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Hybrid Concept with a Fully Variable Valve Train - FlexWork

By 2020 the new CO_2 emission limits are lowered to 95 g CO_2 per km. To reach such challenging limits manufacturers are applying more and more often hybrid concepts. The most common type of hybridization is the usage of a spark ignited internal combustion engine (ICE) coupled with an electric motor (HEV). The idea behind this investment is to avoid running the combustion engine at low load operating points, where its efficiency is rather poor. This approach is often followed by neglecting all engine improvement measures, since the engine is assumed to be running only at its best-point.

However, simulations have shown that such an approach is suboptimal and that the ICE's part-load efficiency is important even for HEVs. Furthermore, we are introducing the 8- and 12-stroke operation mode, which is used to improve efficiency at low power operating points.

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Introduction

A novel, fully flexible valve train has been invented[1], simulated, developed and built as shown in Fig. 1 and mounted on a 1.4 liter SI engine.

The engine runs since October 2018 successfully in fired operation. Dethrottled operation and selective cylinder deactivation have been evaluated and found to be effective measures to increase part-load efficiency[2].

The simulation is calibrated with data from the test bench. In the future additional strategies as 2-, 6-, 8- and 12-stroke (X-stroke) operation will be evaluated and included in the simulation.

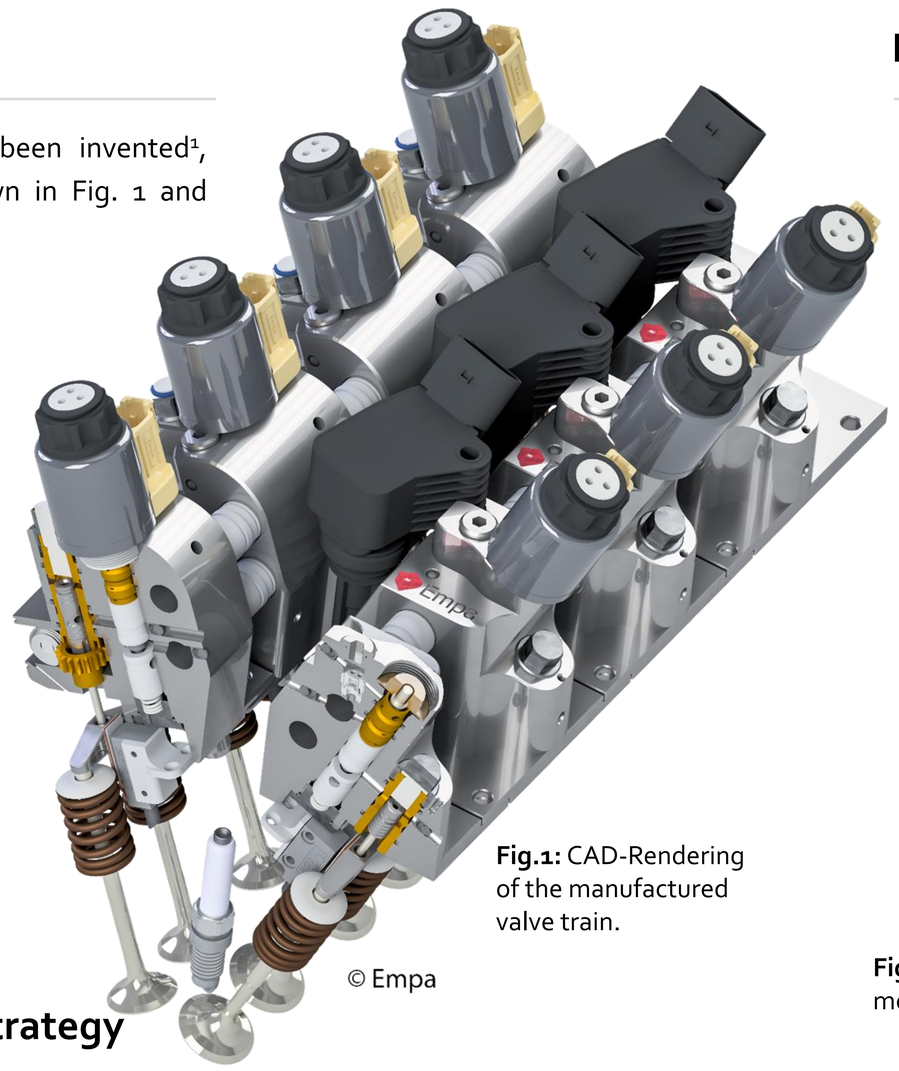

Fig.1: CAD-Rendering of the manufactured valve train.

Hybrid / non-Hybrid CO_2 Comparison

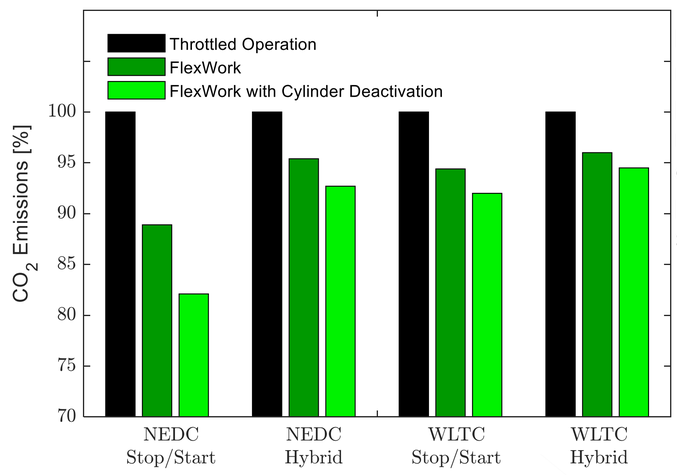

Fig.2: CO_2 reduction potential resulting from dynamic programming simulations[3].

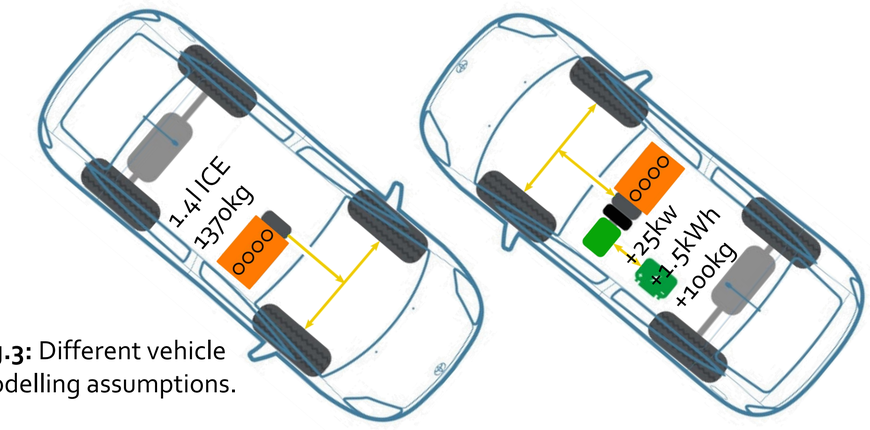

Fig.3: Different vehicle modelling assumptions.

Results & Novel Operation Strategy

For a conventional vehicle **fuel savings from 9% (WLTC) up to 19% (NEDC)** are achieved with the FlexWork system. However, even in a hybrid electric vehicle the fuel consumption is further reduced by 6-7%, depending on the driving cycle. Results are shown in Fig.2 and modelling assumptions in Fig. 3.
Interestingly, the optimal operating strategy indicates that operating point shifting is not occurring due to the losses on the electric path. Hence, we are investigating an **extension of the general 4-stroke operation to 6-, 8- and 12-stroke operation to enhance part-load efficiency**.

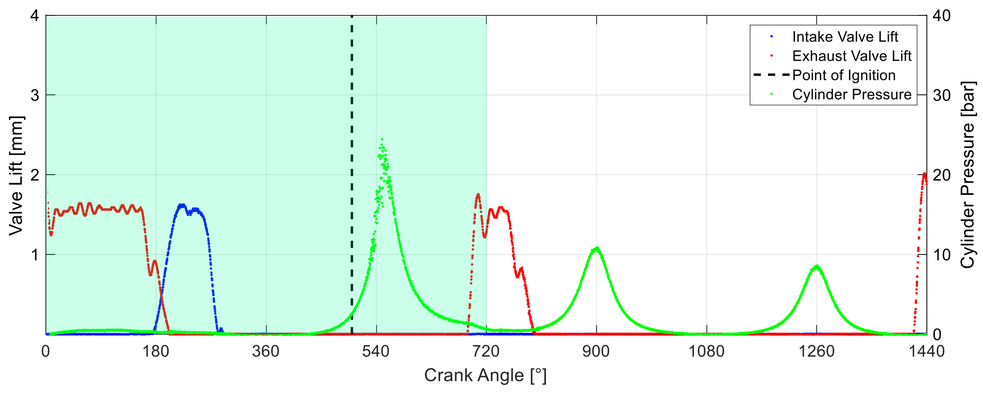

Fig. 4: Fired 8-stroke operation measurement. The light-green background indicates the region of 4-stroke operation, the remaining part is added due to 8-stroke operation.

In Fig. 4 a recorded 8-stroke operation strategy is presented. This enables the engine to run efficiently at very low loads while the **firing cylinder is operating close to full load** and hence, achieving high combustion efficiency. Currently we are investigating the optimization of such X-stroke operations and the applicability in hybrid vehicles.

Further Insights

Part-load efficiency improvement of the combustion engine is for all vehicle configurations beneficial,

is the main conclusion. Furthermore, **fuel savings in the range of almost 20%** without any hybridization are achieved if the FlexWork system is applied with its features as dethrottling and cylinder deactivation.

A **proof of concept was realized with fired 8- and 12-stroke operation**, 2- and 6-stroke operation are planned. An analysis will be conducted to identify dis- and advantages of each strategy.

The FlexWork system helps to minimize the electric part of a hybrid vehicle while decreasing the CO_2 output even further.

References

1 European patents 17172231.7 & 18207848 pending

2 Zsiga, N.; Omanovic, A.; Soltic, P.; Schneider, W., «Wirkungsgradvorteile beim Ottomotor unter Verwendung einer nockenwellenlosen, vollvariablen Ventilsteuerung gegenüber gedrosseltem Betrieb», 8. VDI Fachtagung, Ventiltrieb und Zylinderkopf, Würzburg, 2019

3 Sundström, O.; Ambühl, D.; Guzzella, L., «On Implementation of Dynamic Programming for Optimal Control Problems with Final State Constraints», In: Oil & Gas Science and Technology, Vol. 65 (2010), No. 1, pp. 91-102

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Acknowledgment

Financial support from the Swiss Federal Office of Energy in the framework of the project « FlexWork » is highly appreciated.