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Thermal management at Schaeffler

How much water does an engine need?

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Thermal management is an important factor for reducing CO_2 emissions. This article presents the reasons for the use of a thermal management system, an analysis of the requirements and an approach for implementing such a system.

Thermal management

The term “thermal management” describes the efficient control of thermal energy flows in the vehicle in accordance with the specific requirements and the prevailing operating and load conditions. As a result, vehicle emissions can be reduced, and the thermodynamic and mechanical engine efficiency can be improved. This leads to lower fuel consumption, a longer engine life and improved thermal comfort.

The coolant temperature should ideally be adjusted depending on the operating condition of the engine (Figure 1).

During cold start, the combustion engine should heat up rapidly in order to achieve a significant reduction in friction. Rapid heating of the engine oil and the resulting decrease in oil viscosity are the decisive factors. The heat generated by the engine must therefore not be dissipated by the coolant but used for heating the engine oil.

At low and medium loads, high coolant temperatures (approx. 110 °C) are desirable for further reducing the engine friction.

In addition to the above advantages, the acoustics of diesel engines can be improved by reducing the ignition delay time. Intelligent thermal management can influence the evaporation rate and thus the ignition delay.

To prevent knocking of the gasoline engine and reduce the enrichment of the mixture, the coolant temperature should preferably be reduced (to approx. 80 °C) at high loads and high speeds.

Intermediate stages must be defined between the two limit values for the coolant temperature. These vary depending on the combustion engine and can serve diverse goals (reduced friction, optimized combustion, lower raw emissions, increased comfort etc.).

The ideal thermal management system should be able to adjust the relevant coolant temperature in accordance with the above requirements.

Thermal management measures can achieve fuel savings of up to 4 % in the NEDC (Figure 2). The blue curve shows the accumulated consumption of a reference engine, the red curve that of an engine with a thermal management system. The green curve indicates the savings in percentage terms that can be achieved in the NEDC with the thermal management system. Significant savings potentials of more than 4 % can be expected particularly in short-distance driving operation. This is mainly due to a more rapid heat-up of the engine and the corresponding reduction in friction.

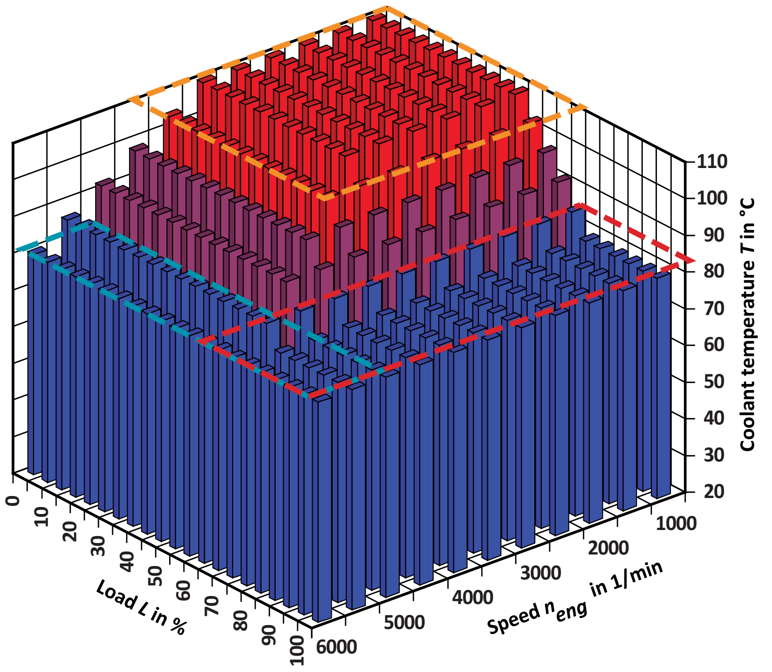

Figure 1 Required coolant temperature depending on load and speed from [1]

Figure 3 gives an impression of the possible reduction in engine friction. If the oil temperature increases from 20 °C to 80 °C, the total frictional torque of the engine decreases by 75 %. At an oil temperature of 110 °C, it decreases by as much as 85 %. This shows that rapid heating of the engine oil and operating the engine at the highest possible temperature make a significant contribution to reducing friction and therefore fuel consumption.

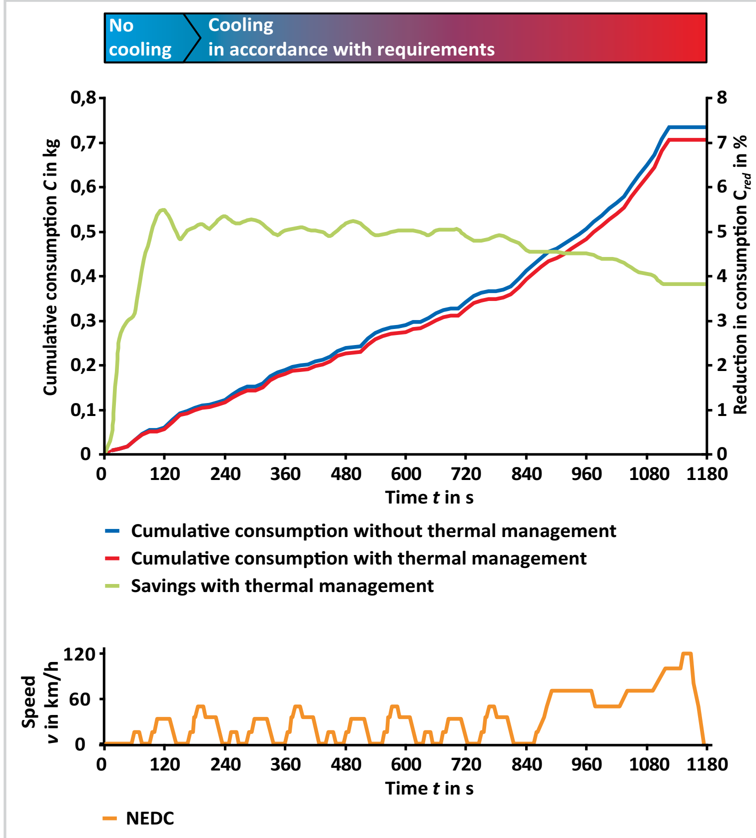

Figure 2 Savings due to thermal management from [2]

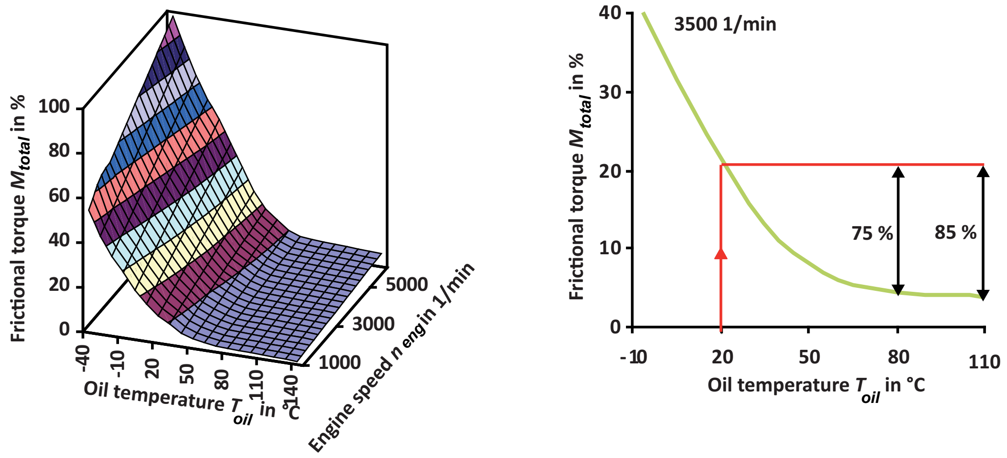

Figure 3 Reduction in engine friction from [3]

Components for thermal management

All components in the cooling circuit as shown in Figure 4 – radiator, fan, louvers, thermostat, engine control unit, and water pump – must in principle be included in the thermal management system. These components are currently characterized by a limited variability.

For example, there are thermostats that are controlled by means of wax elements. Switchable or electrically-driven water pumps are also being used. The cooling air flow can be limited by splitting the radiator into several parts or covering it with louvers. Solutions have been developed for the fan that are similar to those for the water pump (electrically-driven fan, viscous coupling etc.).

However, almost all vehicles today still use uncontrolled, mechanically-driven water pumps. These are permanently linked with the engine speed via the belt drive and therefore allow no variability. Presented below is a controllable water pump that possesses the required variability. The variably adjustable flow rate enables an additional degree of freedom for the cooling system.

Controllable coolant pump

The controllable coolant pump is a centrifugal pump with a shroud that is integrated in the rotor as shown in Figure 5. A defined width of the rotor is exposed when the shroud is moved axially. This enables adjustment of the volume flow.

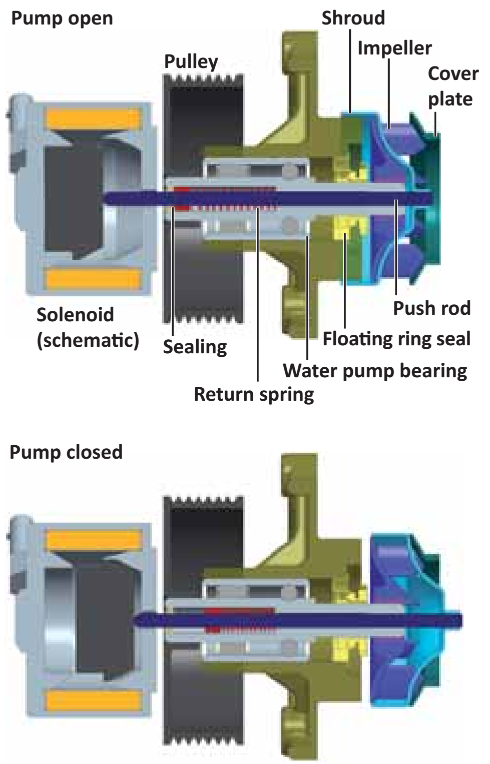

Figure 5 Design of a controllable water pump

If the shroud is in the left position (Figure 5, top diagram), the rotor width is completely exposed and the generated volume flow achieves a maximum. The solenoid, which is located on the left side and serves as an actuator, is not fed with current. If the volume flow is to be reduced, the solenoid is fed with a defined amount of current. The armature is correspondingly moved to the right, presses against the push rod and thus moves the shroud to the right. This reduces the effective width of the flow channel and cuts the flow (Figure 5, bottom diagram).

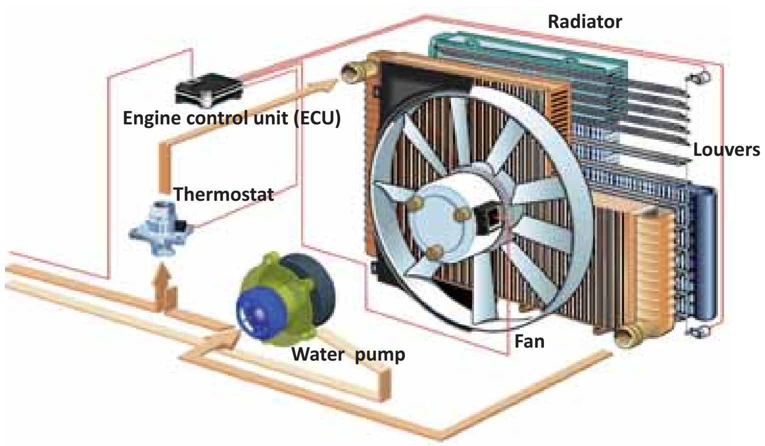

Figure 4 Components of thermal management from [1]

To ensure the fail-safe function in case of a failure of the solenoid, a compression spring retains the shroud in the completely opened pump position. The compression spring is designed so as to ensure that the water pump is completely opened when the flow forces reach a maximum.

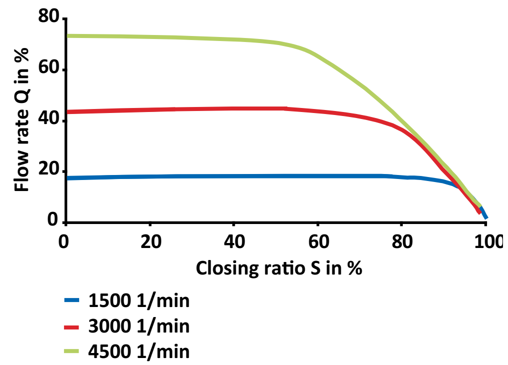

Figure 6 Flow rate in relation to pump closing ratio and speeds

Figure 6 shows the flow behavior of the pump at different closing ratios and speeds. A closing ratio of 0 % corresponds to a completely opened pump. The pump is closed at a closing ratio of 100 %. The diagram indicates that the flow rate decreases significantly with increasing closing ratios. The flow rate can therefore be adjusted by the position of the shroud.

Figure 7 shows the pump efficiency in relation to the flow rate at a speed of 2500 1/min. The diagram indicates that the maximum efficiency at this speed is achieved when the pump is approx. 50 % open. This can be attributed to backflows and turbulences that sometimes occur outside the design point (Figure 8).

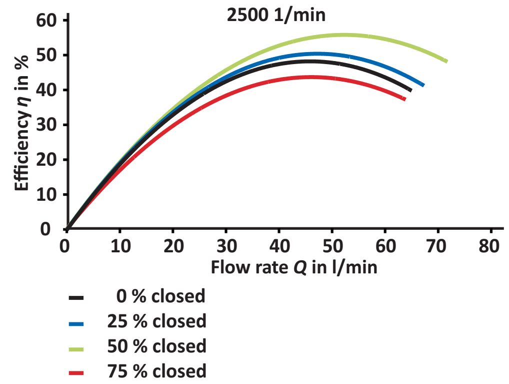

Figure 7 Pump efficiency in relation to flow rate and closing ratio

At nominal speed, the complete rotor width is used for pumping the medium. At low speeds, backflows occur in the conventional pump (Figure 8, left column) and reduce the efficiency. When using a shroud, the rotor width can always be adjusted to the required volume flow (Figure 8, right column). This prevents energy loss caused by backflows and therefore increases the efficiency of the pump.

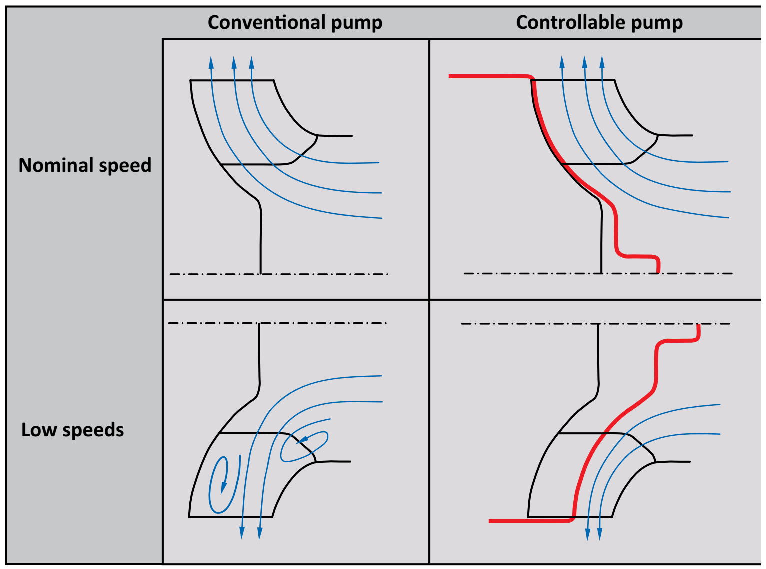

Figure 8 Comparison of conventional and controllable water pumps

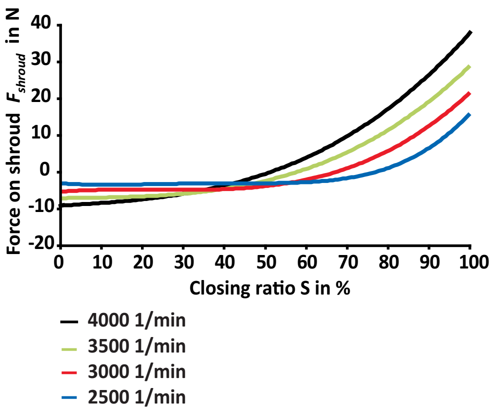

Figure 9 Forces on the shroud in relation to closing ratio and speeds

Actuator

Figure 9 shows the axial forces acting on the shroud in relation to the pump closing ratio at different speeds. The negative axial forces resulting from the flow move the shroud towards "closed", whereas the positive axial forces move it towards "open" (Figure 5).

The diagram in Figure 9 indicates that the force on the shroud changes its direction at different speeds and different closing ratios. This point represents

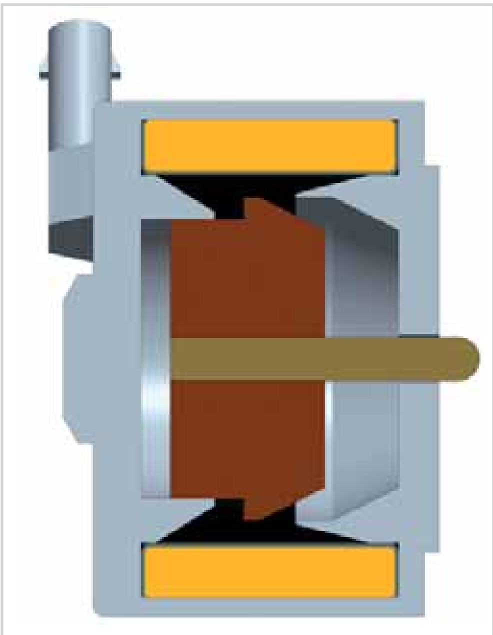

Figure 10 Solenoid

the optimum rotor width at a specific speed. The volume flow can be reduced at widths lower than the optimum width.

Due to its physical functional principle, the forces of the electromagnetic actuator act only in one direction (push solenoid). A compression spring is used for compensation to ensure a constantly positive force level. This way, the shroud is retained in the "open" position in all operating conditions and moved towards "closed" by the push solenoid.

Adjusting the rotor width and thus the volume flow depending on the speed requires an actuator that allows the setting of defined forces. The simplest solution for this is a pull solenoid with a modulated pulse width for influencing the electromagnetic force characteristic curves. Defined currents that generate the required forces can be set by means of pulse width modulation of the voltage. Figure 10 shows the solenoid of the controllable water pump in full section view.

Figure 11 shows the forces exerted by the solenoid depending on the magnetomotive force (current) and the stroke of the solenoid as well as the axial forces on the shroud. The diagram indicates that the magnetic force changes with different currents or magnetomotive forces and the force equilibrium is achieved in different positions of the shroud.

Thus, the position of the shroud can be set in a targeted manner and the volume flow can be reduced to zero. As the forces on the shroud change with

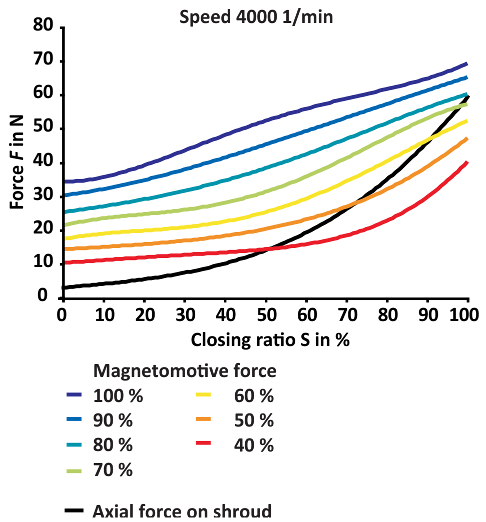

Figure 11 Magnetic forces and flow forces in relation to closing ratio S and magnetomotive force

both speed and position of the shroud, each operating condition requires a suitable current that can be set by means of pulse width modulation.

Summary and outlook

This article presented a variable coolant pump for controlling the engine temperature in accordance with the specific requirements. Significant development objectives of thermal management are reductions in fuel consumption, longer engine life and increased comfort. Due to the presented controllable water pump, the coolant volume flow can be controlled depending on the current operating condition of the engine, and efficiency can be increased depending on the driving situation by adjusting the rotor width. The development objective in this case was achieved by intelligently modifying and combining existing components.

The integration of this controllable water pump and other variable components in a thermal management system is another very promising approach for the future.

Literature

[1] Behr Thermot-tronik GmbH: Kennfeldthermostate – Höchstleistung für den Kühlkreislauf, http://www.behrthermot-tronik.de/produkte/automobil/kennfeld-thermostat.pdf, November 2009

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[3] Brinker, M.: Thermomanagement und Motorkühlung aus Sicht von Opel/GMPT, CTI Forum: Thermomanagement im Automobil, February 2008