Highly Efficient Oil Separation Systems for Minimised Oil Carry Over

Recently developed combustion engines are characterised through supercharging and direct injection. Both processes inherently demand a highly efficient oil mist separation. Deposits on the compression wheel of the charger or on the valves are to avoid, as well as an increase of pollution emissions. Mahle, as the leading developer of crankcase ventilation systems with oil mist separation, accepted the new challenges and developed highly efficient passive separators, such as the switched impactor with nonwoven insert, as well as active systems such as the electrically driven cone stack separator.

1 Introduction

In recent years, the significance of the crankcase ventilation systems in combustion engines has drastically increased as a result of the new exhaust gas legislation. Oil mist separation, which is part of the crankcase ventilation system, influences numerous engine internal processes, which directly or indirectly impact the emissions of newly developed combustion engines.

More stringent emissions limits bring about ever tighter prescriptions for the oil consumption of engines. By continuously optimising the oil consumption at the different sources, oil separation from the blow-by gases is gaining significant influence on the overall oil consumption. In addition to reducing oil consumption, the development of highly efficient oil separation systems in crankcase ventilation is also rising in importance due to two additional concerns:

- The new exhaust gas aftertreatment systems in Diesel engines have a limited service life due to the deposition of particulates caused by the burning of oil.
- In addition to emissions topics, factors that directly impact components of the intake system also call for improved oil separation. In diesel engines, and particularly among commercial vehicles, insufficient oil separation can pose the risk of carbon build-up in the turbocharger, resulting in loss of power and ultimately, component failure. In modern, direct injection gasoline engines, deposits on the intake valves result in insufficient charge air flow. These topics increasingly determine the threshold values of permissible oil carry over through the crankcase ventilation demanded by automobile manufacturers.

The Mahle R&D department responded to this challenge at an early stage by developing highly efficient passive and active oil separator systems. This article will reveal the „best-in-class“ developments, which are represented by the switched impactor with nonwoven insert

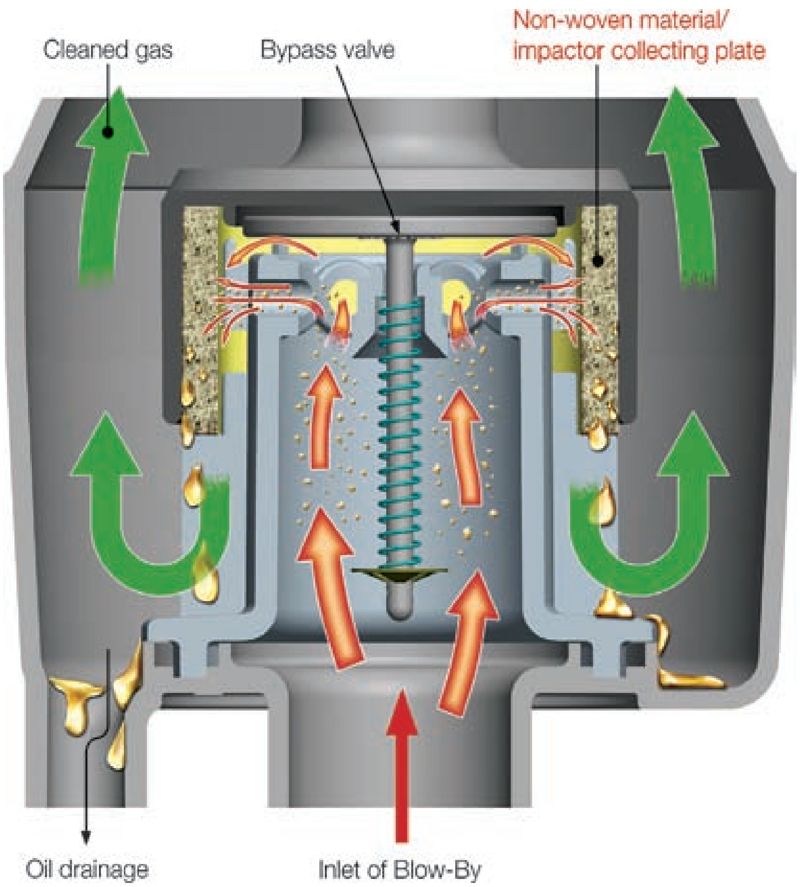

Figure 1: Switched impactor with nonwoven

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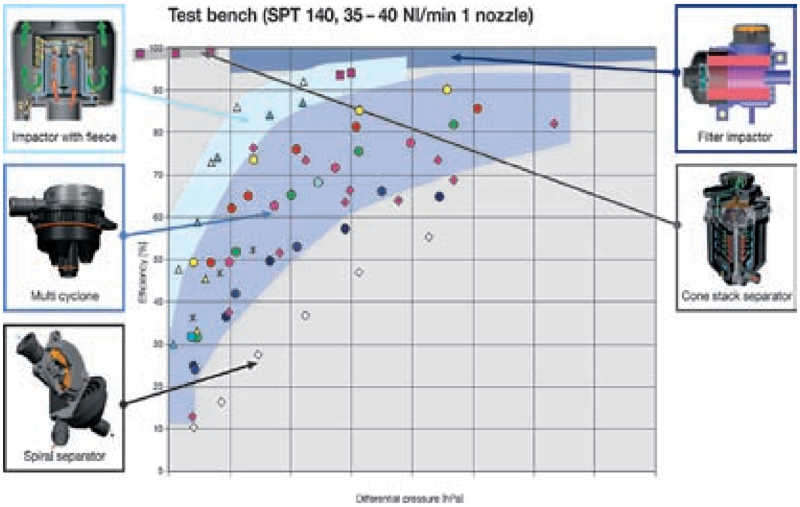

Figure 2: Efficiency of separator systems: Separation level on the laboratory test bench over pressure differential of the separator

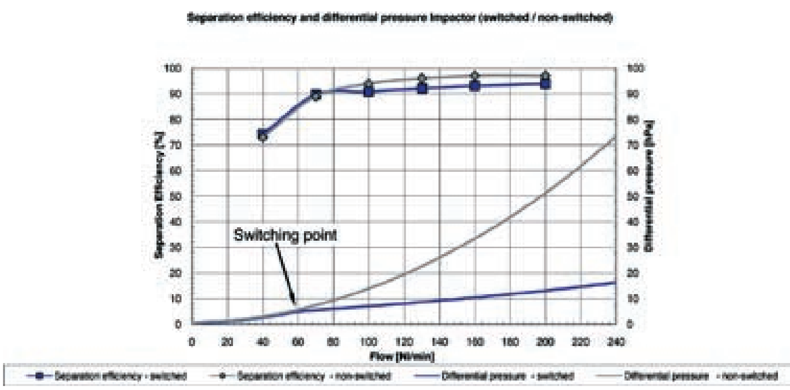

Figure 3: Examples: Pressure differential and separation efficiency of switched and non-switched impactors

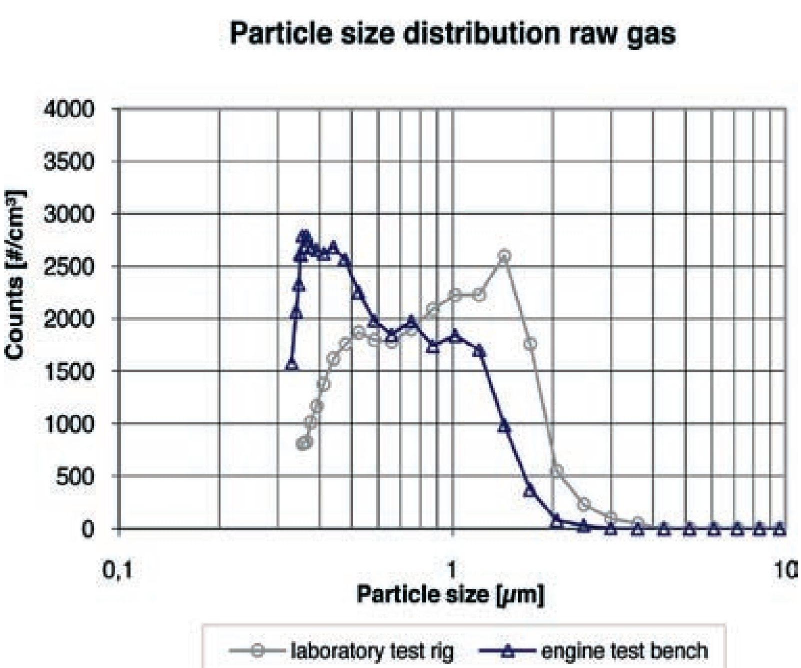

Figure 4: Comparison of particle spectrum on the laboratory test bench and dynamometer

as the passive system, and the disk separator as the active system.

2 Passive System: Impactor

2.1 Operating Principle of the Switchable Impactor with Nonwoven Insert

The Mahle product portfolio includes a wide variety of oil mist separator systems, such as spiral separators or multi-cyclones. An improved design to these systems that is introduced here is a separator which is based on Mahle‘s patented oil mist separation using the impaction principle. The operating principle corresponds to that of an inertial separator. The blow-by flow is sharply deflected and the oil drops cannot follow the flow because of inertia, strike a catch plate and are separated. In the impactor, this effect is amplified by accelerating the blow-by flow by means of nozzles before the forced deflection by the catch plate occurs, **Figure 1**.

The separated oil droplets agglomerate on the catch plate and form large oil drops. As a result, minute oil particles are separated from the blow-by gas flowing in front of the catch plate. At the end of the catch plate, the gas is separated from the now large oil drops and is conducted into the intake system in a cleaned state.

2.2 “Nonwoven” Optimisation Step

The efficiency-enhanced design of this impactor developed by Mahle is characterized by the use of a specially developed filter material and the ideal configuration of the nozzles. The nonwoven insert is positioned behind the nozzle outlet directly in front of the catch plate, Figure 1, and becomes itself a catch plate. Due to its large inner surface, the nonwoven material improves the agglomeration of the oil particles. While an impactor design without nonwoven achieves the efficiency of the previously used multi-cyclones, the use of a nonwoven insert improves efficiency by 20 % at the same energy consumption, i.e. at the same pressure differential, **Figure 2**.

Since, unlike the media in known filter separators, the nonwoven in the impactor is only located along in the flow, without the media flowing entirely through it, it was possible to design the nonwoven as a lifetime component. The selected material, which is the result of

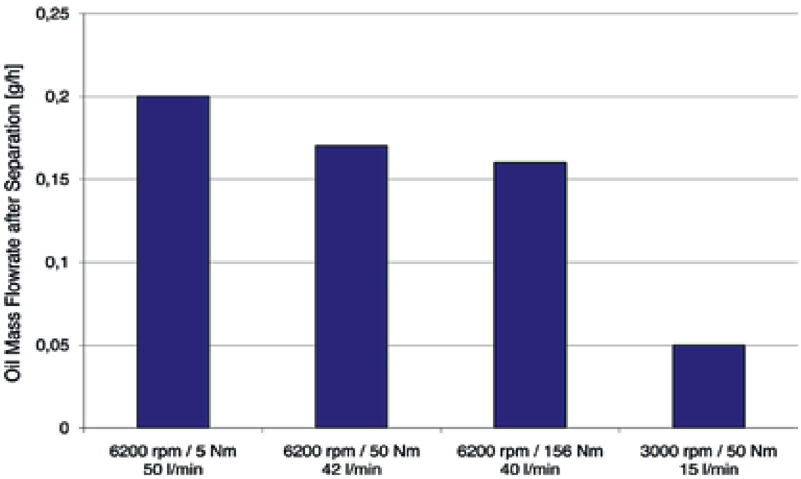

Figure 5: Oil consumption over crankcase ventilation of a 4-cylinder gasoline engine

countless laboratory analyses and engine endurance runs, ensures that the nonwoven consistently remains resistant to the blow-by fluid and does not become clogged. This makes the entire impactor module a lifetime, maintenance-free component.

2.3 "Variability" Optimisation Step

The geometrical configuration of the impactor is extremely variable. The nozzles can be arranged in a straight line or in an annular shape, distributed across a cylindrical surface. The advantage of the round type becomes apparent from the switched model. This design uses a simple flat seat valve, which upon opening exposes an annular gap forming the bypass opening, Figure 1. Behind this bypass opening, the blow-by gas in turn flows against the catch plate with nonwoven. This guarantees that the bypass flow is subjected to the same separation efficiency as the main volume flow flowing through the nozzles. This represents a considerable difference and advantage of the presented module over other design concepts with bypass function.

Thanks to the bypass valve it is now possible to guarantee high separation even at lower volume flows. This is the crucial advantage for oil mist separation. The design for lower volume flows enables the use of smaller nozzles and thus a greater separation efficiency, particularly at these low volume flows. If the volume flow increases, the capacity of the separator is maintained constant by the above-described separation in the bypass system, without considerably increasing the pressure differential build-up, **Figure 3**. Since blow-by recirculation systems are frequently designed for 2 to 3 times the anticipated blow-by volume (with respect to safety-relevant aspects), a switched system has considerable advantages when it comes to the separation during actual operation, specifically at lower volume flows.

The type of the separator shown in Figure 1 with a diameter of 80 mm is designed for a blow-by volume flow of up to 300 l/min. Thanks to the variable number of nozzles and adjustable opening pressure of the bypass valve, the separator can be adapted to nearly every engine application with minimal modifications.

3 Capacity Comparison

In order to establish comparability of all oil separator systems, these are optimised on a laboratory test bench. For this purpose, the particle spectrum likely encountered in the engine is duplicated on the laboratory test bench, **Figure 4**. Unlike most unstable conditions in the engine, the laboratory test bench provides extremely stable raw oil volumes and thus the basis for an ongoing development and the neutral comparison of different separation principles.

For the evaluation of the system quality, the separation efficiency is entered on top of the pressure differential. This allows a direct correlation between the efficiency and the introduced energy, which is provided by the pressure loss of the system. In this type of illustration, an ideal system will appear in the upper left area, a system with lower efficiency in the lower right area, Figure 2. The comparison of different systems from the benchmark conducted at Mahle clearly shows the advantage of the presented impactor compared to other design principles.

Engine measurements confirm the high potential of the separation concept. With the standard design of the impactor, the oil carry over achievable via the crankcase breather is considerably lower than 1 g/h. By way of example, an oil carry over of < 0.2 g/h was achieved on a 4-cylinder gasoline engine with an opti-

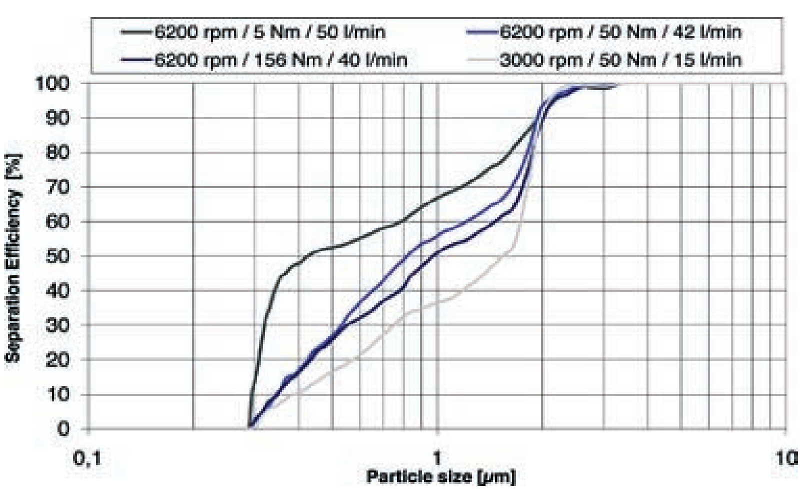

Figure 6: Fractional efficiency of the impactor of an engine measurement on the 4-cylinder gasoline engine

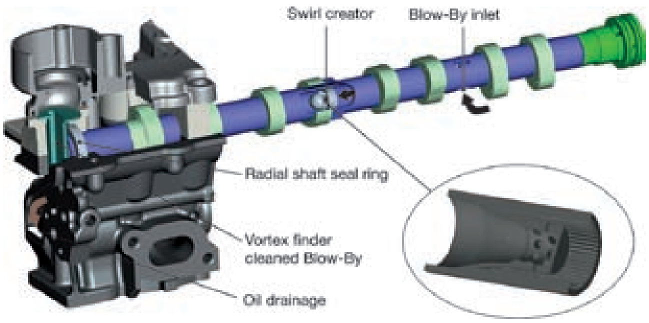

Figure 7: Camshaft – oil separator system

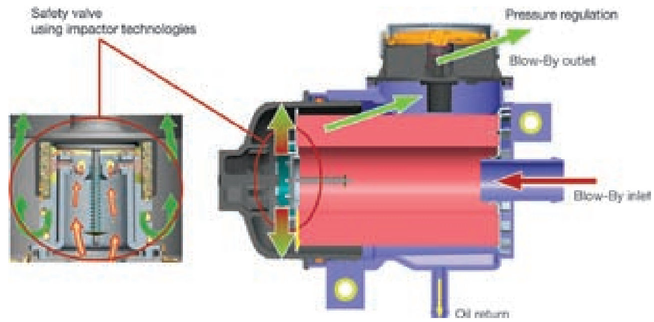

Figure 8: Impactor as overflow valve in the filter separator

mum design of the switched impactor. This oil carry over, however, is highly system-dependent, **Figure 5**, but these are values which previously were achieved only through the use of active systems.

Figure 6 shows the fractional efficiency measured on the engine with an average particle diameter d_{50} of 0.4 µm at 50 l/min.

4 Outlook for Passive Systems

Due to the advantages outlined above, Mahle will consistently continue its development work in the field of switched impactors, even after the system has been successfully introduced in the market. The high design freedom of the system easily allows further applications to be tapped through functional integration or a combination with other separation mechanisms. This creates synergies which allow the separator system to become an integral part of other engine components, such as the camshaft, **Figure 7**. A combination of the impactor with a filter separator is under consideration for commercial vehicle applications. For this purpose, a filter impactor was developed, in which the impactor functions purely as an overflow valve. This ensures for the first time that effective oil mist separation can be achieved in the event of an improperly maintained, clogged filter element, **Figure 8**.

5 Active System: Cone Stack Separator

In addition to the passive separators, Mahle also developed an electrically driven disk separator, particularly for large engines in commercial vehicles with high blow-by volume flows. This separator will be available starting in 2008 in a type with a separation efficiency of 99.9 % for a volume flow of 100 l/min and 99.7 % for a volume flow of 300 l/min. As a result, this active system will be able to meet further increased requirements regarding the separation efficiency compared to the passenger car area.

5.1 Operating Principle of the Disk Separator

The core of the disk separator is the rotor. On the rotor, a set of conical disks, which are arranged on top of each other and connected in parallel, are clamped to the shaft.

Short sedimentation paths are possible due to the small disk distances. When the oil drops flow through the narrow disk gaps, they are moved radially outward by centrifugal acceleration due to their higher density and strike against the bottom of the disk arranged respectively axially above. The separated oil is propelled outward in the form of large drops. These drops are no longer carried in the gas flow. The light phase is able to rise in the outer annular gap and is returned to the combustion air. Due to the flow direction from small to large radii, the disk separator acts as a pump. In this way, a high extraction capacity can be achieved at a positive pressure differential, **Figure 9**.

5.2 Design

The design of the electric cone stack separator can be broken down into two independent assemblies, namely the separation unit and the related drive unit. The blow-by gas flows through the separation unit, and the unit separates the oil, which is recirculated to the oil circuit. The drive unit is supplied with

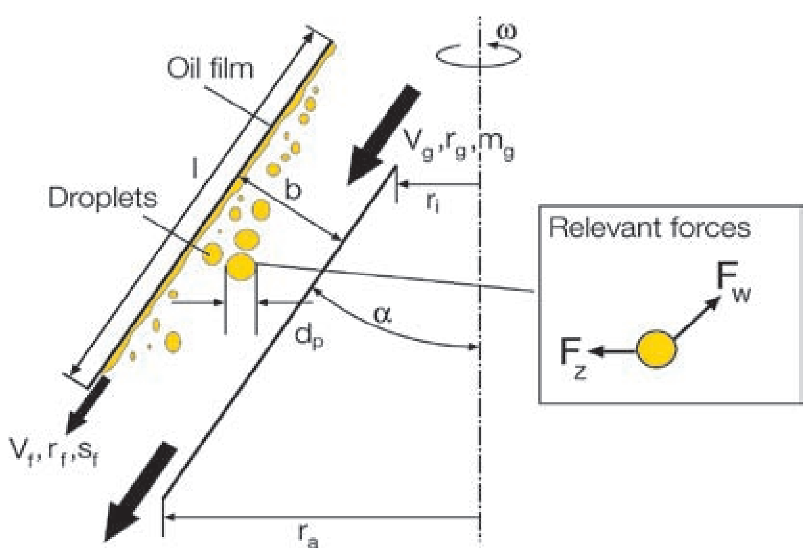

Figure 9: Operating principle of cone stack separator

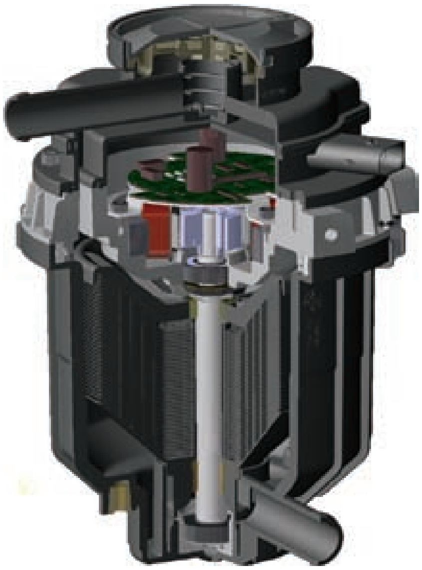

Figure 10: Design of cone stack separator

energy and converts it into rotational speed and torque. Information about the current state of the drive units sent to an external control unit through an electric signal. It is also important to supply the system with control information. To this end, disturbance variables influencing the entire system from the outside, such as vibrations and the ambient temperature, as well as disturbance variables acting from the inside, such as inherent heating and electromagnetic fields, are taken into consideration. In order to cover the large operating range of modern commercial vehicle engines, the blow-by volume flow was used as an important parameter to properly size the separation unit for the requirements. For the electric drive unit, the mass to be set in motion is the decisive design parameter. **Figure 10** shows the design of the cone stack separator, and **Figure 11** its high separation potential.

6 Drive Concept

The demands that are placed on an electrical system in the commercial vehicle sector are extremely complex in the upstream area. The inherent disturbance variables were taken into consideration in the design of the drive unit. Due to the high mileage driven by commercial vehicles, the wear of such systems must be kept to a minimum. Countless long-time tests in an early development stage of the cone stack separator lead to a know how which allows to design the electric drive of the active separation system. The rotor mass to be driven and the associated power consumption, and consequently the efficiency of the electric motor, are crucial parameters. In order to meet these high requirements, special importance is placed on wear-free components. In this type of application, the selection of a brushless direct current motor is extremely beneficial. For the rotor, the premium magnetic material NdFeB (neodymium iron boron) was selected, which has excellent temperature and long-term stability properties. Through an optimised design, the drive unit can be hermetically separated from the separation unit, without the need for an additional seal. In order to transmit sufficient torque and thereby achieve optimised separation of the overall system, a small air gap between the stator and rotor is extremely important.

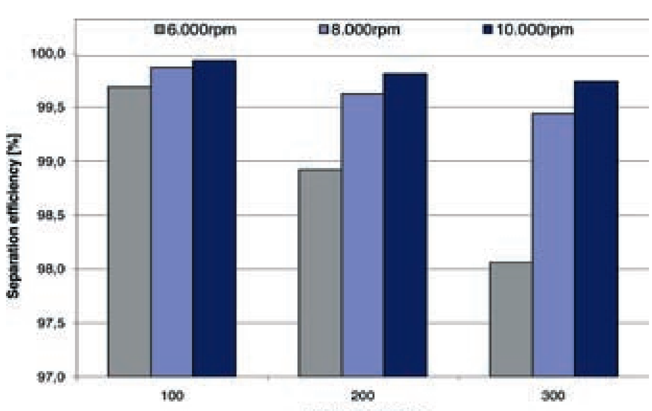

Figure 11: Separation levels of cone stack separator

The integration in the overall electronic system of the vehicle is achieved by connecting it to the vehicle's 24-volt electrical system voltage. Transmission of the start signal is guaranteed by means of digital input and output. The input and output can also be used for operational state signaling or pulse width modulation.

Optionally, control can occur via a CAN bus. Since the rotational speed and the load torque remain nearly constant, or change only slowly, during normal operation, a sensorless positioning system is used. The system measures the induced voltage at the motor winding, which is not powered at that moment.

7 Function of Overall System

The entire component can be mounted to the engine block by means of a suitably designed, adjustable mount, and integrated in the crankcase ventilation circuit. Maximum separation is achieved at a variable rotational speed of up to 10,000 rpm. The rotational speed can be adjusted via a rotational speed-load controller. Start-ups at extremely low temperatures are also guaranteed, and even in this case the blow-by gases are reliably cleaned. In addition, a 12-volt variant was developed through an appropriate adjustment and design of the electric drive unit.

8 Summary

With the presented separation systems, Mahle has enlarged its product portfolio by outstanding systems. Even more efficient and flexible separation systems can be offered for the crankcase ventilation. They can be designed according to customer demands either as an external separation system or as a separation system which is integrated into the cylinder head cover. With the two presented passively or actively acting oil mist separation systems, a far better separation grade than with standard systems is achieved for the total blow-by map. If a fast development of an overall system is required, Mahle can profit from the expertise gained in streaming simulation and countless engine tests conducted in-house and with customers. ■