Potential of variable intake manifolds to reduce CO_2 under partial load

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Leadership in Filtration

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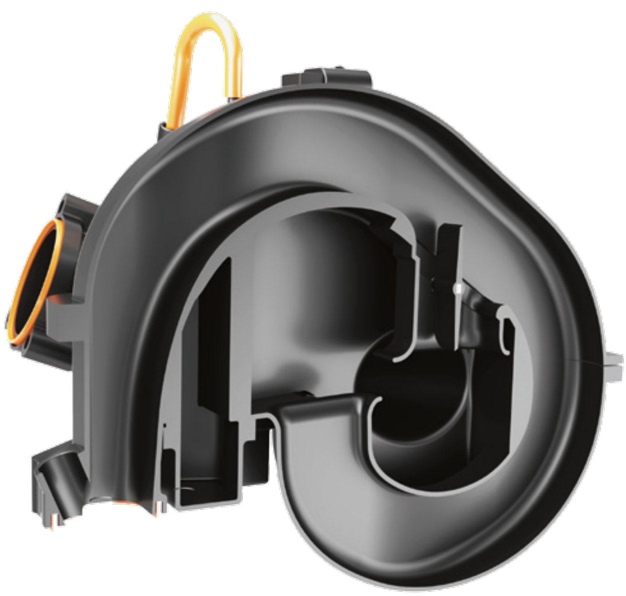
Since the introduction of turbocharging, the use of variable intake manifolds to boost performance has declined. In addition to influencing the full load characteristic curve, active intake manifolds however offer advantages in partial load operation. MANN+HUMMEL and IAV have studied the fuel consumption potential of variable intake manifolds on two current gasoline engine concepts in the NEDC.

Optimization throughout the entire engine map

Against the background of climate change, the EU Commission plans to limit the maximum CO_2 emissions of the fleet average to 95 g CO_2/km by 2020. The CO_2 reduction can take place in the combustion engine as well as through hybridization or by using an electric drive. If these targets are not achieved, the EU Commission intends to introduce a fine as of 2019 of Euro 95 per gram of excess CO_2 for every vehicle sold. The associated, considerable cost burden for the manufacturer is increasing pressure on them to reduce CO_2 emissions.

Variable intake systems are typically used to bring about improvements at full load and partly to lower fuel consumption in the knocking-restricted partial load range[1, 2]. The consistent configuration of an active intake manifold can furthermore improve the efficiency in cycle-relevant map ranges. To this end, the optimization must take place throughout the entire engine map. In this process, characteristic values such as the charging efficiency and the heat input on long vacuum arms, taking knocking phenomena into consideration, are to be factored in. Moreover, the dethrottling effect over the intake arm length taking into consideration the effects of the associated valve timing on the exhaust residual share and residual gas compatibility must also be factored into considerations. The complex interaction between several simultaneously influential design criteria therefore places high requirements on the optimization methodology.



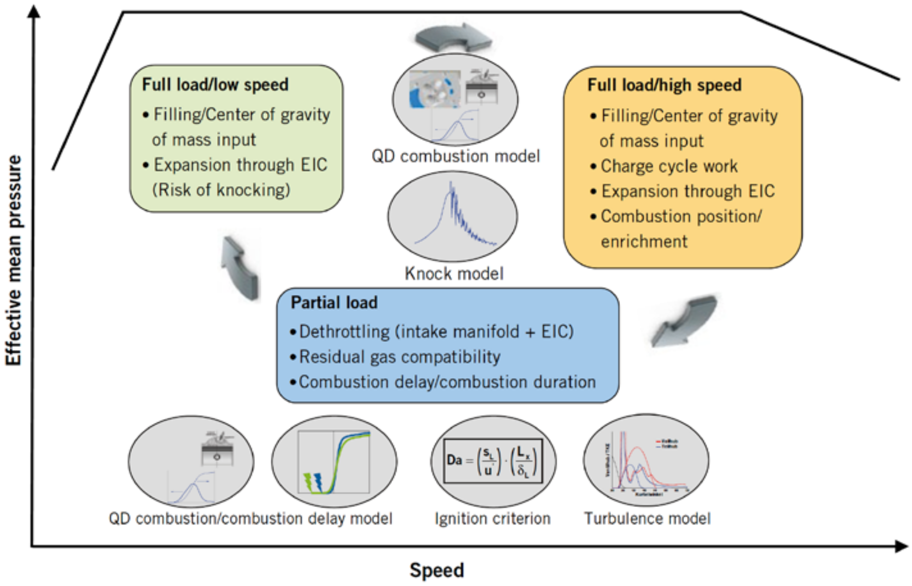


FIGURE 1: Simulation approaches and design strategies in the engine map (qualitative illustration) (© MANN+HUMMEL)

Methodology for charge cycle optimization

The evaluation of the potential of a combined configuration of active intake manifold geometry and valve timings in partial and full load requires a broader simulation approach. The required model approaches are directly assigned to the thermodynamic effects in various map ranges, FIGURE 1.

The charge temperature- and turbulence-reducing effect of early inlet closing (EIC) is mapped with a precisely coordinated quasi-dimensional (QD-) combustion model. With that it is possible to efficiently evaluate both the changed engine-related operating conditions and changes in the charge motion and turbulence level in a combined intake arm and valve timing configuration. The reduced flammability, which is due, among other factors, to the lower temperature in the cylinder at the ignition time, is determined using an approach based on the Damköhler number. An extended Arrhenius approach is used to evaluate changes in the knocking tendency, for example caused by changes in the heat input as a factor of the intake arm length as well as by the expansion effect on EIC.

Optimization to the lowest fuel consumption in partial load takes place at 17 stationary map points, which are determined from the frequency distribution of the engine/vehicle combination in the NEDC (New European Driving Cycle). Less the overrun and start-stop phases, 15 relevant speed/mean pressure pairings result for the intake manifold optimization. The entire result is determined from the stationary consumption levels of the load points as well as the corresponding idle times. To design the intake manifold geometry and valve timings, there is a very large number of possible parameter combinations available in the engine map, which can be optimized using analogous model-supported, stochastic procedures.

Consumption-optimal design of the variable intake manifold

The foundation of the partial load design is, like that of the full load, the speed-dependent utilization of pressure wave dynamics, not to enhance filling however, but instead to increase the intake manifold pressure. In this case, it is the negative pressure wave that occurs on inlet closing (IC) and that leads to the return flow of fresh gas from the combustion chamber that is used, FIGURE 2 (right). To achieve the desired filling in the cylinder, the intake manifold pressure must be increased accordingly, whereby at the same time the center of gravity of the gas mass input is achieved earlier. Both effects bring about a dethrottling and increase the efficiency of the engine.

FIGURE 2 (left) shows a characteristic diagram comparing the basic intake manifold with one that is partial load-

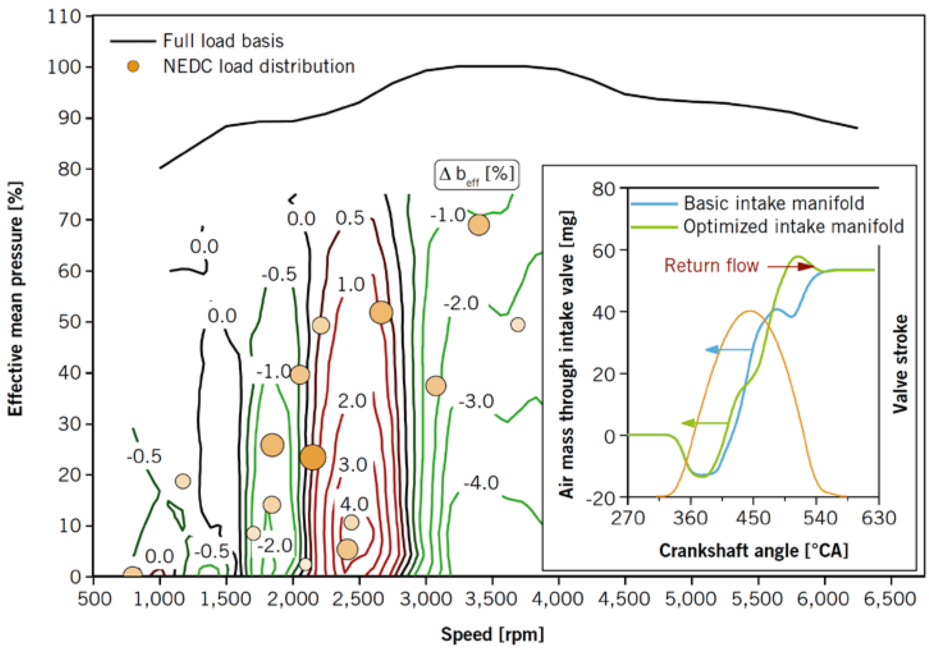


FIGURE 2 Consumption potential of an optimized intake arm length (© MANN+HUMMEL)

optimized for a discreet speed. It is clear that to utilize the full potential, various lengths must be combined. The improvement in the full load characteristic typical for variable intake manifolds can thus be used in addition to the partial load optimization, if the over-capacity achieved is used to shorten the intake cam. The EIC effect [3] used in this process reduces the fuel consumption in partial load even further. FIGURE 3 (left) shows the retroactive effect of the intake closure on the intake manifold configuration for the operating point 2,000 rpm and 2 bar. Achieving the relevant optimum consumption requires a combination of optimized intake arm length and shortened spread angle. As FIGURE 3 (right) shows, every cam reduction, starting from an intake closure in BDC, has a positive impact on consumption.

Potential for the naturally aspirated engine

The potential for fuel savings in the NEDC was evaluated, by way of example, using a three-cylinder naturally aspirated engine with port injection in a subcompact car. The aim of optimization was a consumption reduction with, if possible, unchanged full load by selecting a suitable intake arm length in combination with the intake cam. The best compromise came about with a power length of 300 mm and a torque length of 530 mm with a shortening of the intake cam opening angle by 24 °CA. The configuration determined could yield a fuel saving of 0.9 % in the NEDC, which corresponds to a CO_2 saving of 1 g/km, FIGURE 4 (right). At customer-relevant constant-speed driving points a savings potential of more than 2 % was achieved, while at individual operating points that saving was up to 4 %. In the speed ranges around 1,500 and 2,400 rpm, the only potential arises from adjusting the spread angle, because an optimal wave dynamic is already established there with the basic length, FIGURE 4 (left).

For partial load optimization, the torque length is used below 1,500 rpm and between 2,000 and 2,900 rpm; for all other points the power length is used. At full load, the torque length is used until 4,500 rpm is achieved, above that the power length is used. In the knocking-restricted partial load range, the short length is used where possible. With the selected configuration, the full load characteristic curve is retained despite significant cam shortening. The consumption potential achievable purely with the variable intake manifold without shortening the intake cam opening angle is 0.6 %.

Potential for the turbocharged engine

The investigations into the turbocharged engine were conducted on a four-cylinder concept with direct injection in a compact class vehicle. The wave dynamic of the intake manifold was also optimized on the turbocharged engine with respect to minimal charge cycle losses. In contrast to the design of the naturally aspirated engine, however, the torque-increasing effect of lengthening the intake arm in the lower speed range (Low-End Torque, LET) was used to shorten the intake spread angle.

The optimization of the entire system comprising variable intake manifold and intake spread angle yielded, in the concept selected, a consumption reduction in the NEDC of 0.8 %, which corresponds to a reduction in CO_2 emissions of 1 g/km, FIGURE 5. This was achieved with lengths of 70 and 475 mm in combination with a shortening of the intake cam opening angle of 19 °CA. Here the large length was used along the full load until the nominal torque was achieved at 1,500 rpm and in the marked low load ranges. The short intake arms were used at all other operating points.

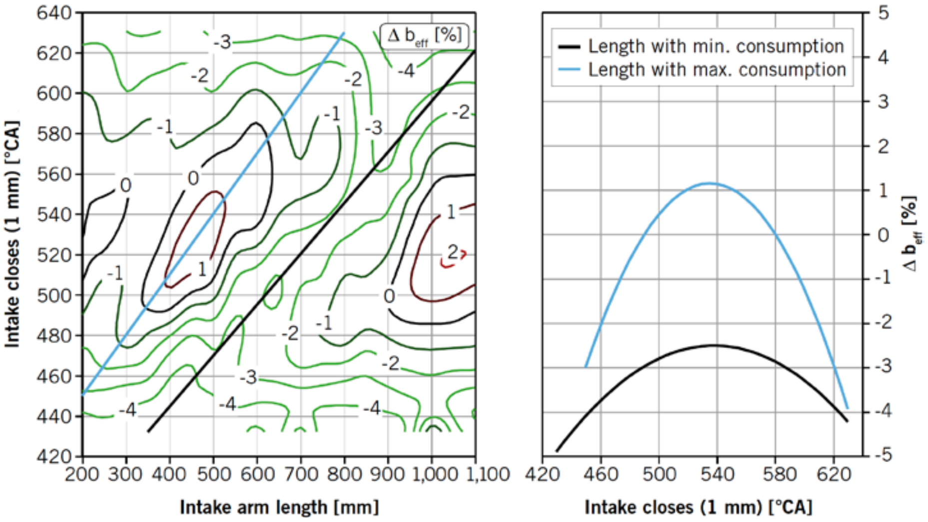


FIGURE 3: Effect of intake arm length and intake closing time (n = 2,000 rpm; p_{me} = 2 bar) (© MANN+HUMMEL)

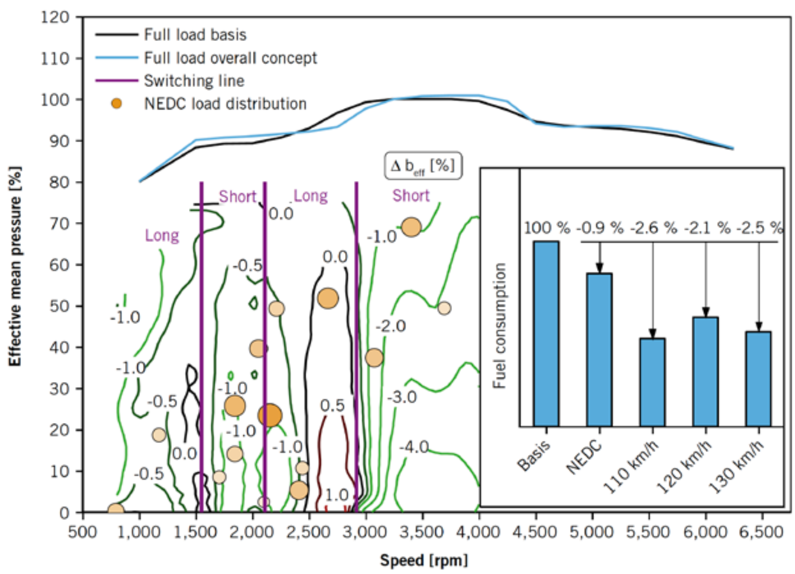


FIGURE 4 Consumption reduction on a three-cylinder naturally aspirated engine (© MANN+HUMMEL)

In addition to the NEDC potential, the shortening of the intake cam opening angle furthermore revealed a positive effect at high load. By utilizing the Miller effect, the charge temperature in the cylinder and thus the risk of knocking can be reduced. The resultant earlier combustion position leads to a reduced enrichment requirement. In addition to the consumption savings at full load of up to 6 % achieved through this, FIGURE 5 (right), it is a further step towards realizing λ = 1 at full load and complying with the emission limits for customer-typical route profiles (real driving emissions).

Construction design of the intake manifold

This intake manifold application can be based on the already familiar variable intake manifold technology with length adjustment that has proven itself over many years. The foundation of the investigation is the principle of the "activator", whereby the short power duct is switched to the longer torque duct. From the available components, such as flaps and rotary slides, switching flaps were chosen to minimize dead volumes (cross-section expansion of the torque duct at the Y branch when the flap is closed). In this process, depending on the requirements with respect to flap shape and size, leaks must be reduced to an acceptable level through targeted positioning of contact surfaces and/or through additional rubber coverings, FIGURE 6.

A key challenge of this application lies in the operation of the drive. Deviating from the load- and speed-dependent switching that has been customary, the number of switch movements increases considerably due to a map-controlled function – an eight-fold increase in the switching frequency can be assumed. Given this simple opening and closing process without intermediate positions, a cost-effective vacuum controller is used as a drive. It is to be ensured here that the design of the components, particularly that of the membrane, takes into consideration the heightened requirements. To monitor the switching function, a contactless position sensor can be integrated in the vacuum controller. If the vacuum supply is non-existent or insufficient, an electrical controller can be used as an alternative.

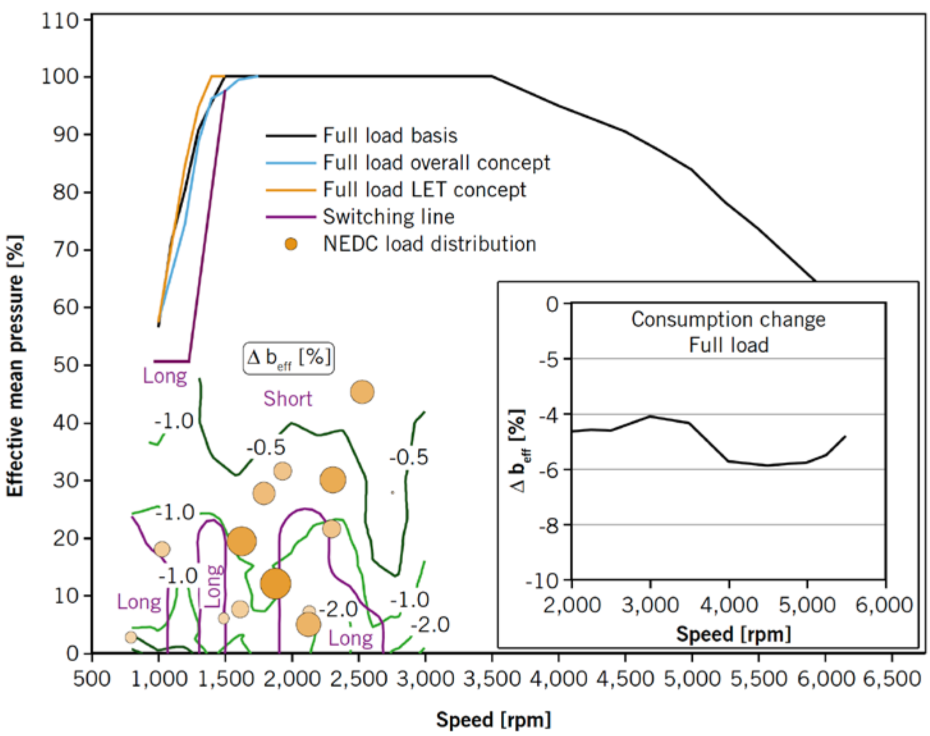


FIGURE 5: Consumption reduction on a four-cylinder turbocharged engine (© MANN+HUMMEL)

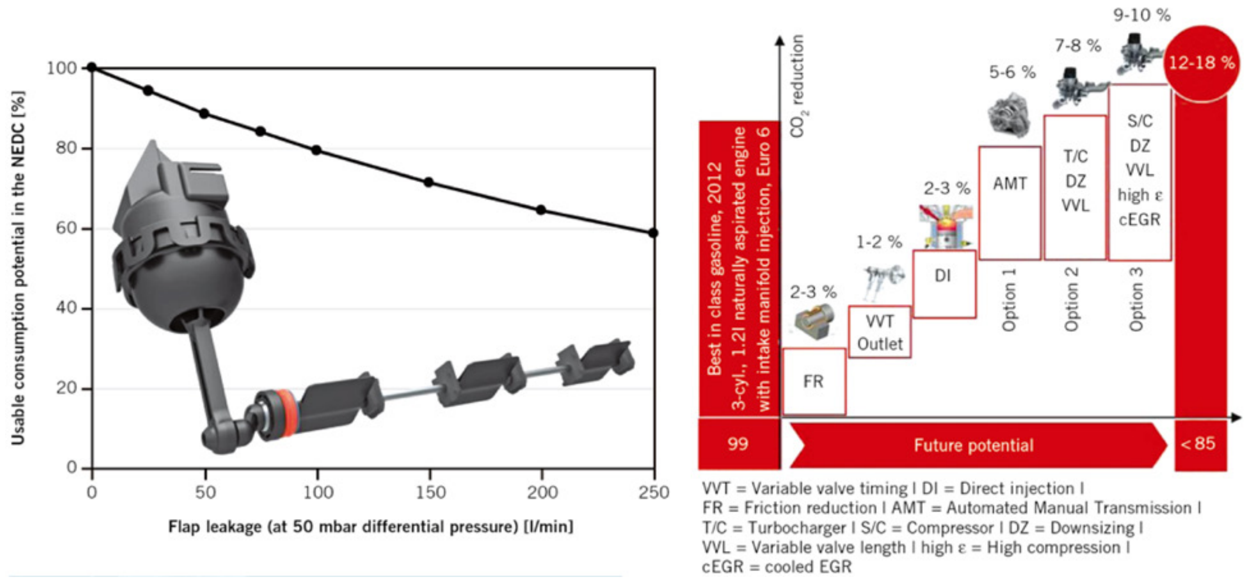


FIGURE 6: Influence of flap leakage on consumption potential and comparison with alternative solution approaches (English original in [4]) (© MANN+HUMMEL)

The solution approach described with installation space-optimized integration of the position sensor in the vacuum controller lid, continuous angled throttle lever and rotational end stops on the throttle lever is OBD-2-(On-Board Diagnosis)-compliant. Areas for function, malfunction and diagnosis are assigned to the sensor characteristic curve. For this new intake manifold application, it is possible to take, as a basis, a technology that has proven itself over many years. Solutions for the extended functionality with respect to the switching frequency and OBD-2 capability are already available at MANN+HUMMEL.

The diagram in FIGURE 6 (right) illustrates the effort involved in reducing CO_2 emissions. With relatively complex solutions such as variable valve timing (1 to 2 %) or direct injection (2 to 3 %) only small increases in efficiency are achieved for a comparatively high outlay. Compared to the alternative approaches to reducing CO_2 described in [4] the cost of realizing a variable intake manifold would be low. The cost/benefit ratio of reducing fuel consumption by approx. 1 % with this solution approach can therefore be viewed positively.

Summary

The concept approach selected for variable intake manifolds reduces fuel consumption and CO_2 emissions in the customer-relevant map range. The potential is concept-dependent and amounts to approximately 1 g CO_2/km in the NEDC. This is achieved through the consistent use of the torque potential available at full load to reduce consumption in partial load. To define the consumption-lowering intake manifolds, however, a new overall approach to the concept design is required. In the simulation, extended model approaches are required for this, in order to map both the charge cycle effects and also the combustion effects. To utilize this potential, modern variable intake manifolds are required, ones designed for a high number of switching cycles.

MANN+HUMMEL has the required technology with low flap leakage and can access components that have already proven their efficacy in the field. The reduction of CO_2 emissions is thus possible with a comparatively small increase in costs.

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