Gasoline Engine Technologies
Focused on Multiple Benefit

Multiple benefit can be obtained in various ways in gasoline engine development through the consequent persual of this as goal. With the AVL-CBR 3 system, for example, the total cost can be significantly reduced by integrating the functionality of variable charge motion directly into the residual gas control by cam phaser. The AVL DGI-tc fuel economy and fun-to-drive concept achieved through uncompromising exploitation of the synergy effects between direct injection, cam phase shifter, turbocharging and exhaust valve masking increases customer benefits disproportionately greater than the increase in cost incurred.

1 Introduction

Gasoline engine technology development has changed significantly in the last two decades. In the past, the development of new engines was carried out in a growing market and with strong emphasis on the introduction of new technologies. As a consequence, development was not only focused on customer benefits, but often more on product differentiation (for example: the introduction of the first four-valve concepts, five-valve technology, Twinspark, GDI-stratified first generation).

Today we are facing a quite different market scenario: worldwide overcapacities result in extreme competition and cost pressure. Due to more stringent legal standards and customer demands, high-tech-features have become essential to fulfill standard requirements. New technologies are primarily used to comply with legislation and to generate noticeable customer benefits.

Such technologies therefore have to offer more than a single benefit – a broad spectrum of benefits is essential.

Not only must each measure be effective under real world conditions, all available synergy effects must be utilised to obtain maximum cost efficiency. Since with the gasoline engines highly effective exhaust gas aftertreatment is available, future development is focussed primarily on improved fuel economy combined with increased fun to drive and less on emission reduction.

2 Fuel Economy Improvement with Gasoline Engines

The actual fuel consumption of a vehicle and the potential for improvement are strongly dependent not only on the driving profile of the vehicle (for example: different test cycles), but also on the engine load profile, as determined by vehicle weight, engine displacement and transmission characteristics. The main fuel economy improvement measures such as

– shifting of engine operation points
– improved engine efficiency
– avoiding idle consumption (start /stop)
– recuperation of braking energy

show quite different improvement potentials in the various test cycles. Figure 1. As expected, both start/stop and recuperation of braking energy are highly dependent upon the driving profile, characterised by average speed and load dynamics.

Even if the efficiency of the gasoline engine could be increased towards the level of most modern diesel engines, the resulting fuel economy improvement would be sur-
prisingly low, in the range of 4 % to 12 %. This is due to the fact that the lower fuel consumption of the diesel engine results to just one third from the higher thermal efficiency of the diesel engine, the remaining two thirds resulting equally from the longer final drive ratio possible and the higher density of diesel fuel.

The shifting of engine operation points towards areas of higher engine efficiency (for example: reduction of engine displacement by 20 % and application of a 30 % longer final drive ratio) provides both the highest and also, with different driving profiles, the most consistent potential for reduced fuel consumption. Nevertheless, technology development in recent years was much more focused on the combustion and gas exchange system to obtain improved engine efficiency, especially at part load.

Technology selection focused on increasing customer value must consider the total engine-drivetrain-vehicle system and include general measures such as reduction of parasitic losses, sophisticated energy management and hybridisation. In this way more effective solutions for the complex trade-off between fuel economy, cost and driving enjoyment can be found than with a purely engine-focused assessment.

3 Gasoline Engine Technologies for Improved Fuel Economy

In contrast to the diesel engine, where at least the main technology route (for example: direct injection, turbocharging) is clear, with the gasoline engine there are a wide variety of technology approaches for fuel economy improvement and which incur and provide quite different add-on costs and benefits.

A comparison of the fuel economy improvement potential of the individual technologies over the baseline of current production engines (four valve, $\lambda = 1$, fixed valve timing), shows quite different characteristics in the engine map, Figure 2 (left column).

For the real-world fuel economy, the nominal values of maximum or mean improvement in the engine map are not decisive, but rather the improvement in that specific part of the map which is used most frequently. A load distribution characterising the combination of large engine displacement with a relatively light vehicle and consequently a strong focus on low engine loads and speeds can be seen in the centre column of Figure 2. With a small engine displacement and large vehicle weight and/or a fuel economy oriented long final drive ratio, or with a power split hybrid, the load focus is shifted significantly towards the higher load regime, Figure 2 (right column). The economy potential of the various technologies varies considerably, depending upon the load cycle.

- The combination of cam-phase shifter and variable charge motion offers only moderate maximum fuel economy improvements, however shows well-balanced characteristics over the whole engine map. Due to the low additional effort, the cost efficiency of this approach is highly attractive and not sensitive to different load profiles [1].
- With a higher valve train flexibility, for example with two-step or continuously variable mechanical valve lift, the improvements can be increased, especially at low engine loads. However, significant real-world benefits compared with the less expensive combination of variable charge motion and cam phase can only be expected for a load focus at low loads and/or high nominal engine speed.
- A real jump in fuel economy is feasible with camless, electro-hydraulic valve actuation [2]. Both valve timing and valve lift can be adjusted to the thermodynamic optimum in the whole engine map. Thus, even with stoichiometric operation, significant improvements are obtained in the whole operating range relevant for real-world fuel economy. At high engine speeds and loads the hydraulic losses increase disproportionately however, causing an even higher fuel consumption within this limited range. Due to the low proportion of engine operation in this range, the impact on real-world fuel economy is negligible. A significant additional benefit is generated by the possibility for selective cylinder deactivation. Especially for engines with more than 4 cylinders, this will be the most attractive approach. Due the high system and development complexity, a widespread introduction of such systems is not expected within this decade.
- Even without cylinder deactivation significant improvements are feasible at low engine loads with spray guided stratified charge GDI. At high speed/load conditions, however, higher fuel consumption is caused by limitations given by the current lean exhaust gas aftertreatment (DE-NO$_x$-catalyst). This behaviour has already been improved compared to the first generation of wall or air guided GDI, however, still remains a clear disadvantage with lean systems. As a consequence, the application of such a technology is only attractive with a load focus at low loads.

- In combination with turbocharging and cam phase, the application of stoichiometric GDI is the most effective basis for fuel economy oriented downsizing concepts. With appropriate system design, significant fuel economy improvements are possible even with a load focus at high loads. This technology is most attractive for the replacement of larger larger four-cylinder NA-engines.

With a multiple-benefit strategy as goal, technologies are of prime interest which offer additional synergy effects beyond the best relationship between fuel economy improvement and additional cost. These can be utilised to

- reduce technology content for the same functional performance
- increase perceived value at similar system cost.

As the huge success of the diesel engine in Europe is not only based on its fuel economy benefit, but also on the added value “fun-to-drive”, this criterion is of significantly increased importance.

Considering only technologies which can be introduced short-term and worldwide in the volume car market, two are good examples of opportunities to provide clearly focussed added customer benefits: For the more cost oriented engines the combination of cam phase and variable charge motion can be developed towards highest cost efficiency. The combination of GDI, cam phase and turbocharging offers a maximum of functional benefits – namely – highest fuel economy combined with excellent fun-to-drive at an attractive system cost.

4 Variable Charge Motion

The original target for the variable charge motion was to reduce the fuel consumption by improving combustion stability characteristics, thus providing significantly enhanced charge dilution tolerance (EGR or lean operation) at part load without compromising the full load performance.

A quite significant add-on benefit can be obtained from the simultaneously improved spark retard tolerance, resulting in a highly efficient catalyst heating strategy with accelerated catalyst light-off and lower engine-out and tailpipe emissions. Thus either an additional secondary air system can be eliminated and/or the precious metal content of the catalyst reduced, resulting in attractive cost reductions.

This first generation of such a variable charge motion system developed by AVI (CBr, Controlled Burn Rate), Figure 3 (left), has been successfully applied in large vol-