SPECTRUM

Technology Highlights and R & D Activities at FEV

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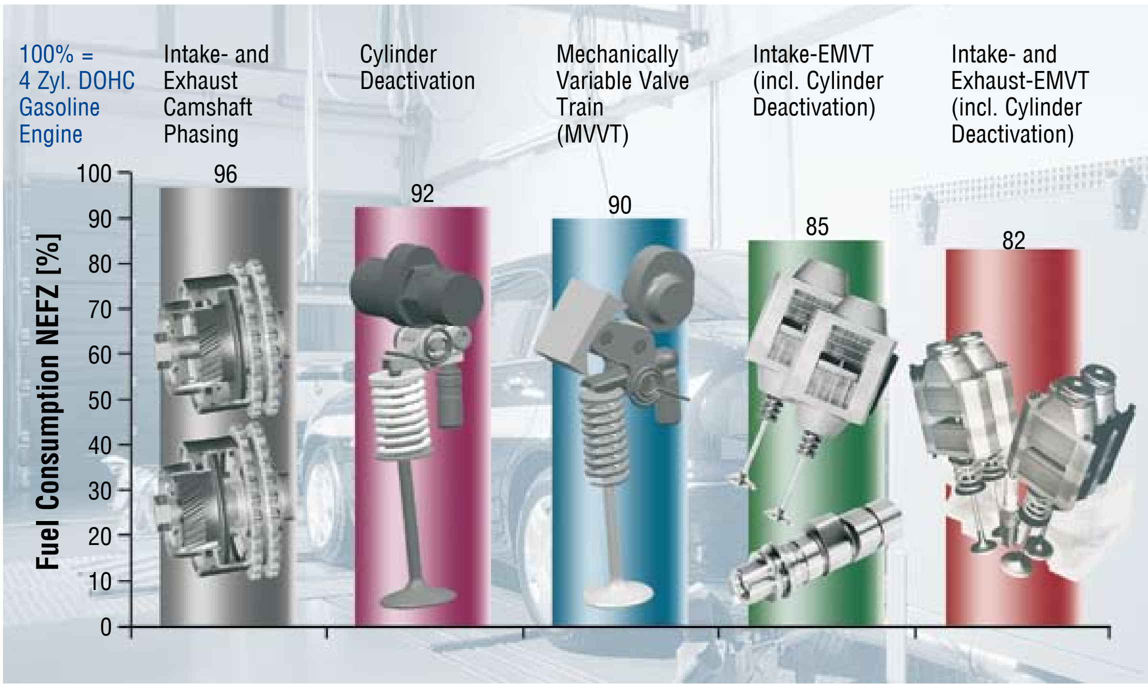

Innovative Valve Train Systems

Over the past 10 years, gasoline and diesel engines have undergone significantly development steps. The diesel engine, in particular, has gone through a dramatic evolution.

Visit our Exhibition Booth at
SAE World-Congress
March 4.-7.2002 in Detroit

Diesel engine power output now approaches the gasoline engine. Yet, diesel engines remain clearly in front with regard to torque. The Diesel engine's advantages in fuel consumption remain unchanged despite the development steps that have been taken to increase its performance.

SUMMARY

Nevertheless, the gasoline engine still has a very strong lobby that drives future development based on the advantages that the gasoline engine presents with respect to

- production costs/profit
- emission behavior
- acoustics/comfort

This is being accomplished through the application of new technologies for the optimization of

- fuel consumption
- torque at low rpm and
- emissions

Along with direct injection and downsizing, the variable valve train offers the largest potential fuel consumption improvement to be gained via an individual measure. Variable valve train technologies have a comparative advantage over direct injection since conventional exhaust aftertreatment technologies can be used. Moreover, they are less dependent on fuel quality and are, therefore, more applicable in a global sense.

http://www.fev.com FEV

PREFACE

Dear Readers,

This issue of Spectrum coincides with the 2002 Society of Automotive Engineers (SAE) International Congress and Exposition, in Detroit, Michigan. This year, FEV continues to support the International Congress through published papers, technical presentations and exhibits. Our Exhibition Booth will highlight a range of cost effective technologies focusing on improved fuel economy meeting future exhaust emission standards.

As 2002 unfolds, the international automotive industry is faced with an economic slow-down, exhaust emission challenges and the never-ending quest for cost reduction and quality improvement. Although FEV is perhaps best known for its development of advanced technologies, our business also focuses on production design (including SIX SIGMA), vehicle integration and production calibration, including OBD.

Presently, cost reduction is critical importance in two areas: reducing the cost of our services and instrumentation products; and lowering the production costs of our customers, without sacrificing quality or reliability. Through the application of our advanced analytical tools, experimental resources and new technologies we accomplish both goals, simultaneously. Come by SAE Booth 1411 to see how we do it.

Yours sincerely,

Gary Rogers
President and CEO, FEV Engine Technology, Inc.

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Over the past few years, various new variable valve train solutions have been established. Their inherent degree of variability is the main criterion in characterizing the different technologies. These solutions are described below.

The first step towards a variable valve train is the application of a cam phaser for the intake and exhaust camshaft. The potential of this measure, in comparison to a base engine (2.0L, 4-Cyl., 4V DOHC valve), is an improvement of approximately 4% in fuel consumption, reduced emissions as well as an increase in the mean effective pressure over the complete engine speed range. The anticipated system costs for a double cam phasing system are approximately 100 EUR ($US 85) for the reference engine.

The next level of variability is a cylinder deactivation system. The primary focus of this measure is to reduce fuel consumption. The nature of the system qualifies it for engines with larger number of cylinders. FEV has developed a roller finger follower with a stationary hydraulic lash adjuster (HLA). The system is suitable for nearly all roller follower valve trains. In realizing a system, the distances between valve axis and HLA can be as small as 35 mm. A reduction in fuel consumption of about 8% is realistic with this measure, compared to the base engine. The improvement is primarily a consequence of reduced gas exchange work together with increasing the load on the remaining cylinders. However, this system does not have a positive influence on engine performance or torque. The system costs of the cylinder deactivation system are approximately 125 EUR ($US 108).

The fully variable valve train system represents a substantially larger innovation. Here, two principles can be differentiated, both of which are currently being developed at FEV:

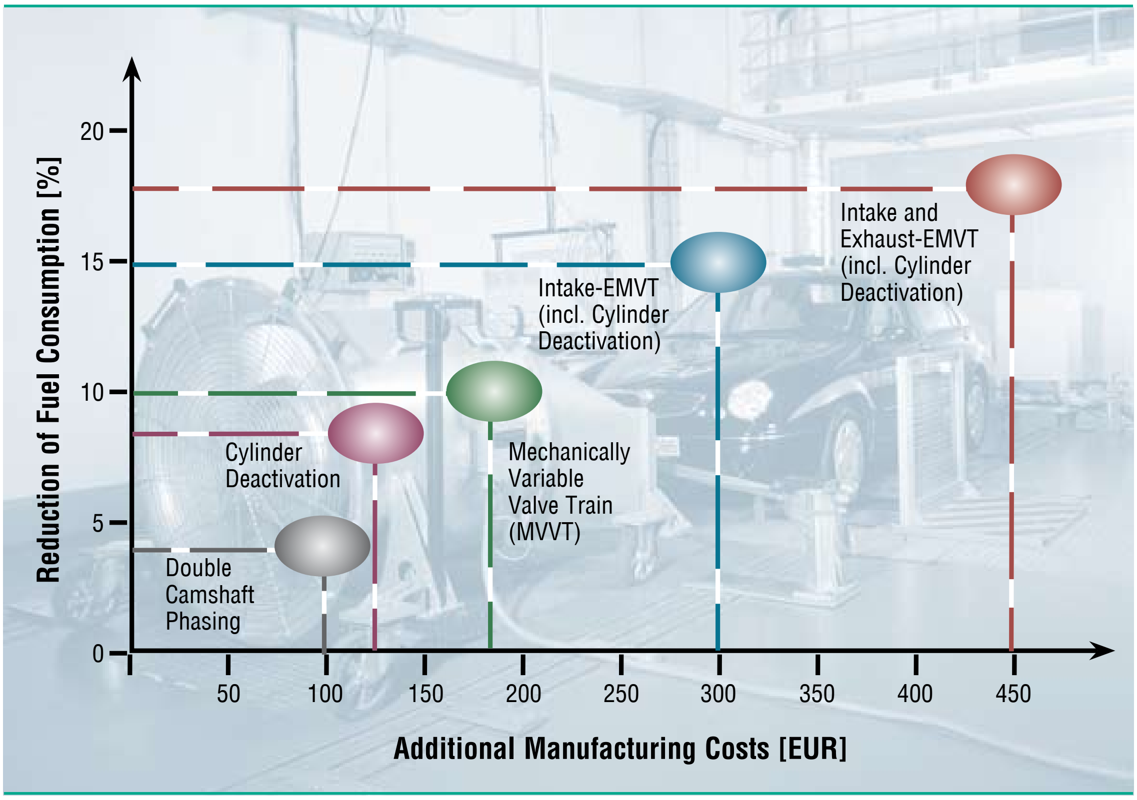
- Mechanically Variable Valve Train (MVVT)
- Electromechanical Valve Train (EMVT)

The MVVT is currently the focal point of a very significant development effort in the industry. The start of production (SOP) of BMW's "Valvetronic" engines characterizes and has accelerated the activities in this field. FEV is currently developing a mechanically variable valve train system together with a large automotive supplier that will fulfill the mass production requirements for such a system. The system is being developed on the basis of a roller follower arrangement as well as for a tappet system. The valve lift is continously variable in a range between 11mm lift and zero lift. In parallel, the lift duration can be reduced within the thermodynamically relevant region of the engine map. FEV's unique thermodynamic knowledge in the EMVT area is directly applicable to its work on the MVVT system. Compared with the base engine, the fuel consumption potential of the MVVT engine is over 10%. In addition, a clear emissions improvement as well as optimized torque characteristics at low rpm's is evident, as a result of better cylinder charging. The incremental cost of the MVVT are approximately 170 EUR ($US 145).

A full (applied on intake and exhaust side) electromechanical valve train system represents the maximum potential functionality. This solution combines throttlefree load control with the option of cylinder deactivation (fixed or rotating) as well as single valve deactivation (2-/4-valve function). The inherent functionality of this system provides the greatest potential for reducing fuel consumption, on the order of 18%. The incremental costs of a "full" EMVT are approximately 450 EUR ($US 400) for the reference engine considered here. This estimate includes a cost savings associated with the elimination of certain conventional components.

The intake side only EMVT (or "half" EMVT) valve train system in combination with a conventional exhaust camshaft represents a good compromise with respect to cost/use. With this constellation, full variability is provided on the intake side and the exhaust valve opening process, where high opening forces are required, is handled by the cam. If the intake EMVT is combined with finger followers on the exhaust side that can be deactivated, nearly the same fuel economy potential results (approximately 15%) as in the case of a full intake and exhaust EMVT. However, disadvantages exist, in this case, regarding raw emissions. The incremental costs for the "half" EMVT are anticipated to be approximately 300 EUR ($US 260).

FEV conducts and accelerates the development of these valve train systems with efficient application of modern simulation tools and statistical test procedures. Here both specialized FEV software as well as commercial software is used, so that the simultaneous engineering program can be optimally conducted together with an OEM customer and the necessary know-how regarding the design, mechanical development, combustion development and eventual application of the engine in a vehicle is efficiently completed.



Within the field of gasoline engines featuring variable valve trains, various systems that possess different degrees of variability are being developed in parallel. The selection of a particular technology depends on the engine concept and market strategy as well as further factors such as displacement, number of cylinders and the production volume for the projected engine. FEV currently has systems in development for all of these valve train designs and levels of variability. We would be honored to leverage our unique knowledge in this field to support you in the development of your new engine concept.

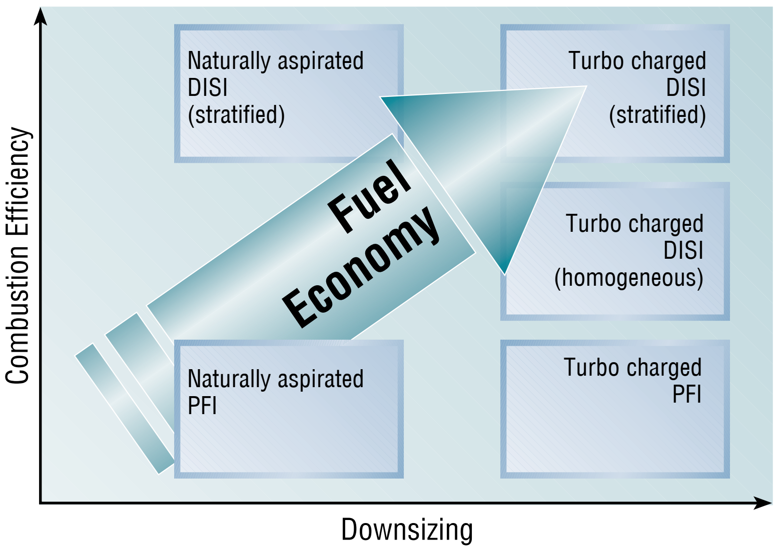
Dipl.-Ing. Markus Duesmann

Turbocharged Gasoline Direct Injection Engines

Although turbocharging spark ignited (SI) engines has traditionally only been applied to high-performance vehicle powertrains, recent focus has turned toward mainstream mass production cars. The reason for this trend is related to downsizing, which is enabled by boosting.

This leads to the replacement of larger engines by smaller, downsized engines, which provide the same power output and, thus, driving performance with significantly improved fuel economy. Downsizing enables the engine to run at higher specific loads; under normal driving conditions as well as during test cycle conditions, the engine is operated at higher BMEP levels with correspondingly lower BSFC.

Fuel Economy Concepts



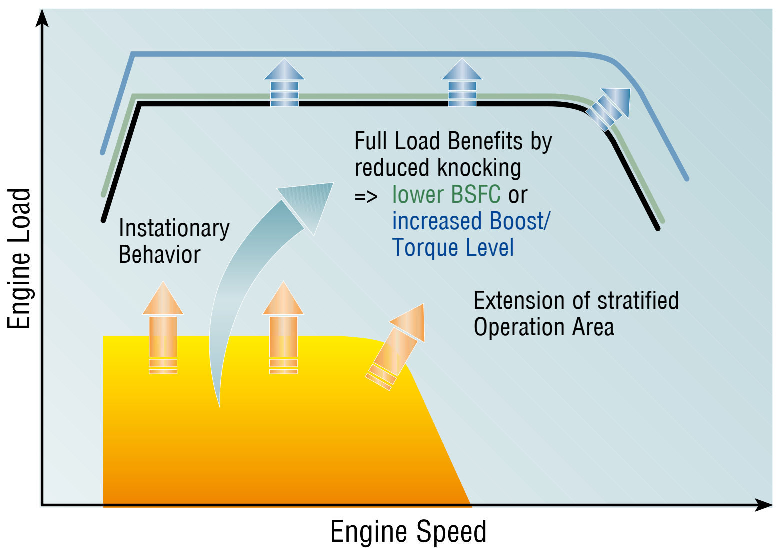
On the other hand, compared to naturally aspirated (NA) engines, turbocharged SI engines present fuel economy disadvantages at full load, which are related to knocking tendencies. Therefore, turbocharging normally requires a reduction of compression ratio by 1-2 units. Unfortunately, this also influences fuel economy at part load, so that the downsizing benefits partially deteriorate. Moreover, it is necessary to limit the exhaust gas temperature by air/fuel mixture enrichment in order to avoid turbine overheating. For the sake of part load efficiency, the compression ratio should be preset to relatively high levels, requiring that knocking be avoided by retarded ignition timing, again leading to increased exhaust gas temperatures and requiring even more full load enrichment.

As a result, the fuel economy of turbocharged SI engines very often turns out to be rather poor. Typically, this effect is even more pronounced under normal driving conditions than it is for test cycle operation. The combination of turbocharging and downsizing with direct fuel injection can help to overcome most of this problem.

Based on FEV's experience in this field, even the application of homogeneous direct injection (during the intake stroke) to stoichiometric operated turbocharged engines leads to significant fuel economy improvements. Compared to conventional PFI turbocharged engines, the compression ratio can be increased by more than one unit. During NEDC (New European Driving Cycle) operation, this results in a fuel economy improvement of about 3-5%.

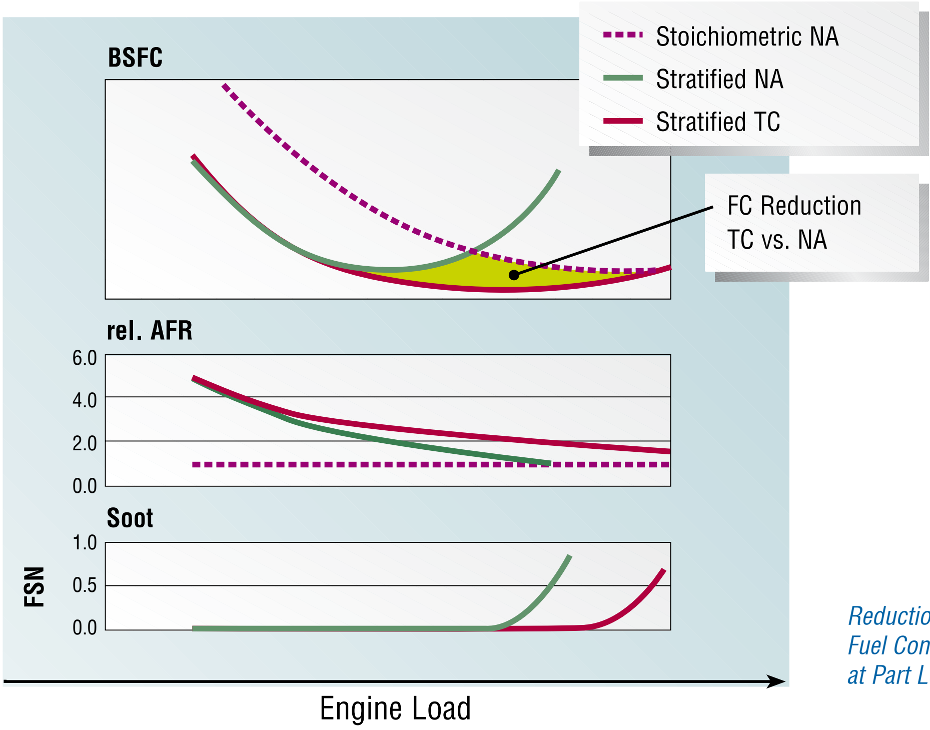
Another attractive aspect of this combination is improved transient behavior of the turbocharged engine. Moreover, the homogeneous λ=1 approach does not require additional efforts in the field of exhaust gas aftertreatment, nor does it require an expensive NO_x adsorber catalyst, which is one of the most critical issues for stratified DISI applications.

Potential by Combination of Direct Injection and Turbo-charging



The combination of turbocharging and gasoline direct injection still has additional potential. One such aspect is the possibility of calibrating idle operation and even the lower speed/load regime for lean mode operation. Within this area of the engine map, the raw NO_x emissions are low, which might allow the omission of additional measures for exhaust gas purification beyond the application of a three-way catalyst (TWC).

This approach leads to an attractive stratified lean burn combustion configuration. The initial investigations on FEV's test benches have indicated that the lean operational area in the engine map can be significantly extended.



Reduction of Fuel Consumption at Part Load

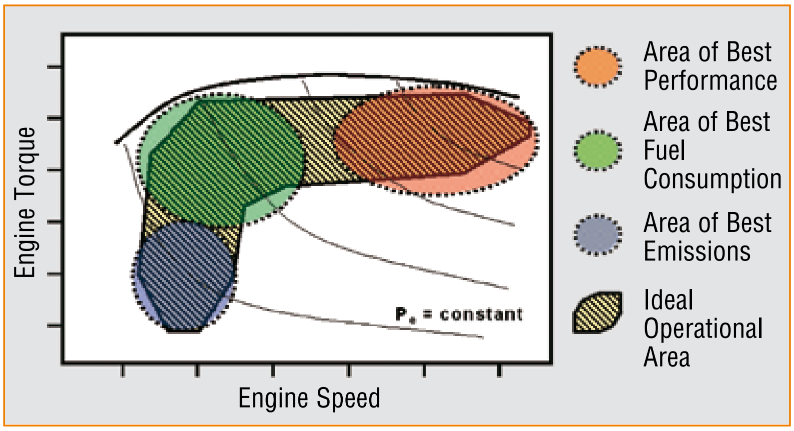
Based on FEV test bench results as well as engine/vehicle models, evaluations were conducted that indicate a fuel economy potential in the range of 10 to 15% compared to PFI turbocharged engines.

Without doubt, today's point of view is that this engine concept is very complex and requires substantial efforts for vehicle application. However, recent R&D activities in the field of model based engine control algorithms indicate an evolutionary process, which might end with feasible solutions for managing this complexity. The prudent approach, therefore, is to develop this new engine concept step-by-step, beginning with the λ=1 concept.

FEV anticipates that the combination of turbocharging and gasoline direct injection may ultimately establish a new mainstream concept for SI engines, leading to a significantly emphasized role for turbocharging in passenger car SI engines.

Dr.-Ing. Peter Wolters

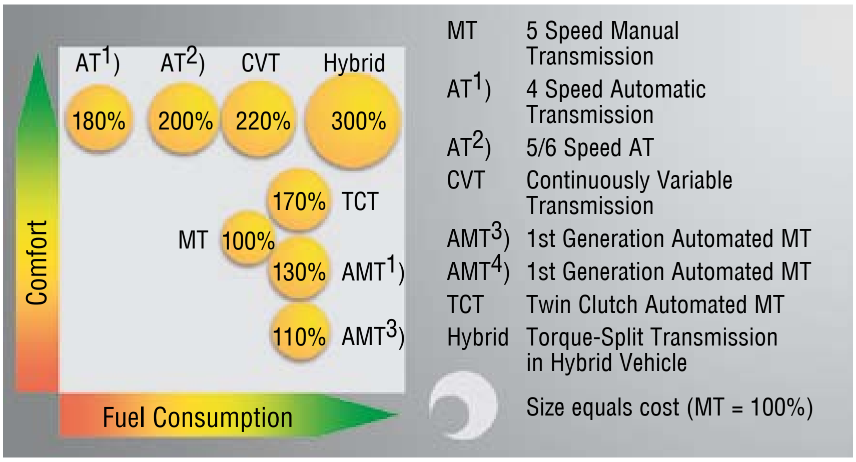
Intelligent Powertrain



Optimal Operational Areas for the Calibration of Powertrains

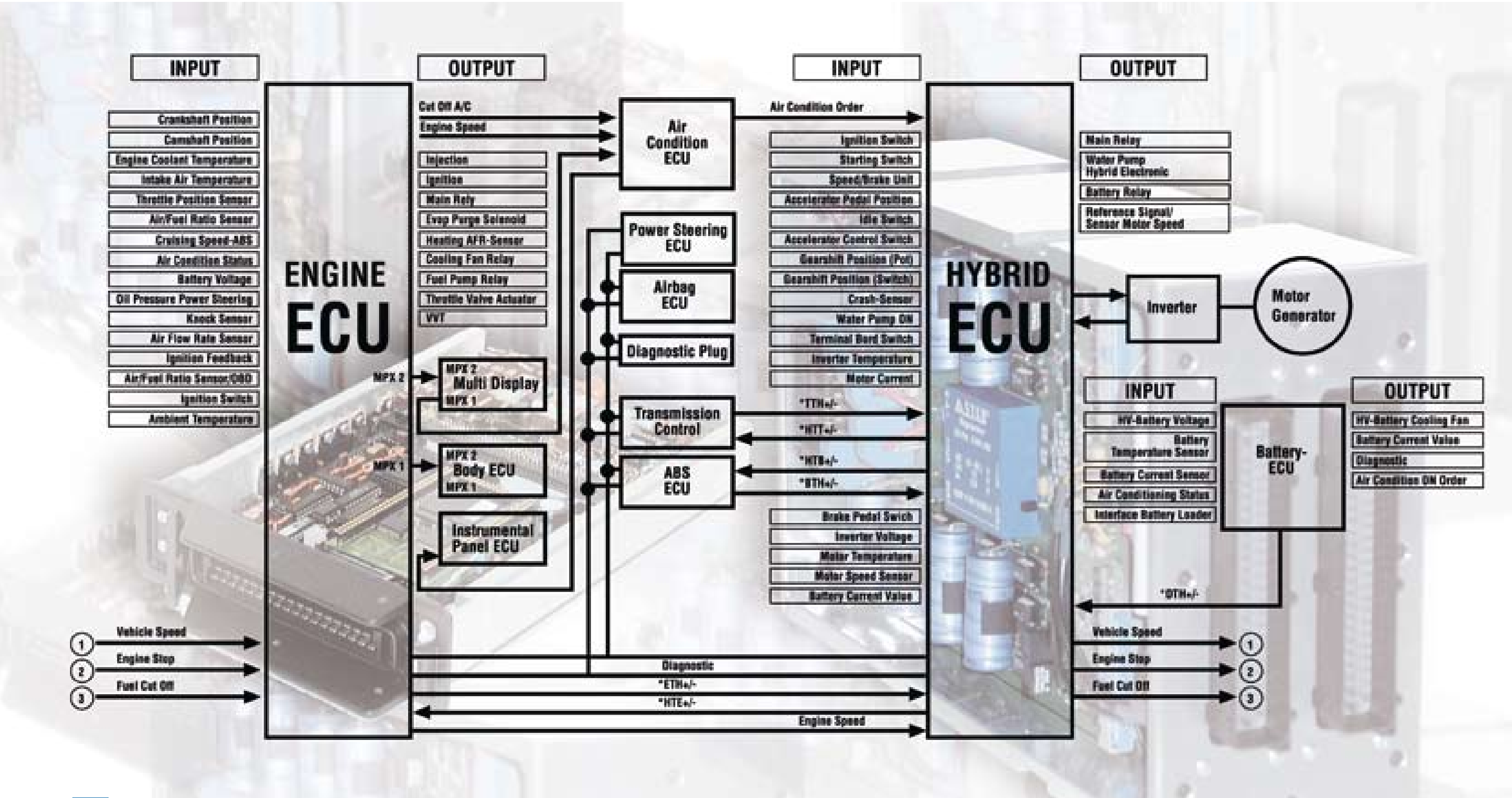
It is no longer possible to meet growing demands on vehicle powertrains related to driving dynamics, comfort, best possible fuel consumption and minimum emissions under all foreseeable operating conditions, without the use of complex electronic powertrain control systems. Since the initial application of electronic engine control systems in the 1970s, the complexity of these systems has increased one-hundred fold. The transition to an intelligent powertrain control system has become possible through the introduction of torque-based functions (control algorithms), as well as the implementation of electronic throttle systems. Intelligent powertrain control systems include all systems that can influence the available torque at the vehicle's driven wheels. For conventional powertrains, traction control, drive stability and transmission control systems come to mind. In order to achieve additional increases in fuel economy, the first automated manual transmissions have been successfully introduced into the market. Current production automatic transmissions are almost exclusively electronically controlled. To achieve optimum driving dynamics together with the lowest possible fuel consumption, a rapid data exchange characterizing the current engine condition is necessary, as well as direct intervention of the engine's torque behavior to adapt for deviations from the set point values. A very close cooperation between engine and gearbox calibration is necessary to ensure a comfortable but also dynamic tuning, especially during gear changes, together with the exploitation of the potential for fuel economy improvements. FEV now offers calibration services for transmission controls, as a complement to the existing services we offer in the field of engine control applications. Engine and transmission calibration engineers work closely together within each project to achieve technically optimized and highly efficient solutions. The two service offerings also present benefits in terms of synergy effects, optimised data exchange and communications.

Joint test trips under extreme environmental conditions allow verification of the influences of changes in the calibration of one electronic control and their influence on the other control system, ensuring optimal functionality in all customer relevant operations. New vehicle concepts supply the standard powertrain with additional torque sources. Examples for these additional sources are an integrated starter generator unit or the electric motor in hybrid applications. Such designs aim at the provision of certain technical features, such as an increase in torque for downsizing concepts with high pressure supercharging or brake energy storage/regeneration. The complex connection of these functions within a dense network for total vehicle management, including power management (electric energy/battery) is the future goal. This effort makes high demands on the integration of these technologies in the vehicle, on the functions development itself and on the calibration of the degrees of freedom for each function. FEV partners with automotive OEM's and suppliers, providing support and, as required, taking on full responsibility for all of the relevant tasks related to powertrain application and vehicle integration.



Assessment Matrix for Future Powertrains

Dipl.-Ing. Rolf Weinowski; Dipl.-Ing. Hans Kemper



System I/O-Diagram of a parallel Hybrid Drivetrain

Vehicle Physics/Acoustics

The generic term "Vehicle Physics" comprises a number of technical disciplines that FEV has mastered to improve an existing car model or to develop a new one. One primary task lies in the integration of the powertrain into the vehicle while realizing challenging powertrain noise and vibration comfort targets. FEV takes a holistic approach that concentrates on airborne and structure-borne noise interfaces to the vehicle. This is accomplished early, during the design phase of the engine and its auxiliaries. Throughout the entire development process, airborne noise radiation due to the powertrain and its vibration excitation at the engine mounts are constantly evaluated with regard to vehicle aspects. Sound Cleaning, which refers to the elimination of acoustic peculiarities, is considered an important precondition for successful Sound Design.

At FEV, Vehicle Physics includes NVH optimization of the engine, gear box and auxiliaries, reduction of acoustic excitation due to the engine combustion process, powertrain benchmarking as well as integration of the powertrain into the vehicle and the entire vehicle development with regard to acoustics and comfort.

At present, FEV conducts full vehicle NVH projects from prototype to SOP. In developing these capabilities, one important strategic decision was to abandon the separation between calculation (analysis) and experiment to fulfill the requirements posed by short development cycles.

FEV's Engine and Gear Box NVH Optimization department offers its customers fast and economical solutions to noise and vibration problems. When a new engine is developed, acoustic calculations are already being conducted early in the concept phase. The results of these calculations are then considered in the following development phase. Special finite element models facilitate acoustic optimization in step with engine design. If noise or vibration problems still occur, they are solved using CAE and CAD tools. FEV has assembled teams of specialists in a manner that allows experimental and computational procedures to be simultaneously implemented (also combined) to effect solutions. Our customers achieve effective solutions as they work together with FEV's designers and in close collaboration with suppliers.

The NVH Process Evaluation and Powertrain Benchmarking department recently introduced an acoustic component-FMEA evaluation service. An expert system was created to identify acoustic weak points on the basis of powertrain benchmarking results.

This procedure is also used for optimization. FEV has developed a special computer based procedure for the acoustic evaluation of combustion process that supports the thermodynamic development effort. Together with the widely-used assessment of direct combustion noise, this procedure also enables conclusions about indirect combustion noise shares and flow noise. Issues such as diesel cold start and knock detection are also addressed. Vehicle emission calibration is supported by acoustic investigations at an early stage of development to prevent potential fuel consumption and exhaust emission target conflicts and to ensure good vehicle acoustics.
FEV's Vehicle department specializes in experimental as well as analytical procedures. The integration of the powertrain into the vehicle creates the link between engine and vehicle development. In essence, components (engine mounts, drivetrain, intake and exhaust system) need to be designed and adapted for this purpose. During this process, thermoacoustics and encapsulation of the powertrain in the vehicle are dealt with.

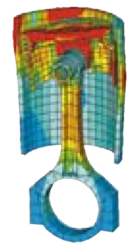
One core element of experimental work is the evaluation of the vehicle in relation to the state-of-the-art. Various commercial CAE programs are available for the analytical optimization. The main focus is on acoustic issues related to the full vehicle. Vibration optimization of the drivetrain and chassis components is also included. Moreover, comfort issues such as air conditioning, ventilation and fan noise are dealt with.

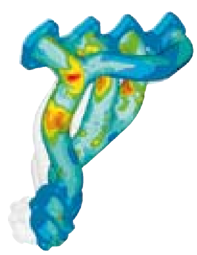
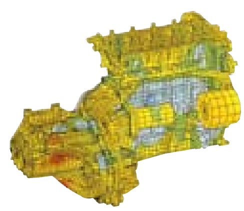
FEV applies innovative methods to efficiently optimize the vehicle interior noise. Using Interior Noise Simulation – a special tool developed by FEV – components with annoying noise can be attributed to their associated noise sources and transmission paths. Based on simultaneous measurements of airborne and structure-borne noise excitation of the powertrain, Interior Noise Simulation facilitates the calculation of individual vehicle interior noise components. Potential modifications can be predicted with regard to their influence on interior noise.

Finite Element Analysis (FEA), Multi-Body Analysis (MBA) and Computational Fluid Dynamics (CFD) are used for the optimization of vibration comfort as well as interior and exterior noise. Typical applications deal with intake and exhaust side orifice noise, noise radiation by the exhaust system surfaces as well as their global vibrations. Engine mounting and drivetrain problems are solved with up-to-date CAE support.

By combining these diverse activities, all customer demands can be met beginning with the optimization of single components up to engine application in a new vehicle. NVH troubleshooting plays a vital role in this process.

Dr.-Ing. Norbert Alt




NVH Troubleshooting

Increasing complexity combined with shorter development cycles incurs the risk of noise and/or vibration complaints toward the end of the development process of a new vehicle.

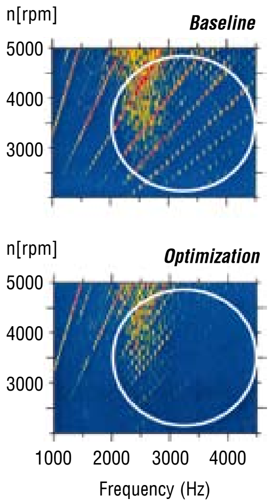
In these situations, NVH troubleshooting is highly effective in finding remedial measures. Powertrain noise and vibrations and their excitations are identified by specially developed analysis and calculation methods.

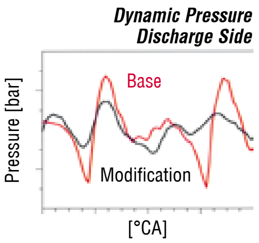
NVH troubleshooting projects that are performed by FEV stand out due to the application of a successful optimization strategy that has been tested and verified in the solution of many problems. By means of an NVH checklist, causes are investigated systematically. Efficient optimization measures are subsequently derived and realized. The NVH checklist contains all potential noise excitation mechanisms as well as the corresponding noise patterns, analysis methods and efficient remedial measures. Special FEV measurement procedures include the use of a zero-clearance piston, the recording of the crankshaft displacement or the tumbling movement of the flywheel, and the analysis of the valve train dynamics, among others.

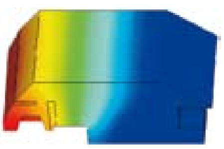
Ultimately, this optimization process is only successful if not only acoustic but also all of the other development targets (such as cost, packaging, output and emission targets) are considered. FEV ensures this through interdisciplinary project teams and close collaboration with the OEM and/or suppliers.

At the beginning of every NVH troubleshooting project, identification of the disturbing noise through objective measures is undertaken at the operating conditions that are critical through analysis of the frequency and time domain signatures. In the next step, an evaluation criterion for quantifying the noise problem is developed. This is helpful in defining the optimization target (Target Setting) as well as for an objective evaluation of improvement measures. The quantification of noise quality problems frequently calls for specific individual evaluation parameters.

Troubleshooting Oil Pump Noise







Within the subsequent root cause analysis, experimental and analytical sensitivity analyses as well as parameter variations are performed to identify the excitation mechanism. Optimization alternatives derived from this are built as prototype specimens and verified in engine and vehicle experiments. The development of powertrain optimization measures can be supported by analyses with respect to vehicle interior noise (FEV's Interior Noise Simulation) to support efficient product optimization.

FEV offers all of the expertise and experience necessary for time and cost efficient NVH troubleshooting. The palette of services ranges from motor dynamics to powertrain components and gear to drivetrain and vehicle.

Dipl.-Ing. Jakob Nehl

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