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HYBRID VEHICLE POWERTRAIN WITH RANGE EXTENDER

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Introduction

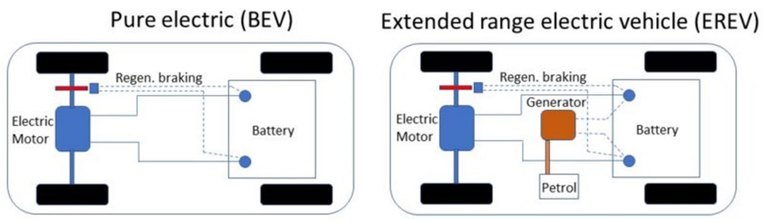
Transport plays an essential role in the contemporary world. The current transport system relies on energy derived from fossil fuels since the internal combustion (IC) engine is the most common primary power source. Along with all the benefits transport provides, the significant number of motor vehicles negatively affects the natural environment and human life, and leads to many problems, such as air pollution, climate change, global warming, or the exhaustion of crude oil resources. That is why further measures are needed to increase the overall efficiency of the vehicle's powertrain and meet new, stricter and more demanding emission standards.

During the past years, R&D in the automotive industry focused on this issue, and a lot of different solutions were proposed, including alternatives to conventional motor vehicles, such as hybrid and electric vehicles. In modern hybrid electric vehicles (HEVs), the IC engine is also the main option for a primary power source. It is joined together with an electric generator, an electric battery and an electric motor.

In contrast, electric propulsion systems are supported by electrical energy coming from an electric battery. They offer better energy efficiency and a lower environmental impact (measured on a local scale). However, the overall performance and range autonomy of BEVs is still limited due to the lower energy density of electric batteries. Improvements in battery technology are needed to reduce cost and weight and increase capacity, which is a long-term process.

Definition of Hybrid Powertrain with Range Extender

A solution to this issue can be achieved by a discreet modification of the BEV powertrain, which is supplemented by an auxiliary power unit called a Range Extender (REx). It is used to extend the travel range by supplying the battery system with electricity. However, in most cases, it serves as a safety measure to eliminate range anxiety. The newly emerged vehicle concept presents a distinctive type of hybrid electric powertrain (primary energy source = electric battery, propulsion = electric).



REx uses a secondary fuel-based power source (a small heat engine) that drives a mechanically connected electric generator to supply the battery and the electric motor with electricity. There are a variety of different heat engines, but the main focus is on reciprocating IC engines.

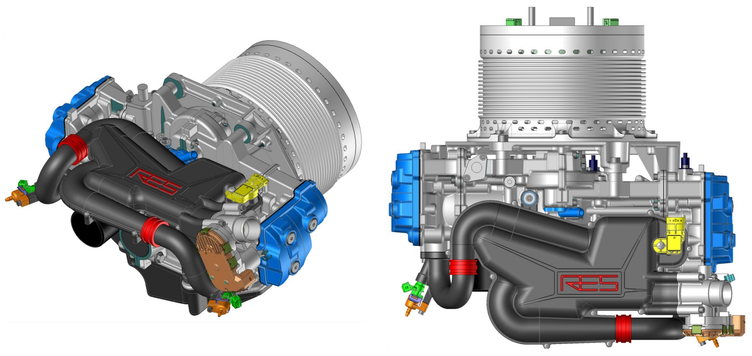


Fig. 1 Range extender system

Requirements and Characteristics for Range Extender :

- **size and dimensions** – small and compact; installation in EV; 1, 2 or 3-cylinders; inline, V-type, flat; displ. up to 1,0 litre;
- **weight** – as low as possible, around 50 - 60 kg, most of the time it is only an unnecessary weight;
- **cost** – low as possible -> simple and proven technologies;
- **output performance** – in general limited – narrow speed range, around 20 kW to 35 kW;
- **efficiency** – as high as possible; optimised with regard to required power, low fuel consumption and emissions;
- **emissions** – proper thermal management of the engine and exhaust system control the emissions;
- **superior NVH characteristics** – quiet operation, low vibrations, noise insulation and dampening;
- **optional equipment** – selected at a client's request.

Internal Combustion Engine for Range Extender Unit

Considering all the criteria and requirements, the most suitable option for REx is a naturally aspirated four-stroke spark-ignition engine. It is simple in design, undemanding and cheap. Because the engine has to be adapted to the requirements, it differs from other types – in design, size, operation and control and its implementation into REx implies some issues and challenges.

Goals

The design of an IC engine for a REx unit is not a simple task, due to quite different requirements and operating conditions. The design requires a much more complex design approach, even asking for completely new design solutions. Often, the REx engine uses proven serial solutions with some adaptations.

This leads to the choice of general focus on **the design of ICE for REx unit using modifications of available cylinder units in order to obtain appropriate solutions offering an acceptable trade-off between the operating characteristics, efficiency and ICE package and design** by means of methods for:

– mechanical design of ICE components and subsystems, aided by parametric CAD modelling techniques, thermodynamic analyses of the engine cycle, structural analysis, etc.;

– reduction (optimisation) of weight, size and volume of ICE;

– optimisation (design/operation) of REx and HEV layouts.

With regard to these general goals, **the particular objectives of the doctoral thesis are defined as follows:**

– examine, identify, or determine the EREV power demands by a suitable approach (measurement, calculation, or simulation);

– examine, identify, or determine the power of the REx ICE by a suitable approach (measurement, calculation, or simulation);

– suggest a suitable workflow for the initial phase of the design process, aiming at an increase in productivity;

– suggest a suitable approach, method, model, or tool for quick initial (conceptual) design of the ICE, its mechanical systems (components) during the first phase of development;

– create and implement the tool using the available software;

– test the developed method and workflow on the ICE design;

– provide a preliminary design proposal of the ICE, including initial analysis, with respect to the requirements, which will serve as a basis for further design stages.

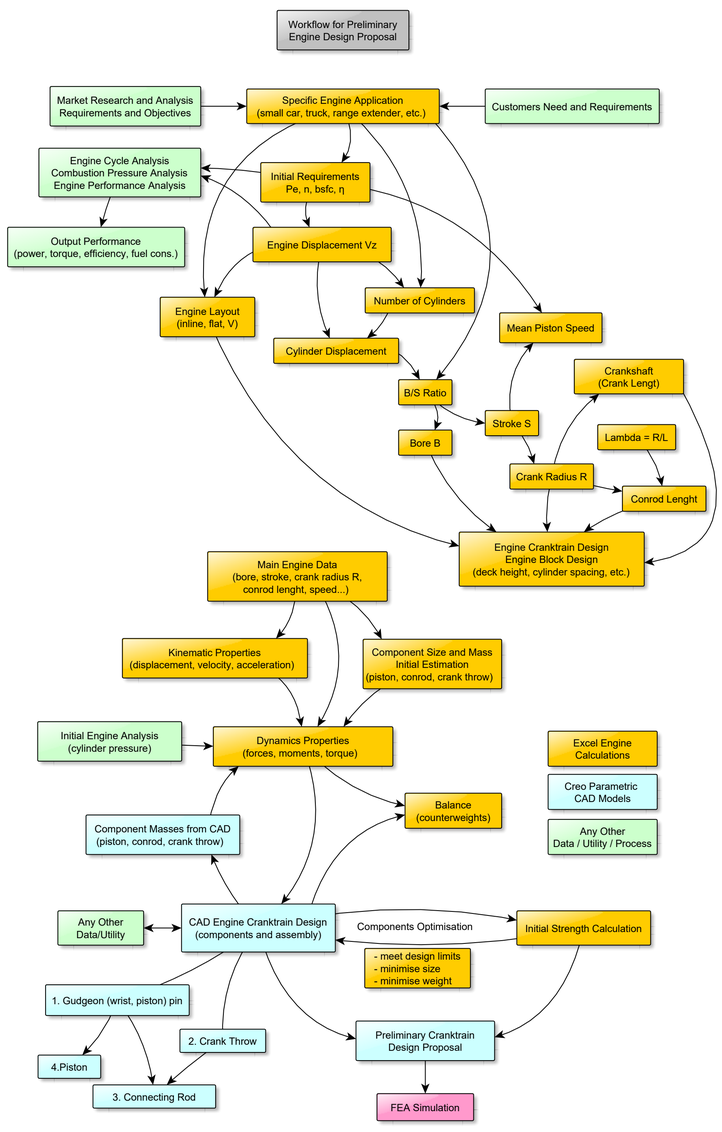


Fig. 2 Workflow for preliminary cranktrain design proposal.

Methods

The suggested method for initial conceptual design of the engine components is based on the application of traditional analytical and empirical calculations for designing and dimensioning the engine components in combination with parametric 3D CAD modelling techniques.

The **suggested method** involves:

– preparation of a model for preliminary calculation of ICE parameters

– preparation of a model for initial design proposal of the ICE components by applying traditional analytical and empirical calculations methods and models for designing and dimensioning (dimensions, kinematic, dynamic properties, strength analysis);

– preparation of parametric 3D CAD models of the ICE components using parametric CAx modelling techniques in order to:

– gain the best from both worlds, incl. a feedback between them (from calculation to design and vice versa),

– design and optimise the parameters of the ICE, and

– obtain a preliminary design proposal of the ICE cranktrain, providing a basis for further consideration, decision-making or detailed design of units.

By using pre-prepared models of the ICE components, it is possible to complete the initial design steps and tasks, obtaining a preliminary engine design proposal. It might seem that the analytical methods are not very accurate for some tasks or in some cases they may seem a little obsolete, but they have their merits.

The suggested method is applied to the mechanical design of ICE. However, the approach is practically intended to be versatile and applicable in the design process of other mechanical systems as well. The method strives to conduct critical engineering calculations relatively quickly with sufficient accuracy and to provide direct feedback on the design, aiming to increase productivity in the initial stage of the development process. It can be considered as a preliminary stage before the use of more advanced simulation-based design methods (simulation-driven design).

The final result is a preliminary design proposal of the ICE and its cranktrain, optimised in a first approximation by means of analytical calculations. Thus, the designers have at their disposal a solution in which they can find important data and context for the newly designed ICE. This initial design proposal can serve as a basis for the subsequent detailed design of the individual components, for package (size, weight) and installation analyses, etc.

The suggested method is applied to the initial design of a twin-cylinder inline engine intended for a REx. It shows that the chosen approach has good potential for application in practice. The effectiveness of the method depends on the available software tools, and their flexibility and approach to implementation.

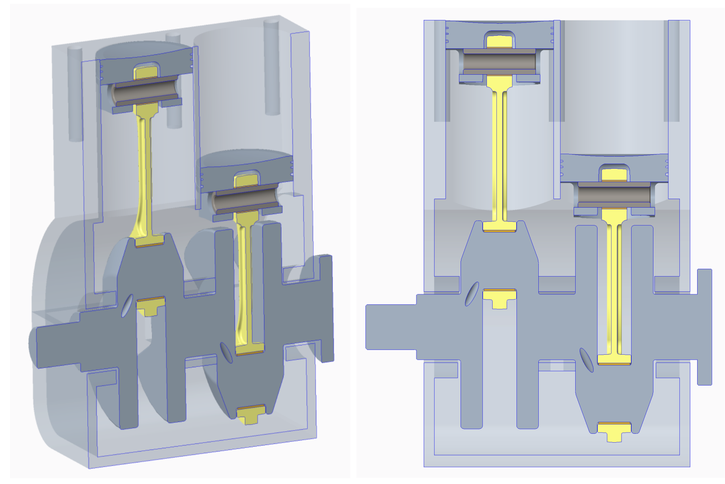


Fig. 3 Parametric 3D CAD model of twin-cylinder engine

Conclusion

The range extender unit presents an accessible solution to the issues of electric vehicles. It involves a discreet modification of the pure electric powertrain, which is equipped with an auxiliary power unit used to extend the travel range to a more acceptable limit by supplying the system with electricity. This solution allows reducing the total capacity (thus weight and cost) of the electric battery. Other energy needs are covered by the range extender. A comprehensive simulation study of ICE parameters for REx successfully identified the areas of optimum values.

The doctoral dissertation aims to explore ways to enhance the individual steps of the design process and to improve productivity, thus obtaining the desired results faster. Traditional design approaches were chosen as an instrument to meet the goals.

The dissertation suggests and presents a theoretical and practical development of a suitable method (model) for conceptual design proposal of mechanical systems during the early phase of development. The aim of this tool, in our case, is to provide a preliminary design proposal of ICE components, using intuitively all the knowledge and experience gathered over the years, including an initial analysis, while respecting the specific requirements. It can serve as a basis for further design stages. The designing method also involves the need for a suitable workflow to carry out initial design tasks with better productivity.

The designing method has been successfully tested on a model example of an ICE suitable for a REx unit. The design study of the IC cranktrain presented shows that the suggested design method has good potential for application in practice. By the use of an integration of both analytical and parametric CAx models, a preliminary virtual design solution can be prepared while maintaining an awareness of the physical nature of the design issues.