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The engine

Understanding it in its entirety

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Introduction

In the past, the development of automobiles and their drive systems was influenced and pushed forward by the application of the latest technologies in many cases. This meant it was possible for market participants to strengthen their position or the position of their product brands by direct differentiation in a generally growing market.

The current market scenario is influenced by:

- Product life cycles which are continuously being shortened
- Increased segmentation
- High cost pressure
- Demanding customers expectations
- High social expectations

The situation is also characterized by:

- Increased legal requirements
- A growing perception about the limitations of resources
- Significant overcapacity of production
- Different regional and market-segment-specific requirements

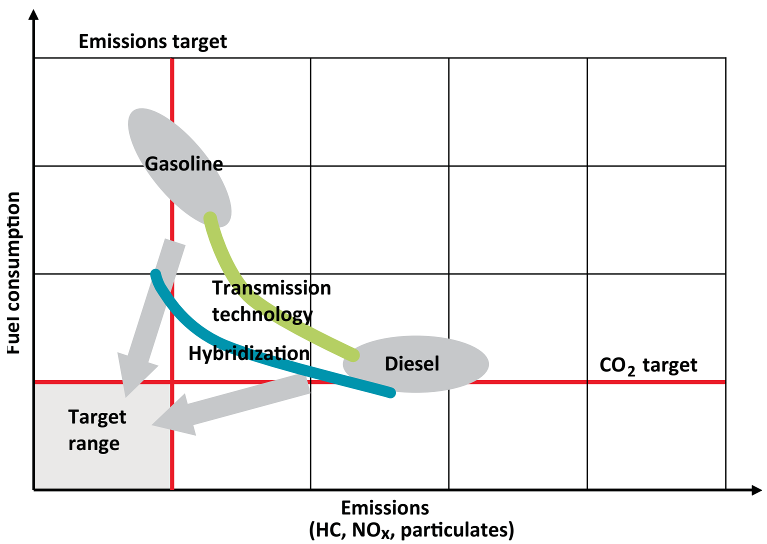


Figure 1 Fuel consumption/emissions

The sum of all these requirements and challenges requires a holistic approach so that added value can be achieved with new technologies compared with current volume production products. The development of added value can affect customers, society, legislators or producers. Mastering or controlling this complexity is the actual challenge of the present time.

Core issues for current drive system development

The core issues for passenger car drive system development are the conflicting aims of reducing fuel consumption (CO_2 emissions) on the one hand and limiting pollutant emissions on the other hand (Figure 1).

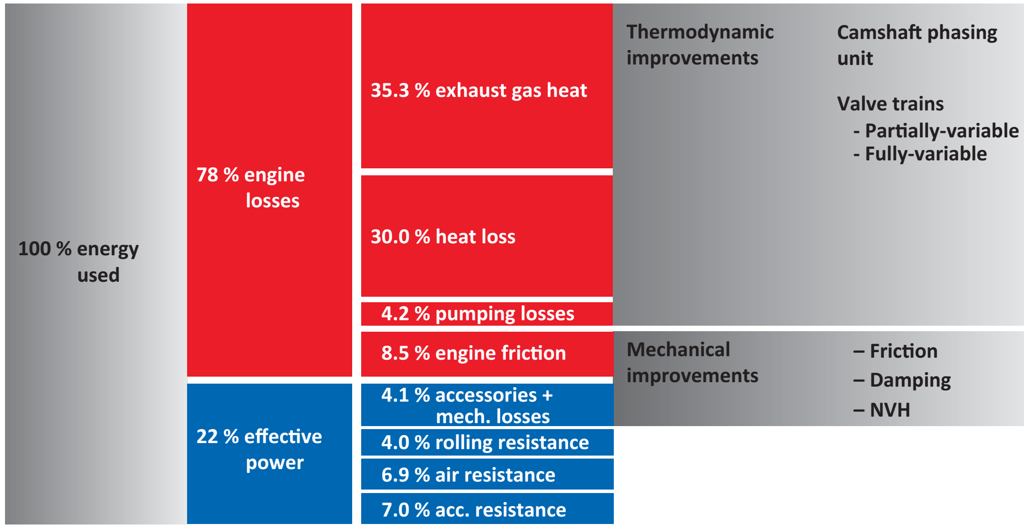
Boundary conditions such as costs, brand image, driving pleasure, comfort, noise and reliability must also be taken into account.

Gasoline and diesel engines are positioned completely different with regard to the conflicting aims of fuel consumption and emissions.

The gasoline engine is positioned very much in the low-emission category due to its very efficient aftertreatment of exhaust gases. The diesel engine, on the other hand, is positioned very much in the low consumption category due to its favorable, thermodynamic efficiency and advantageous low end torque characteristics. The proceedings of this article refer mainly to the gasoline engine.

Figure 2 shows a loss distribution analysis relating to the NEDC using a gasoline engine as

Efficiency chain of modern gasoline engines



NEDC related
Reference: Prof. Leohold, U. Kassel

Figure 2 Gasoline engine efficiency chain in the NEDC

reference. The starting points for making improvements are in the area of variability in the camshaft drive. These are:

- Camshaft phasing units
- Partially-variable valve train systems
- Fully-variable valve train systems

Due to the variability in the valve train, the thermodynamic process is influenced in the area of the low-pressure process so that there is a positive effect on the pumping losses and the combustion process is optimized in the area of the high-pressure process. These interventions also have a direct influence on the formation of emissions in the internal combustion engine and are, therefore, parts with direct relevance for engine out emissions.

The mechanical improvements refer to the minimization of friction losses and the reduction of parasitic losses of the accessory drives. The order of the mechanical losses is around 10 % to 12 % of the fuel energy used. I.e. detailed optimization with an improvement of 10 % to 20 % with regard to mechanical losses generates a total contribution of around 1 % to 2 % in the driving cycle.

Thermodynamic improvements

The significantly greater potential for improvement is due to the reduction in the thermodynamic losses. The thermodynamic improvements are targeted at enabling throttle-free load operation. Instead of controlling the intake normally by means of a throttle valve, control of trapped fresh air is transferred to the valves. The required pumping losses are reduced due to the increase in the intake manifold pressure. The required control of trapped fresh air is primarily undertaken by varying the opening time of the intake valve or by the design of the valve lift curve in the form of the cam contour.

At the same time, the charge motion can be directly influenced by the use of variable valve control systems in the combustion chamber. The forced inflow motion resulting from the motion of the piston is converted into a swirl or tumble motion due to the design of the intake ports. If the valves open at different times, the in-cylinder flow can also be strongly influenced. In conjunction with the position of the spark plug and the general layout of the combustion chamber, this opens up opportunities for a wide range of optimization measures.

The percentage of residual exhaust gases which remain in the cylinder can be directly influenced by the design of the valve overlap or the phasing of the valve opening. The temperature of the charge mass at the start of the compression stroke can be influenced by adding hot residual exhaust gas directly to the fresh mixture. This also enables the temperature at the end of the compression stroke to be influenced indirectly. This variability opens up a new alternative method of carrying out optimization for modern autoignition combustion systems.

The possibilities for influencing the thermodynamic process can be described as follows:

- Low-throttle operation under part load (charge cycle)
- Control of trapped fresh air (load control)
- Incylinder charge motion
- Percentage of residual exhaust gases in the combustion chamber
- Temperature at the start of the compression stroke

There are different requirements for optimizing engine characteristics (Figure 3) depending on the load and speed:

A Longer intake and exhaust valve lift events with greater valve overlap are desirable in the full load range at nominal speed, in order to ensure that the engine can "breath freely" (later closure of the intake valve).

B The intake and exhaust valve opening times should be shortened to optimize the volumetric efficiency in the low-speed and high-load range. The valve overlap must also be reduced compared to the overlap at the nominal speed.

C The pumping losses should be reduced in the center area of the engine map by early closing of the intake valve.

D Exerting an additional influence on the in-cylinder flow and maintaining the temperature of the charge composition are required in the low-load range in order to positively affect the combustion process. Cylinder deactivation can unlock further potential.

E For starting the engine, separate measures for ensuring the highest and most effective compression ratio are also required for improved starting behavior. A limited charge throughput by means of reduced valve lift or closed valves has proved reliable for enabling easier restarting with stop-start functionalities.

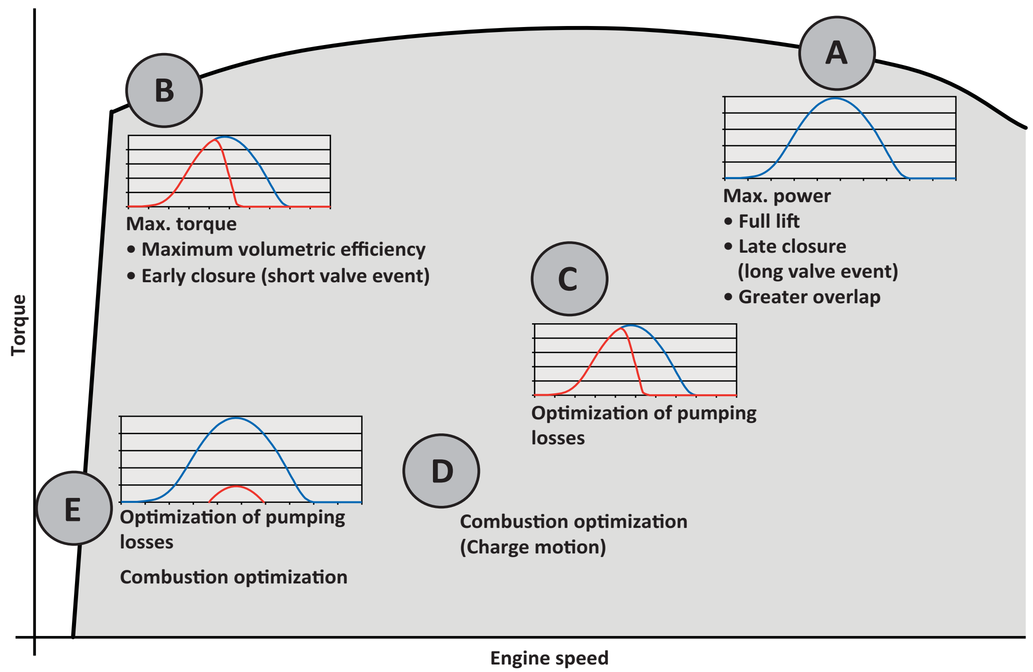


Figure 3 Diagram showing requirements for engine characteristics

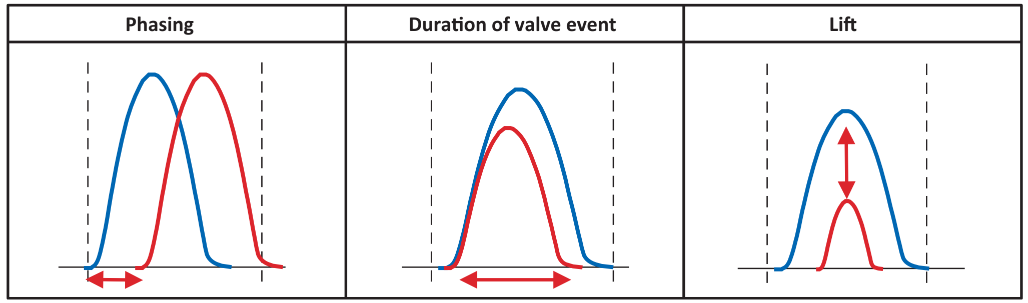


Figure 4 Division of variability in the valve train

Division of variability in the valve train

The following are used to characterize variability in the valve train (Figure 4):

- Phasing of the valve event
- Duration of the valve event
- Maximum lift of the valve event

In Figure 5, variability is divided with regard to phase and valve lift and according to the characteristics of discrete or continuous adjustment. The level of variability increases from left to right in the diagram accordingly.

Figure 6 shows a stationary data map with four operating points as an example to show the influence of dethrottling on the engine operating behavior. It can be seen that the influence of dethrottling by means of different measures

- Intake phase adjustment only
- Intake and exhaust phase adjustment
- Double phase adjustment & variable valve lift

is particularly pronounced in the lower area of the data map and can amount to a fuel consumption saving of up to 12 % at a stationary operating point.

The potential for improving fuel consumption in the driving cycle is between 4 % and 6 % compared with an engine with a standard valve train, depending on the variability selected.

The control concept and the dynamic response behavior are particularly important for the transient operating behavior of the systems. Reliable recognition of the current operation mode in individual cylinders is of particular importance for controlling the air, fuel and ignition paths. Therefore, "dynamic" valve train systems also unlock greater potential for fuel consumption savings in the driving cycle.

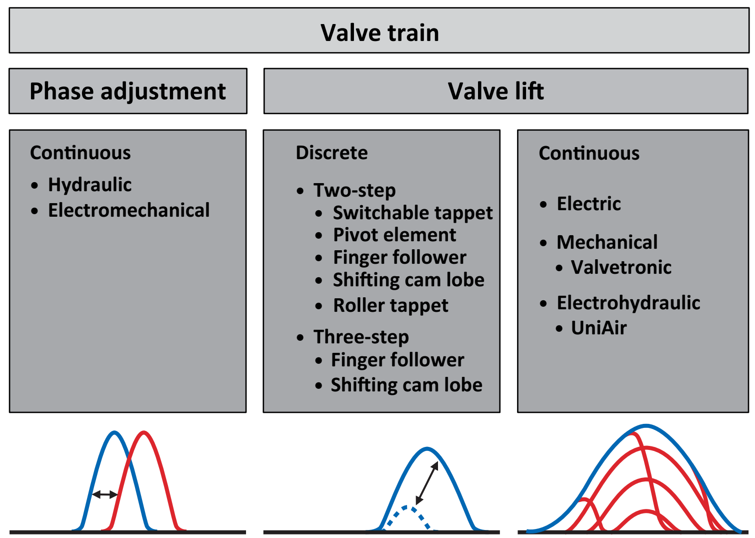


Figure 5 Level of variability in the valve train

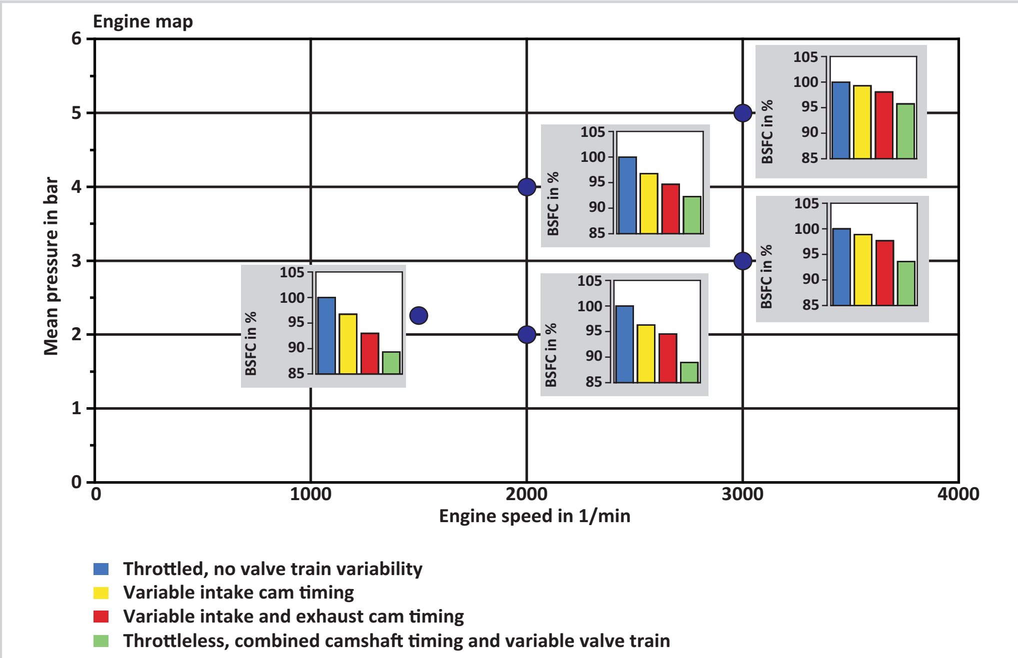


Figure 6 Improvement in fuel consumption by means of dethrottling

	Camshaft phasing unit	Camshaft phasing unit + electro-hydraulic tappet	Camshaft phasing unit + shifting cam lobe + electronic actuator	Camshaft phasing unit + electro-mechanical shaft	Electrohydraulic system (intake only)
Fuel savings*:	approx. 4 %	approx. 7 %	approx. 8 %	approx. 8 %	approx. 8 % - 15 %
Control:	per cylinder bank	per cylinder bank	per cylinder	per cylinder bank	valve by valve cylinder by cylinder
Dynamic response:	slow	slow	medium	slow	fast
Characteristic:	continuous	two-step	two-step (poss. three-step)	continuous	continuous
In volume production since:	1997 (Ford, BMW, VW, Audi, GM, Fiat, Opel, Porsche, Ferrari, SAIC, Chrysler, Volvo, …)	1989, 1999, … (Porsche, Honda, …)	2006 (Audi, …)	2001 (BMW, PSA)	2009 (FIAT)

* NEDC related, relative to standard valve train

Figure 7 Comparison of different, variable valve train systems

Design examples and the influence of variable valve trains on the engine operating behavior

Figure 7 shows an overview of current, variable valve train systems and their market launches.

The following are used to evaluate the different systems:

- Fuel consumption in the driving cycle
- Control concept
- Dynamic response behavior
- Timing characteristic

An evaluation of the influence of valve train variability on the combustion process is conducted on the basis of the following five criteria:

- Pumping losses
- Percentage of residual exhaust gases
- Temperature at the start of the compression stroke
- Charge motion
- Trapped fresh air

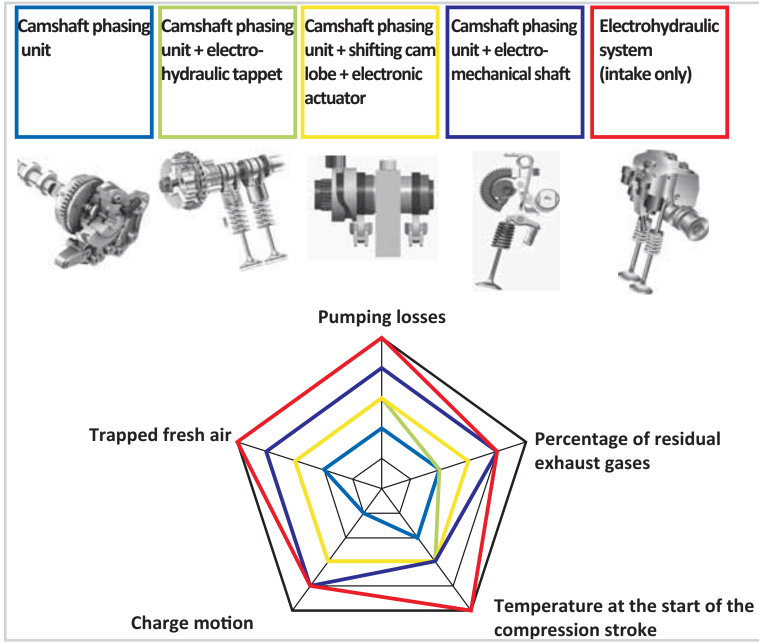


Figure 8 Evaluation of different variable valve train systems

Figure 8 shows evaluated design examples using a spider diagram. The "filling capacity" of the spider diagram also increases with an increasing level of variability.

In summary, the following can be noted in view of the thermodynamic improvements:

- Variability in the valve train is not only relevant for reducing pumping losses, but also assures potential for reducing fuel consumption and emissions during combustion (especially with direct-injection gasoline and diesel engines).
- Downsizing and downspeeding increase the requirements for the basic layout of the drive train.
- Stop-start functionalities change the load profile for timing drives.
- Fast and cycle by cycle variabilities make use of the full potential in the transient operating mode, increase the comfort of stop-start functionalities and improve the starting points for hybridization.
- A good timing drive is more than the sum of good individual components, but a comprehensive overall design.

Mechanical improvements

As already noted in Figure 2, the mechanical improvements refer to the friction and parasitic losses of the accessories. Overall, the following optimization criteria must be taken into account:

- Friction
- Damping
- NVH behavior

Along with the challenge of transmitting the drive power, there are further requirements for the basic design of the components in the timing and accessory drive:

- Preloads should be kept as low as possible (low bearing loads, low friction)
- Noise generation in the timing drive should be minimized
- Dynamic peak loads should be avoided

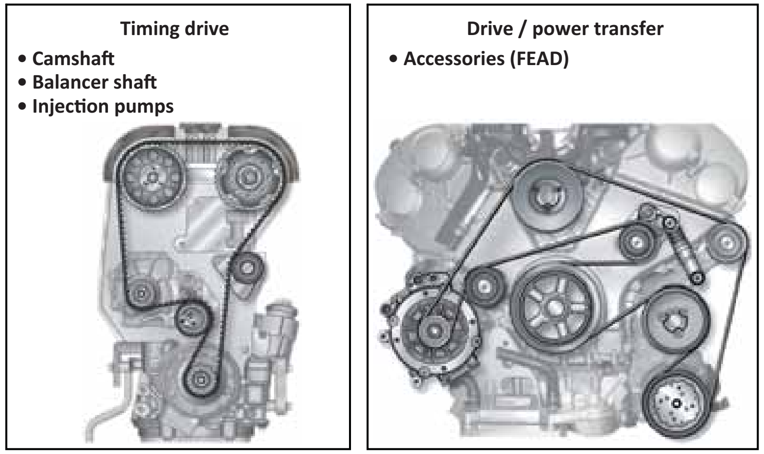


Figure 9 Accessory and timing drives of internal combustion engines

Figure 9 shows design examples.

The potential improvement can be derived from Figure 2. The percentage losses due to mechanical friction in the engine and the drive power for accessories in the NEDC are approximately 12 % to 13 % of the primary energy.

Figure 10 shows the components which the Schaeffler Group supplies as typical engine components and modules. It can be seen that most parts are components which are subjected to a sliding or rotary motion.

The minimization of losses is particularly important. In addition, these components are elements

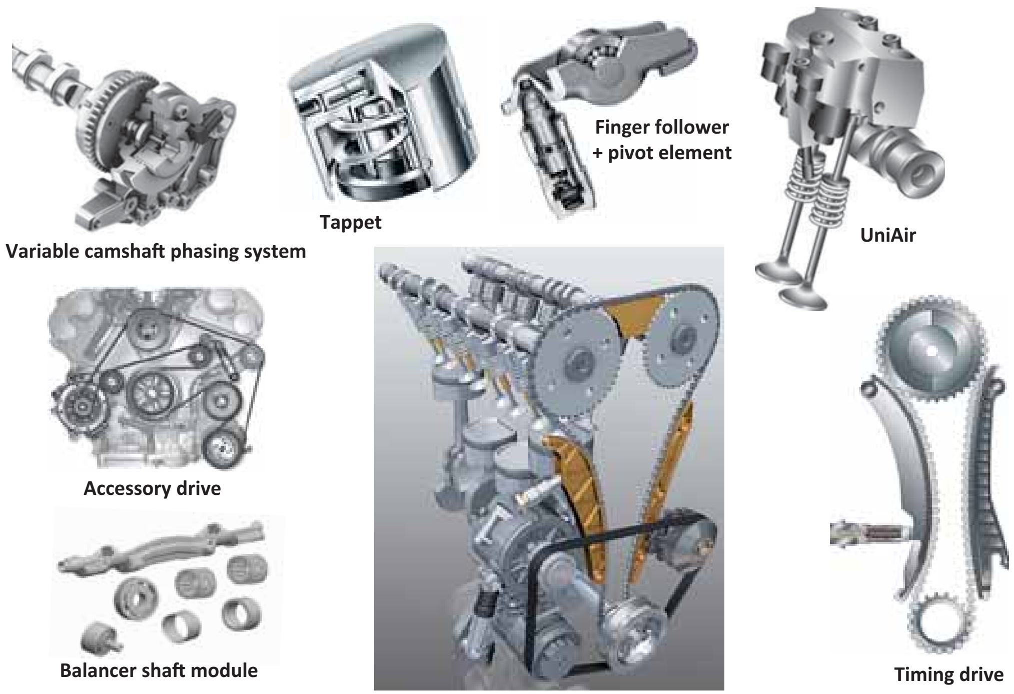


Figure 10 Typical components for engine applications

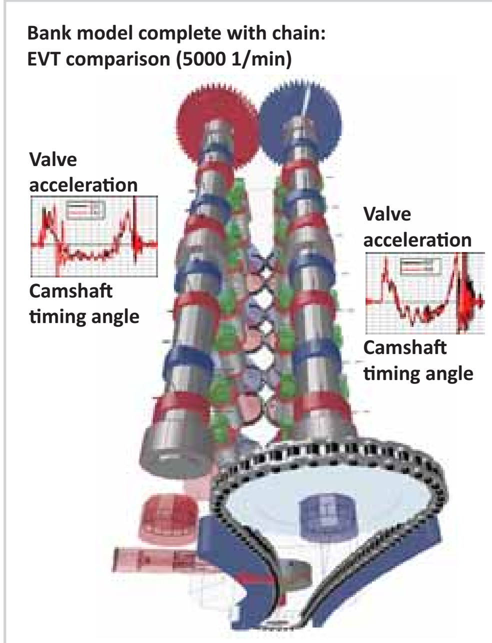


Figure 11 Complete system simulation

of vibratory systems, which can only be optimized to a limited extent as individual components and must, therefore, be optimized in a total system approach.

Figure 11 shows this relationship using the example of a chain-driven camshaft of a four-cylinder engine. It is assumed in the complete dynamics simulation that excitation is initiated in the crankshaft plane, and consideration is given both to the behavior of the

- chain
- chain blades
- hydraulic tensioner

and also the valve actuation components on the camshaft side

- finger follower
- valve spring
- valve

and, therefore, represents a complete system simulation. The challenge to come up with an optimized system solution is to find the right trade-off between reduced friction and ensure the necessary level of damping. This requires the development of calibrated and validated simulation models which model the overall relationship.

Summary

Figure 12 shows an overview of the potential for making individual improvements to current internal combustion engines. It can be seen that in the case of diesel engines there is only minimal potential for improvement by means of thermodynamic measures. Improvements of 10 % to 12 % can still be achieved for gasoline engines.

In addition, an overall potential of 3 % to 5 % can be unlocked by initiating mechanical measures in the engine. The potential due to stop-start functionalities, downsizing and thermo management round out the overall potential for improvement.

With the modular range of components and engineering services on offer, Schaeffler Engine Systems is well equipped to make a contribution towards unlocking potential for improving fuel consumption.

Diesel < 3 % Gasoline < 7 % Combustion system optimization	1 – 2 % Demand-controlled accessories
4 – 6 % Throttling losses Gasoline	2 – 3 % Friction reduction
3 – 5 % Stop-start Function	1 – 2 % Thermal management
Thermodynamic improvement Mechanical improvement Further improvements	5 – 8 % Downsizing

Figure 12 Overview of the potential for improvements

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