UNIVERSITY OF PITESTI   SCIENTIFIC BULLETIN
FACULTY OF MECHANICS AND TECHNOLOGY   AUTOMOTIVE series, year XIX, no.23

VALVETRAIN TECHNOLOGY FEATURES AND OPERATION STRATEGIES FOR FUTURE SPARK IGNITED POWERTRAIN

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Article history:
Received: 08.05.2013; Accepted: 10.07.2013.

Abstract: *In the next years the automotive world will meet very severe challenges to overcome, to meet the CO2-targets probably will be the most difficult one. As E-mobility will take some more years to deploy, the conventional combustion engine will maintain as the core-contributor for achievement of these future targets. A very strong emphasis of course will be spent for friction reduction, thermal management, etc. to achieve highest efficiency of the complete powertrain. Beyond that time horizon further highly advanced SI combustion systems will come into the game: Miller cycle, variable compression ratio, cooled external EGR and other technology features which extensively will extend the so called sweet spot in BSFC map. The extended operation range at significant lower levels together with latest transmission technology will support the achievement of future CO2 emission targets.*

Keywords: future, valvetrain technology, spark ignited powertrain.

INTRODUCTION

In the next years the automotive world will meet very severe challenges to overcome, to meet the CO2-targets probably will be the most difficult one. Most of the countries all around the world already have introduced specific regulations to deal with reduction of pollutant emission as well as reduction of green house gases (GHG). Some countries tend to be ahead, others follow in certain distance, but all need to substantially reduce in very short time. And not to forget that all these regulations are additionally forced by extensive penalty payments for the case of non-compliance. For European fleet average the 2015 CO2-targets are very likely to be met, but until 2020 an enormous step has to be achieved to come down to 95g/km CO2 fleet average.
After a short time of extreme enthusiasm for electric mobility, the automotive industry has returned to realistic scenarios whereby the conventional combustion engine still is seen as the main contributor for global CO2 reduction.

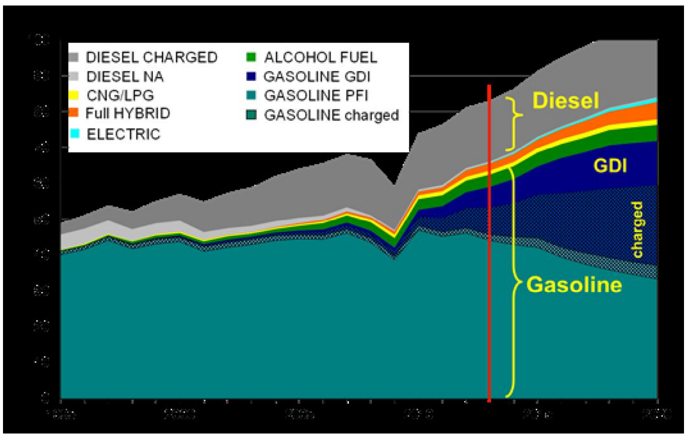

Figure 1. Global Engine Production for Passenger Cars by Propulsion Technology

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Having a look to the global deployment of the different propulsion technologies for passenger cars, Figure 1, we see the clear dominance of spark ignited gasoline and a huge portion of Diesel engines produced worldwide. Full hybrid and electric mobility is expected to grow, but only is able to contribute very small within the next decade in achieving substantially lower CO2 emission. It has to be pointed out that the slow penetration of new technologies is not primarily related to the readiness of systems or availability of components, but - of course – potentially for price reasons. Even more the fact has to be accepted that the average useable lifetime of a vehicle is somewhere between 10 to 15 years. Even in strongly growing markets the exchange rate for new vehicles is determining the penetration rate of new technologies. As an example for quite successful technology penetration we may take Gasoline Direct Injection (GDI). After starting mid of 90´s last century it took approximately 10 years after a volume of 1 Mio. GDI-engines was achieved (around 2005), Figure 1. At the end the breakthrough of GDI-technology started by combining GDI with turbo-charging. This technology combination turned out to be one of the mainstream technologies for the next decades.

TECHNOLOGY PENETRATION IN LOCAL MARKETS

Even global trends for some preferred propulsion technologies can be observed, the local markets all around the world show very significant differences. These differences can be explained by individual culture and car-owner perception of certain technologies, but to very wide extent are driven by regulations and pricing of fuels.

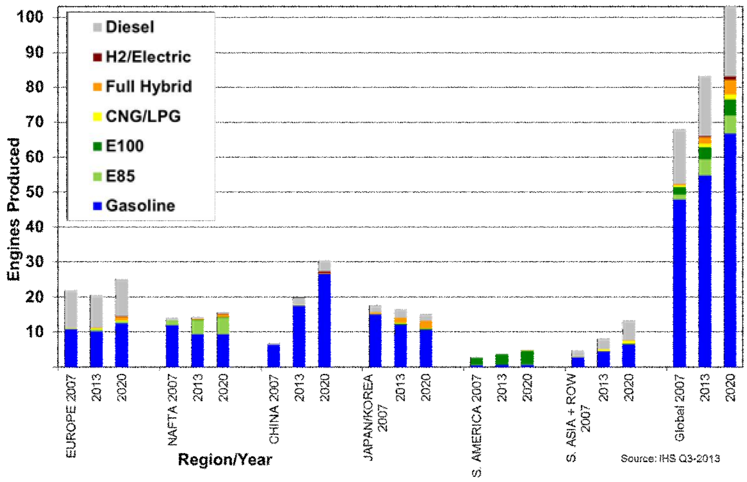

Figure 2. Engine Production for Passenger Cars in main Markets differentiated by Propulsion Technology

Looking closer into the shares of different propulsion technologies in the main automotive production regions we may see the following characteristics, Figure 2.
Europe: Since many years the Diesel share in Europe is approximately 50%. Especially in heavier vehicle segments (Upper class and SUV) the share of Diesel engines is over-proportionally high. For the next years the share of spark ignited gasoline engines produced in Europe is forecasted to rise, which may be seen as result from shrinking fuel price-benefit of Diesel compared to Gasoline fuel.
Full hybrid powertrain and alternative fuels like compressed natural gas (CNG) will gain importance within next few years as highly attractive solutions, but even by growing shares of alternative propulsion systems, the Diesel engine will maintain the backbone of achieving the forthcoming very stringent CO2 regulations.
NAFTA: Estimating a slight growth in overall production numbers, the main growth is expected for Hybrids and E85 Flex Fuel powertrain.
South America: The production of passenger car engines will steadily grow with a clear dominance of alcohol powered engines.

China: China will maintain with the strongest growing PC production worldwide. Growth forecasted mainly with conventional technology: Gasoline, but also Diesel engines used for Light Duty Vehicles (LDV).
Japan/Korea: Taking a moderate shrinking of local production of gasoline engines into account, the clear move towards Hybrid technology mainly in Japan is obvious. The Diesel engines produced in this area to wide extent are exported to Europe.
South Asia and ROW: The South East Asia area (including India) covers the second largest growth market after China. From a technology standpoint, this region demonstrates a very significant dynamic which is strongly driven by total cost of ownership (TCO). Therefore, the local availability and price of fuels has dominating impact to technology. Besides of Gasoline, the Diesel and CNG engines play an important role in the local Asian markets.

FUELS AND ENERGY SOURCES FOR LOWER CO_2-EMISSION

As already mentioned in last paragraph, the fuel used for propulsion has very significant impact to cost but also CO2 emission. But, it is not only the composition of fuel and the properties which qualify for highly efficient conversion into vehicle motion. Probably even more the origin of fuel and the utilization of primary energy resources have to be taken into consideration. Renewable fuels (e.g. ethanol from sugar cane) are quite positive in a well to wheel perspective. Electric mobility only can positively contribute for CO2 reduction if electric power generation is carbon-free (e.g. hydro-power) or preferably even from fully renewable sources.
Anyway, from a tank to wheel perspective the conventional naturally aspirated (NA) gasoline engine still covers the upper range of CO2 emission scatter band, Figure 3. But clearly it can be seen in this cloud of dots that the representatives of the new generation of downsized Gasoline Turbo engines consequently move into the CO2 range of modern Diesel passenger cars. In that kind of completion for lower CO2 emission the Diesel engine still dominates its role, especially with vehicles of higher weight. In higher vehicle segments (SUV, luxury class) the considerable oncost for the diesel engine itself and additionally for exhaust aftertreatment obviously still pays back. This maybe explains the market success for Diesels since many years especially in Europe. In terms of low CO2 the Diesel engine meets more and more competition from Hybrids. Especially the Plug-in Hybrids are able to open new dimensions for ultra-low CO2 emission.

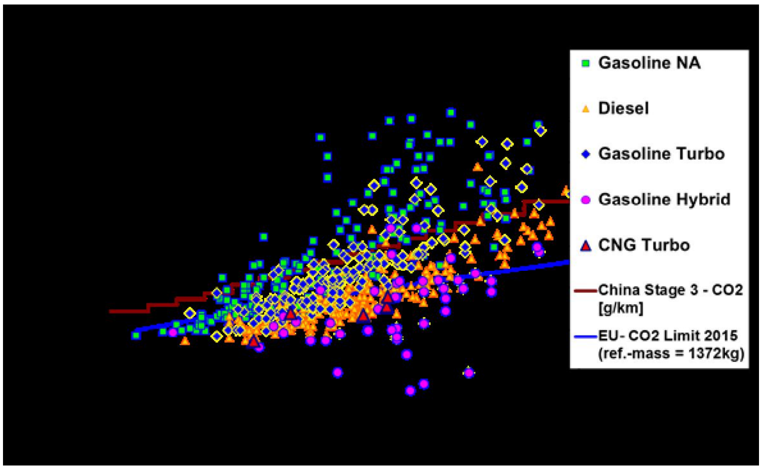

Figure 3. CO2 Emission of Passenger Cars in NEDC versus Vehicle Weight relative to forthcoming CO2 Limits.

But, let´s return to conventional SI combustion system and have a look to compressed natural gas (CNG) as automotive fuel. Due to specific heat value of CNG (relating with ratio between Hydrogen and Carbon content of Methane), CNG operation reduces CO2 emission by more than 20%. The loss in volumetric efficiency which occurs with gaseous fuels widely can be compensated by turbo charging. Such CNG Turbo concept, see Figure 3, offer good driving performance without power constraints together with very attractive fuel price.

Furthermore, we may not forget that CNG as well as Ethanol by nature have very big advantages for SI-combustion due to high knock resistance. As long as engines which are prepared for ethanol or CNG, and still have to run on standard gasoline fuel, the potential for highest possible efficiency usually for these excellent fuels is restricted and cut. But, it may be expected that in the close future more combustion system will come to market, which are dedicated to these kinds of fuels and therefore will be able to utilize supreme efficiency potential with SI combustion.

TECHNOLOGY PACKAGES FOR INCREASING EFFICIENCY

In the previous paragraph it was described how the fuel quality may support the reduction of CO2 emission. Apart from origin of fuel (renewable fuels) or chemical properties (e.g. CNG) which reduces CO2 by its nature, the octane number has direct impact to combustion performance of SI- engines. Besides of knocking, furthermore intake throttling and imperfect load exchange can be marked as the dominating limitations in thermal efficiency of SI-engines.
In the following, trends and solutions are described which shall overcome these inherent drawbacks for SI-combustion of homogeneous λ=1 air/fuel mixture.

VARIABLE VALVETRAIN AS KEY ELEMENT FOR SI-ENGINES

As the very most SI-engines operate with homogeneous and stoichiometric air/fuel mixture, the load exchange has very strong influence to performance as well as efficiency. Therefore, many different technical solutions for variable valve train elements have been introduced to mass production in the last decades. Whereas such variability in valvetrain become more and more a standard for gasoline engines, the Diesel engines just are at the very early beginning to introduce VVT (Variable Valve Timing) to series production.
The cam phaser mounted to the camshaft already has gained a very wide coverage with modern gasoline engines. For gasoline engines produced in Japan nearly all of them are equipped at least with one cam phaser, mostly on intake side. For gasoline engines produced in Europe we see a quite very differentiated pattern in the various valvetrain technology features. When analyzing the European production in 2012 of 10 Mio. gasoline engines, there are approx. 2 Mio. engines which do not feature any VVT-element, Figure 4. For the following years the number of produced gasoline engines is forecasted to increase by 30% within next six years, and the amount of engines thereof without VVT elements will shrink drastically.

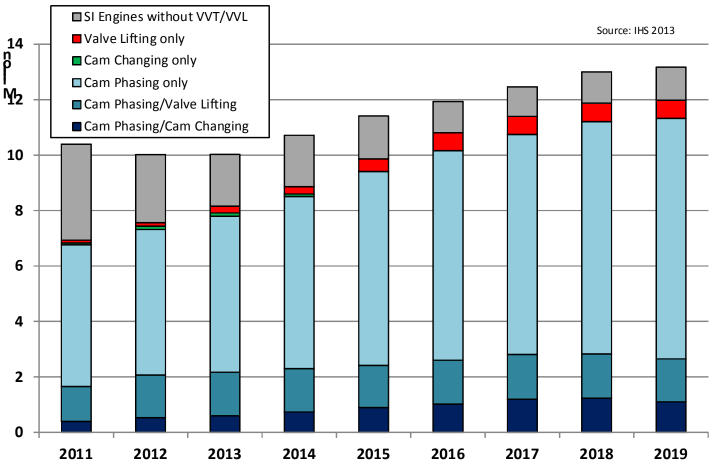

Figure 4. Valvetrain Technology Shares for Gasoline Passenger Cars produced in Europe.

But have a closer look to the different variable valvetrain technologies in Europe. The chart in Figure 4 showing the trends and distinguishes between the following VVT resp. VVL (variable valve lift) principles:

- Valve Lifting only (valve lift can be changed continuously, e.g. FIAT Twin Air system);
- Cam Changing only (switching between different valve lift curves, e.g. Honda VTec system);

- Cam Phasing only (able to continuously shift timing of valve opening, whether on intake or exhaust camshaft);
- Cam Phasing/Valve Lifting (at least one cam phaser, additionally the valve lift can be changed continuously, e.g. BMW Valvetronic);
- Cam Phasing/Cam Changing (at least one cam phaser, additionally switching between different valve lift curves, e.g. Audi AVS system)

The growth for VVT system components from today onwards is dominated by consequent implementation of cam phasers. As the bigger gasoline engines and especially the premium applications already are saturated with this design feature, the cam phasers are expected to penetrate further into small engine applications. The fully continuously VVL+VVT systems currently are demonstrating a relative high share of 15% within European gasoline engine production, but the absolute number of these elements are forecasted to maintain at similar level. Purely VVL-systems as well as Cam Phasing/Cam Changing systems are expected to significantly grow in numbers over the next years, whereas special attention has to be paid for switchable cam profile systems (2- and 3-step), which additionally offer the possibility for cylinder deactivation. Cylinder deactivation in any case has to be judged as very strong technology trend for next few years.

TECHNOLOGY EVOLUTION IN TURBOCHARGED SI-ENGINES

When speaking about "Evolution" in technology with spark ignited gasoline engines, we even may use the term Technology "Revolution" instead when we think about the huge progress achieved within the last few years especially together with turbo charging and gasoline direct injection (GDI). A lot of progress took place in combustion refinement, which at the end hopefully shall erase the former image of turbo charged SI-engines to be gas-guzzlers. The progress especially for turbo charged GDI engines (TGDI) is demonstrated in the widening of spread between higher specific torque (BMEP) and reduced specific fuel consumption (BSFC) at full load, Figure 5.

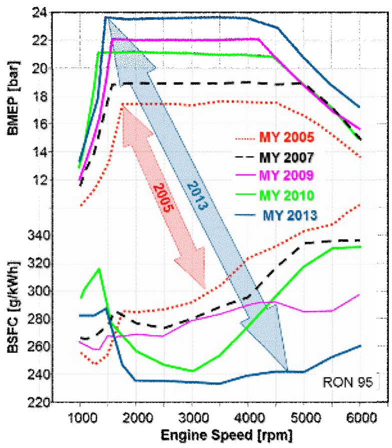

Figure 5. Evolution of BMEP versus BSFC of Turbo Charged GDI Engines over the last Years.

Particular improvements have been made in refining the combustion systems in many directions by reducing knock sensitivity, increased combustion stability due to higher charge motion, utilizing special functionality of the valve train (e.g. scavenging), multiple injection, high energy ignition and better charging systems. In former times the mixture enrichment at full load operation was the widely preferred measure extensively used to maintain the exhaust gas temperatures below the allowable limits for protecting TC and catalyst. With modern combustion systems, featuring higher compression ratio and faster combustion the enrichment requirement already has been reduced significantly, but complementary active measures are foreseen to further reduce exhaust gas temperatures. This may be improved exhaust gas cooling by water-cooled or integrated exhaust manifold. As an option, a water cooled turbine housing even would enable the application of variable TC turbine geometry for gasoline engines (similar as already standard with Diesel engines), but not requesting high temperature resisting alloys as known from premium high performance applications. As highly effective measure to reduce exhaust gas temperature at full load is to introduce cooled external EGR. All the listed measures are aimed to enable stoichiometric air/fuel mixture even at rated power and maintain BSFC at very low level.

For many of the gasoline- and alcohol-fuelled powertrain the turbo charging technology widely opened the door into the world of downsizing. Downsizing means smaller engine displacement with higher specific power output and torque, therefore minimized friction and losses which consequently is promoting higher efficiency. But for the challenges of forthcoming CO2-limits these achievements already made are not any longer sufficient. Future technology for turbo charged SI-engines has to evolve still much further!

But, what may we expect to come from current evolution to a technology revolution at the end ? Here the activities for highly advanced SI-technology start. Next generations of TGDI engines significantly will extend sweet spot area. Some of the new technology elements (all λ=1) which will be introduced may be Variable Compression Ratio (VCR) as well as Miller cycle + extended Expansion Ratio (ER), Figure 6. With all these new combustion features, besides of internal EGR, also the external induction of huge amounts of cooled EGR will play an increasingly important role. Generally, with all these advanced combustion system configurations it is aimed to achieve best point BSFC of approx. 10% lower as nowadays level with stoichiometric systems.

Due to still extensive difficulties and cost with non-stoichiometric exhaust aftertreatment, lean combustion systems probably are not expected to significantly expand in volumes short-termed. Also auto-ignited (HCCI) systems still generate high public awareness, but are not announced to enter mass production within the next few years.

In former times the throttling losses were considered as the major drawback of SI-engines. Consequently, most of technologies developed and introduced to mass production were focused to minimize these losses from load exchange. As the majority of SI-engines were naturally aspirated and power was transferred to the wheels by manual transmission (MT), this approach for improving part load efficiency was very well suitable. But also for turbo charged engines special attention is paid to minimize gas exchange losses. Cylinder deactivation currently is gaining higher interest not only for V-engines, but even with smaller cylinder numbers.

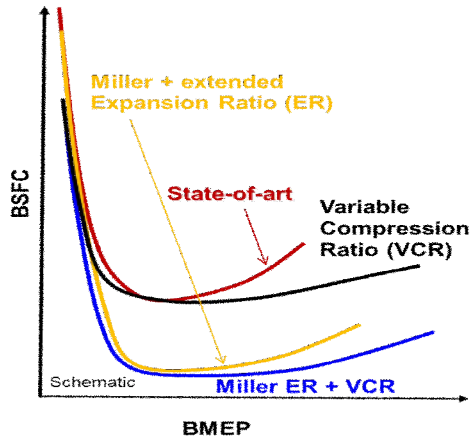

Figure 6. Schematic Indication of BSFC Improvement with Forthcoming Advanced TGDI Technology Features.

For the next generations of powertrain the share of automated transmission is expected to grow, featuring a steadily increasing number of gears. The wide gear spread of such transmission will enable to set engine operation point directly into the so-called "sweet spot" which is the speed/load area in engine map of highest efficiency. That means that the engine not only will be operated in areas of good fuel efficiency, because it is envisaged to preferably operate in sweet spot. Due to application of advanced gasoline technology features this sweet spot is expected to be enlarged extensively, Figure 7. This engine characteristic together with advanced transmissions will promote better fuel efficiency also in real world operation.

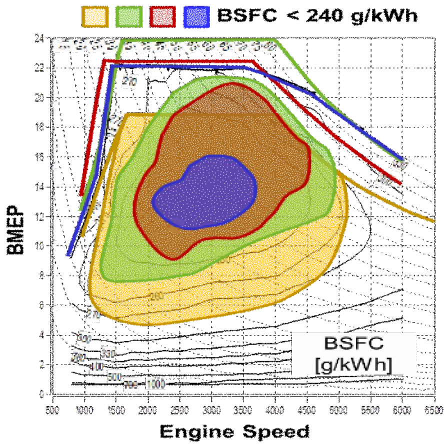

Figure 7. Extension of "Sweet Spot" Area in Engine Map by Application of Advanced TGDI Technology Features.

SUMMARY/CONCLUSION

Due to forthcoming penalty taxes, worldwide strong efforts are taken to reduce fuel consumption and CO2 emission. The targets are technically feasible, but very strong attempts have to be undertaken to achieve 95g/km CO2 by 2020 with forecasted PC population in Europe. For the next years the main trend probably will lead to more lightweight design and hybridization in all vehicle segments. As E-mobility will take some more years to deploy, the conventional combustion engine will maintain as the core-contributor for achievement of these future targets. Especially for the SI-engine, there still will be a wide diversity of different (what we call) base gasoline "technologies" such as variable valve train, turbo charging, alternative combustion systems and different fuels. Complementary to that, a very strong emphasis of course will be spent for friction reduction, thermal management, etc. to achieve highest efficiency of the complete powertrain. Beyond that time horizon further highly advanced SI combustion systems will come into the game: Miller cycle, variable compression ratio, cooled external EGR and other technology features which extensively will extend the so called sweet spot in BSFC map. The extended operation range at significant lower levels together with latest transmission technology will support the achievement of future CO2 emission targets.

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