, downspeeding may not be fully successful due to increased wall heat transfer loss.

Road fuel consumption or, in other words, tank-to-wheels efficiency, is influenced by engine features at loads relevant to real operation modes with reduced torque and power. The car taken as an example with the original engine requires load-and-speed averaged power less than 10 kW in NEDC. Lighter downsized engines will decrease this power by 1 – 2%, as it can be estimated from the reduction of engine mass described roughly in the chapter 5. The main effect of downsized powertrains consists in higher bmep's for achieving necessary engine power, which increases both mechanical and indicated efficiencies. It is demonstrated by Fig. 5 and 6 comparing bsfc for two versions of extremely downsized engines with 30 bar (short stroke) and 35 bar (long stroke) engines. Since the maps are in dependence on torque, the bsfc at the same power demand can be compared directly. Although the more downsized engine features a little worse rated power bsfc, the effect of low-load-low-speed domain can reduce bsfc by at least 3%. These effects will deliver approx. 5% gain on efficiency if increasing engine bmep from 25 to 35 bars. The tests for higher bmep's at WLTP are being performed currently. In any case the last figures show that rightsizing should exchange downsizing.

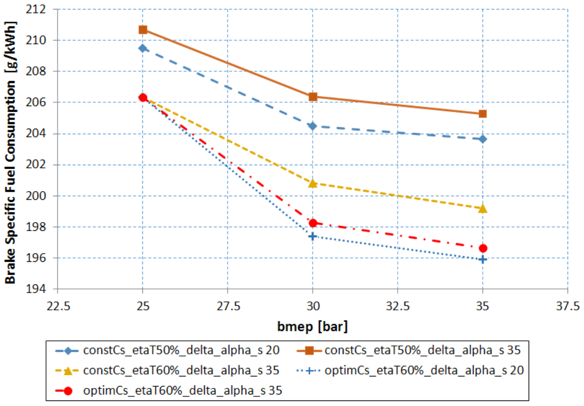

Fig. 3. Optimization results - brake specific fuel consumption as a function of engine load for engine speed 4000 r.p.m. and different engine optimization constraints (defined by constant or optimized mean piston speed, total turbocharger efficiency and length of reference combustion angle).

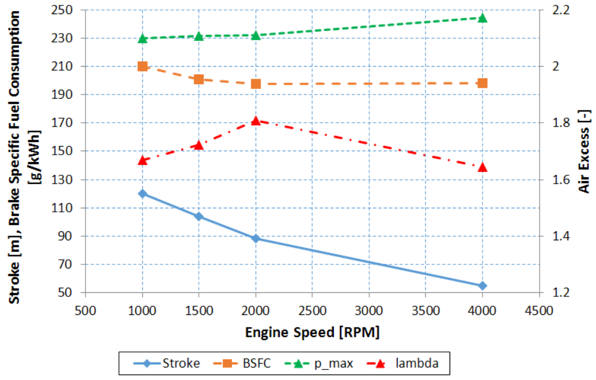

Fig. 4. Optimization results – engine stroke, brake specific fuel consumption, peak pressure and air excess as a function of engine speed for engine with optimized mean piston speed, total turbocharger efficiency 60% and length of reference combustion angle 35 deg.

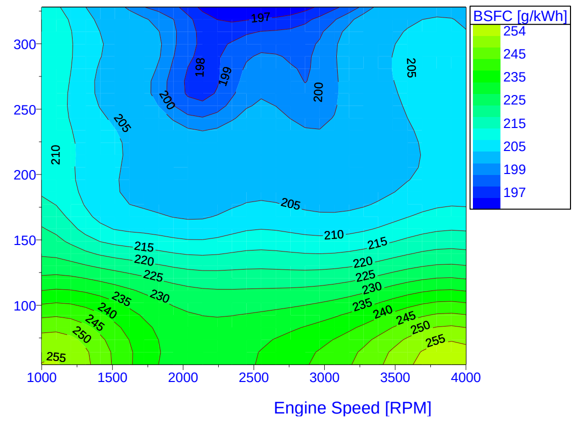

Fig. 5. Optimization results – map of brake specific fuel consumption as a function of engine speed and torque for engine with displacement 1.4 liter (maximum bmep. 30 bar) and stroke of 88.4 mm, total turbocharger efficiency 60% and reference combustion duration 35 deg CA.

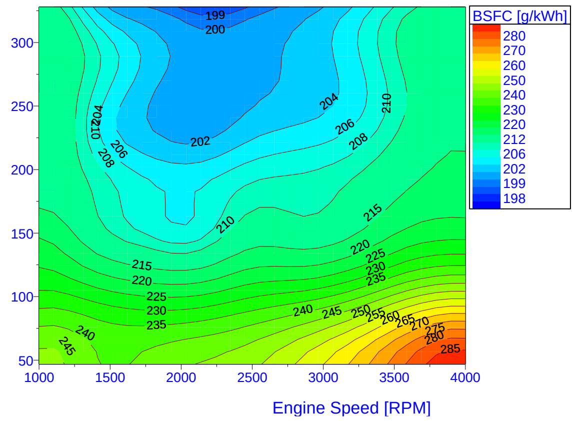

Fig. 6. Optimization results – map of brake specific fuel consumption as a function of engine speed and torque for engine with displacement 1.2 liter (maximum bmep. 35 bar) and stroke of 115 mm, total turbocharger efficiency 60% and reference combustion duration 35 deg CA.

5. Engine design changes during downsizing

Crankshaft is a decisive component for bore spacing and engine weight if peak pressure is increased. Crankshaft dimensions for 3-cylinder diesel engine were optimized to minimize crankshaft mass. Two different engine designs for optimum cycle were selected. Parameters of these designs used for optimization and optimization results are shown in Table 1. The results of optimizations have shown, that with a reasonable fatigue safety factor higher than 1.5, the relative bore spacing can be kept at the same value (approx. 1.15) for a downsized engine with higher peak pressure, especially in the case of a long stroke, large journal diameter crankshaft. Optimization goal was to have minimal mass with reasonable stress concentration safety factors and bearing speeds. Stress concentration safety factors were computed in several cuts and are shown in Fig. 8. Maximal allowed mean pressures in main and connecting rod journals bearing were 50 and 80 MPa and journal circumference speed was limited by 20 $m.s^{-1}$. DASY uses improved Strength Pareto Evolutionary Algorithm 2 (Mifa Kim et al., 2004). The analysis of constraints showed that the only free parameters are cylinder bore spacing and journal circumferential speed (i.e., bearing diameter) if the mass of a crankshaft is to be minimized.

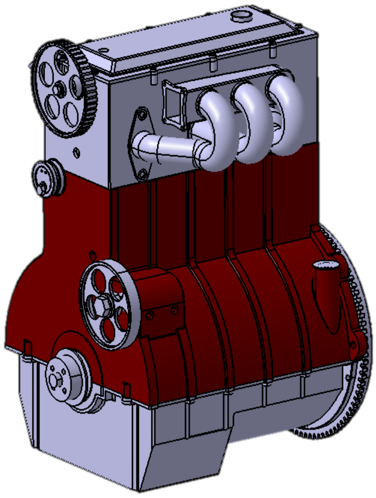

Fig. 7. Engine model used for optimization.

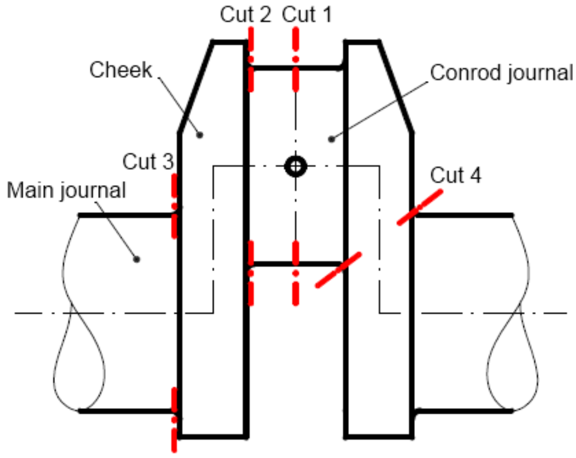

Fig. 8. Crankshaft sketch.

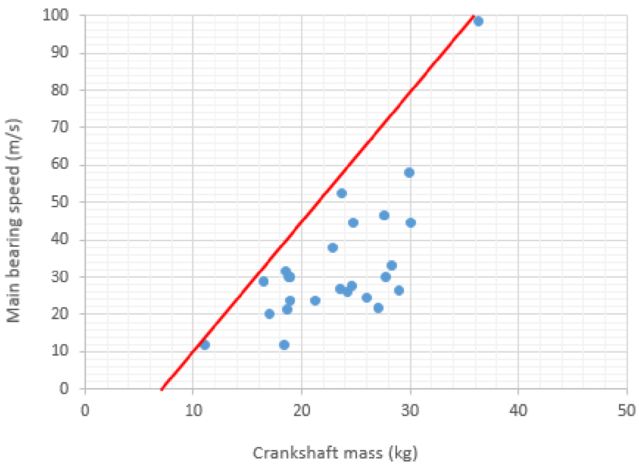

Fig. 9. Pareto front for crankshaft optimization

Table 1. Design parameters used in optimization and optimization results

Parameter	Design #1	Design #3
Bore (mm)	80	61.23
Stroke (mm)	82	100
Speed	4000	4000
Peak pressure in cylinder (MPa)	21.89	27.44
bmep (MPa)	2.5	3.5
Relative bore spacing	1.19	1.14
Crankshaft mass (kg)	16.97	14.8
Minimal stress concentration safety factor	1.54	2.28

Stress concentration safety factors were computed using algebraic model described in (Bogomolov S. et al., 2012) and (Kmoch M., 2011). Performed optimization is a preliminary study and does not take into account all details and constraints. However, it shows the possibility to connect optimization of thermodynamics with design optimization using DASY software. The result of multi-objective optimization is a Pareto set which can be presented as several Pareto fronts (like the one shown in Fig. 9). In reality, the results could be even better, if more designs would be considered during optimization. The mass of engine will be further reduced due to the possibility to decrease bore spacing.

6. Conclusion

Design Assistance System 2 is still under active development, but already implemented features allow its usage in real tasks. The main features are descriptive model definition, algebraic equations parser, numerical solvers, optimization algorithms, CAD and other plugins. These features allow easy model definition. Modular structure of DASY model provides a convenient way for nearly effortless structural changes and what-if studies. Definition of input and output parameters is separated from the model definition, which means that both direct and reverse design tasks can be solved. Models in DASY are organized in a way that allows easy re-usage of model parts and knowledge in different projects. Performed crankshaft optimization shows possibility to use DASY software to connect optimizations in different fields and use them in final design.

DASY has been used for a diesel downsizing study. The unlimited peak pressure optimization does not call either for extreme peak pressures or very short combustion durations. Surprisingly, new combustion patterns may be important if connected to simpler and less expensive exhaust gas aftertreatment systems, but they do not contribute directly to engine efficiency, if the whole engine cycle is taken into account. The optimum air excess values reflect in-cylinder temperatures and speed, decreasing with increased engine speed. The values are suitable for pollutants aftertreatment. The results of unlimited optimization constraints have shown the importance of cooling loss at reduced engine speed and the need of a long-stroke engine design, if low speed is used dominantly in engine operation. Optimum valve timing requires a moderate Miller cycle, compression ratio being kept at standard values of 16 -18, except for reduction at lowest speeds. It is caused again by the increase of cooling loss at low speed. Downsizing may be accompanied by downspeeding, reflected in lower cycle frequency (speed in r.p.m.), which positively increases time for unsteady events during combustion and gas exchange while the cycle cooling loss and the threat of knocking is increased, as well, and mechanical losses are reduced. According to the current results, more can be achieved if downspeeding is done only by moderate mean piston speed reduction. Especially in the diesel (CI) engine case the stroke can be increased for a downsized engine, keeping mean piston speed and engine speed constant while downsizing the engine.

The gains achieved by downsizing and downspeeding depend on the initial level of power concentration. For today’s state-of-the-art, they can reach 10%-15% measured in TTW test efficiency if all feasible ways of improvement of engine thermodynamics and friction losses are applied and if engine weight effect on driving resistance is taken into account. The next steps are focused on the same investigation of spark ignition ICE, limited moreover by knocking. In parallel, the future research is being already focused on assessment of low speed/load operation of engines and their dynamic response, including smart control systems. These both features are unavoidable for vehicle road test application. The results of dynamic response simulations may employ even 3-D models, as demonstrated, e.g., in (Macek J. et al., 2010).

Considering future ICE improvement, the relevance of correctly simulated model of wall heat transfer inside a cylinder calls for further experimental investigation of this issue together with assessment of wall insulation, low thermal inertia materials. This loss limits the potential of downspeeding. The second decisive factor is turbocharger or supercharger efficiency improvement. The future research will be focused on coupling waste-heat recovery cycles to current ICE performance considering the size and weight of appropriate systems with impacts to vehicle performance, which is possible in DASY.

The overall experience with ICE optimization stresses that holistic approach is the only way to a better engine. The separated optimization of details cannot achieve this target. The rightsizing and rightspeeding is the goal for reaching total optimum obviously.

Acknowledgements

This work was supported by:

- Technological Agency, Czech Republic, programme Centre of Competence, project #TE01020020 Josef Božek Competence Centre for Automotive Industry.

- EU Regional Development Fund in OP R&D for Innovations (OP VaVpI) and Ministry of Education, Czech Republic, project #CZ.1.05/2.1.00/03.0125 Acquisition of Technology for Vehicle Center of Sustainable Mobility.
- The Grant Agency of the Czech Technical University in Prague, grant No. SGS13/184/OHK2/3T/12.

This support is gratefully acknowledged.

References

Banzhaf W., Nordin P., Keller R., Francone F. (1998). Genetic Programming – An Introduction. Morgan Kaufmann, San Francisco, CA, 1998

Bogomolov S., Mikulec A., Macek J. (2011). Development of Design Assistance System and Its Application for Engine Concept Modeling, SAE Technical Paper 2011-37-0030, 2011, SAE World Congress 2011, doi: 10.4271/2011-37-0030

Bogomolov S., Mikulec A., Macek J., Valasek M., Doleček V. (2012). Knowledge-Based Design and Optimization of Engines, THIESEL 2012 Conference on Thermo- and Fluid Dynamic Processes in Direct Injection Engines.

Curtis E. (2013). Near Term Combustion System Development and the Influence of Transmissions, Drive Cycles and Fuels (Ford Motor Company). High Efficiency IC Engine Symposium, SAE 2013

Eilts, P. et al. (2013). Investigation of Extreme Mean Effective and Maximum Cylinder Pressures in a Passenger Car Diesel Engine. SAE Paper 2013-012-1622

Emrich M., Fuente D.S.J., Macek J. (2011). Simple Physical Model of ICE Mechanical Losses. SAE Paper 2011-01-0610

Hejlsberg A., Torgersen M., Wiltamuth S., Golde P. (2010). C# Programming Language, The (4th Edition)

Hyvonen J. (2013). Higher Efficiency for Further Downsizing; Example from Large Bore Medium Speed Engines (Wärtsilä). High Efficiency IC Engine Symposium, SAE 2013

Kmoch M. (2011). Optimization of a crankshaft. Diploma Thesis DP 2011 – M 05, FME CVUT in Prague, CZ, 2011

Macek J., Vítek O., Doleček V., Srinivasan S., Tanner F.X. (2010). Optimization of Engine Control Strategies during Transient Processes Combining 1-D and 3-D Approaches. SAE Paper 2010-01-0783

Mifa Kim, Tomoyuki Hiroyasu, Mitsunori Miki, Shinya Watanabe (2004). SPEA2+: Improving the Performance of the Strength Pareto Evolutionary Algorithm 2, Parallel Problem Solving from Nature - PPSN VIII, 8th International Conference, proceedings pp. 742-751.

Motta, E., Zdrahal, Z. (1996). Parametric Design Problem Solving. KAW 96, Banff, Canada, 1996

Reitz R. (2013). Reactivity Controlled Compression Ignition (RCCI) for Ultra-High Efficiency IC Engine Operation with Low NOx and PM Emissions Plus Transient Control. High Efficiency IC Engine Symposium, SAE 2013

Vítek, O., Macek, J., Polášek, M. (2006). New Approach to Turbocharger Optimization using 1-D Simulation Tools. SAE Paper 2006-01-0438