7th LuK Symposium

11./12. April 2002

Publisher: LuK GmbH & Co.
Industriestrasse 3 • D -77815 Bühl/Baden
Telephon +49 (0) 7223 / 941 - 0 • Fax +49 (0) 7223 / 2 69 50
Internet: www.LuK.de

Editorial: Ralf Stopp, Christa Siefert

Layout: Vera Westermann
Layout support: Heike Pinther

Print: Konkordia GmbH, Bühl
Das Medienunternehmen

Printed in Germany

Foreword

Innovations are shaping our future. Experts predict that there will be more changes in the fields of transmission, electronics and safety of vehicles over the next 15 years than there have been throughout the past 50 years. This drive for innovation is continually providing manufacturers and suppliers with new challenges and is set to significantly alter our world of mobility.

LuK is embracing these challenges. With a wealth of vision and engineering performance, our engineers are once again proving their innovative power.

This volume comprises papers from the 7th LuK Symposium and illustrates our view of technical developments.

We look forward to some interesting discussions with you.

Bühl, in April 2002

Helmut Beier

Helmut Beier

President
of the LuK Group

Content

Temperature-controlled Lubricating Oil Pumps Save Fuel

Heiko Schulz-Andres
Dirk Kamarys

Introduction

Reducing fuel consumption in automobiles will continue to be a major focus for development in the automotive industry in the future. In addition to developing new technologies (e.g. direct injection), it will become increasingly important to optimize existing components. This allows significant savings potential to be realized without the immense costs that new systems can cause. The key word here is ‘requirement-oriented auxiliaries’.

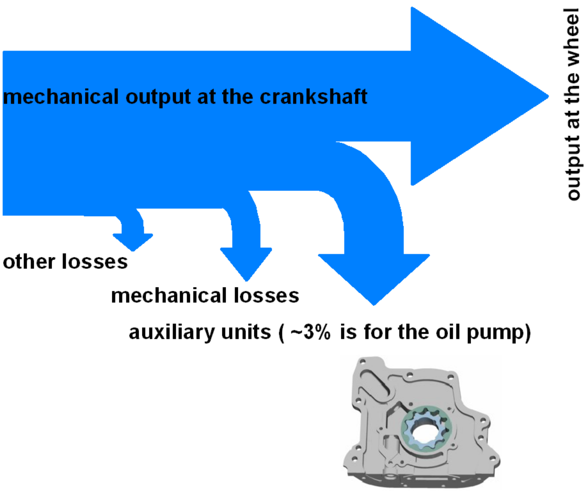

Fig. 1: Energy Balance in the NEDC

Figure 1 shows the energy balance of a mid-size automobile in the New European Driving Cycle (NEDC). Looking at the number of consumers that are connected, it is easy to understand why auxiliaries are the second-most important factor in fuel consumption. [6] The oil pump, however, using up to 3% of the mechanical power, is particularly striking. It is easy to see that adjusting the oil pump based on actual demand would reduce power loss. LuK has taken on this task, and would like to present here a new innovation in oil pumps, which will lead to considerable savings in fuel consumption.

Basic Principles

The oil pump is a very important component of the engine. If this pump fails, it causes the entire engine system to fail within a very short time.

The oil pump has three functions:

- Lubrication
  There must be a sufficient lubrication film at all bearing points. This applies in particular to the highly stressed crankshaft and connecting rod bearing points.
- Cooling
  The heat generated by the engine must be dissipated. This applies both to the heat caused by friction in the bearing points and the heat of the piston lubrication oil generated by the combustion process.
- Control
  There are various hydraulic control elements, such as hydraulic valve lifters, camshaft control, etc. These adjusting elements are actuated from the engine control. The oil pump must provide the pressure required by these elements.

In sum, the main function of the oil pump is to provide a required pressure [1], [2].

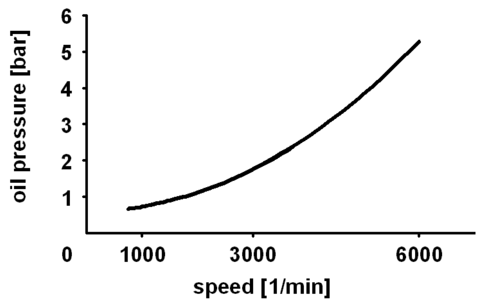

Fig. 2: Engine Oil Pressure Demand

Figure 2 illustrates the engine’s oil pressure demand over engine speed. This oil pressure increase is needed to ensure the required lubricating film on the individual bearing points.

Viewed hydraulically, the oil circulation is a combination of throttling and splitting, which, in the pump design, can be replaced by a compensating choke. From this, it is possible to calculate the flow rate required for the pressure buildup.

In addition, it is generally known that oil viscosity drops sharply as the temperature rises. The result is an increase in the flow rate as the temperature rises to generate the required pressure buildup.

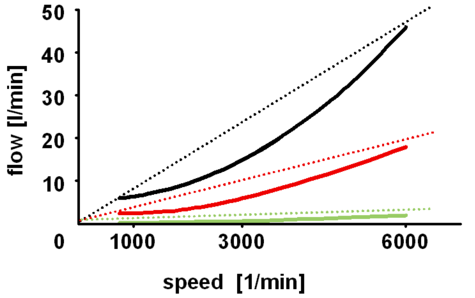

Fig. 3: *Temperature-Dependent Flow Rate Demand*

Figure 3 shows the flow rate demand of the engine derived for different temperatures. In addition to the speed dependence, there is a sharp increase in the required flow rate as the temperature increases. With a fixed-displacement pump, the flow rate increases in a linear relationship to the speed. At a constant temperature, therefore, it provides a good approximation of the demands.

For this reason, a suitable temperature regulation is also sought.

Figure 4 shows the characteristics of the fixed-displacement pumps that are state of the art. The hot idle, as it is called, is the main factor in designing the pump. This is the operating point at which the oil temperature is highest when idling. This state is generally only achieved with high power requirements and low vehicle speeds (e.g. during uphill driving with a trailer). This hot idle occurs if the engine is operated in idle after such an event. The minimum pressure to supply the bearing and control points must still be ensured at this operating point. That minimum pressure is generally 0.7 - 0.8 bar. At higher engine speeds the fixed-displacement pump always supplies the oil requirement.

In general, however, the engine is only operated at oil temperatures of up to 90 °C. This leads to an undesirable increase in oil pressure, which is controlled by the pressure limiting valve, thus causing a greater portion of the oil to circulate needlessly. The lower the engine temperature, the greater this loss of efficiency.

Many vehicles are normally used in short-distance driving operation. The operating temperature is seldom reached. In order to accurately reflect this process, the New European Driving Cycle (NEDC) is started cold. The engine then heats up to the operating temperature over the course of the cycle.

Figure 5 shows the increase in the oil temperature over the operating time of the NEDC. Since this cycle conforms very well to reality and is also used for consumption comparisons, it makes sense to evaluate new concepts for oil lubrication using the NEDC.

Figure 6 shows the difference in power consumption between a current fixed-displacement pump and an ideal pump based on actual oil requirements in the NEDC. As can be seen, reducing the flow rate based on temperature could significantly reduce the power consumption of the oil pump.

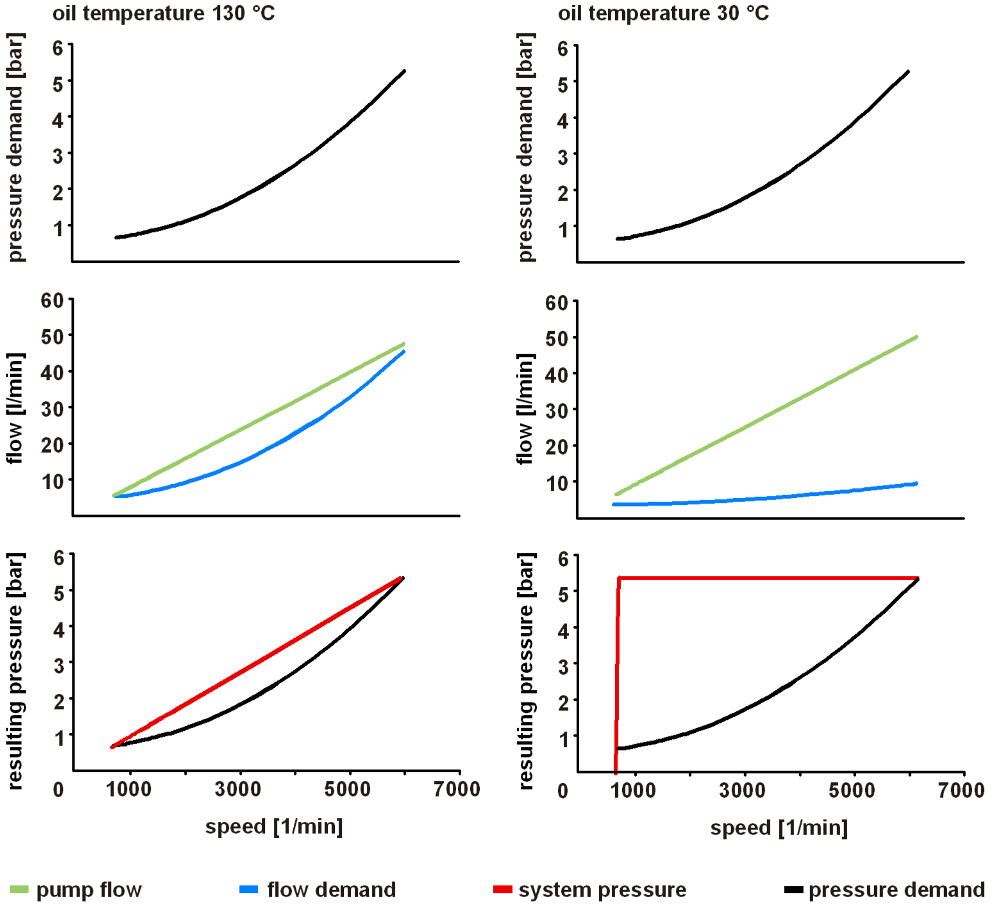

Fig. 4: *Design of a Fixed-Displacement Pump*

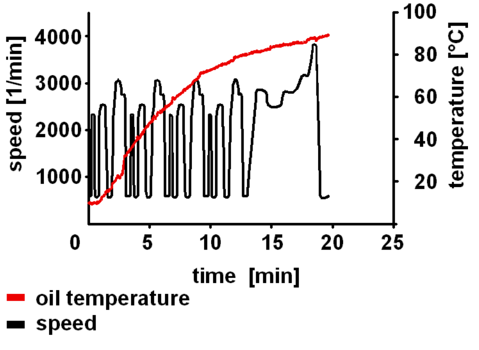

Fig. 5: *Engine Warm-up during the NEDC*

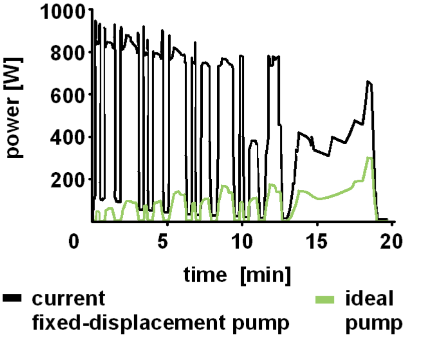

Fig. 6: *Power Consumption in the NEDC*

Solutions

There are two principle solutions to the problem of providing a variable flow rate depending on the temperature. Either the speed or the displacement volume of the pump can be regulated based on the temperature (figure 7).

$$Q = V \cdot n$$

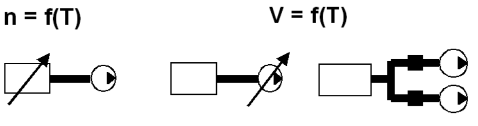

Fig. 7: Adjustment Principles

Variable Speed

One way to power a fixed-displacement pump with variable speed is to use PowerPacks (electrically driven pumps).

The advantage of this design concept is that the pump can be operated at the optimal operating point based on the engine characteristics. This makes it possible to provide the required pressure prior to starting, thus preventing wear to the bearing points in the start-up phase. The pump could react to any additional pressure demands via the control.

However, these advantages are partially canceled out by the efficiency of the electrical drive chain, which must also be taken into consideration. This design also requires significantly more space than today's models, which are driven directly by the engine. The additional cost of the electrical machinery and the electronics is an especially important factor. The low reliability of this design is another critical factor, since failure of the electric motor can result in the complete destruction of the engine.

Variable-Displacement Volume

Another possible solution (figure 7, center) is to vary the displacement volume with the temperature. Variable-displacement pumps are available in a wide variety of designs.

The design principle of vane pumps makes them perfect for variable-displacement volume control. By varying the rotor eccentricity of a single-stage vane pump, it is possible to vary its displacement volume without requiring any expensive or complicated components. Other advantages are high efficiency and low pulsation [4].

Figure 8 shows a production application in the area of transmission pumps. In this example, we have a single-stage vane pump with pressure compensation. In the diagram, we can see the spring-loaded slide, which is turned around the pivot pin inside the housing by the control pressure, thus regulating the stroke volume [3].

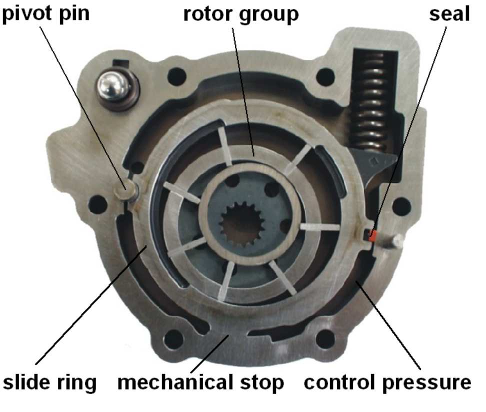

Fig. 8: Variable-Displacement Pump

Continuous adjustment allows excellent approximation of the actual pressure requirement, resulting in low power requirements. Its mechanical connection means that it has a reliability level similar to that of a standard pump. Disadvantages include greater space requirements, higher costs for the adjuster unit and poorer efficiency due to the higher friction radii of the single-stage design.

Switch Pumps

Instead of varying the displacement volume, the pump can also be designed with different stages (figure 7, right). The dual-flow switch pump is the simplest design here. Figure 9 shows the working principle of this pump.

This is a two-stroke vane pump in which the discharge ports can be separated to provide two flows. This elegant, space-saving solution is possible only with this type of pump.

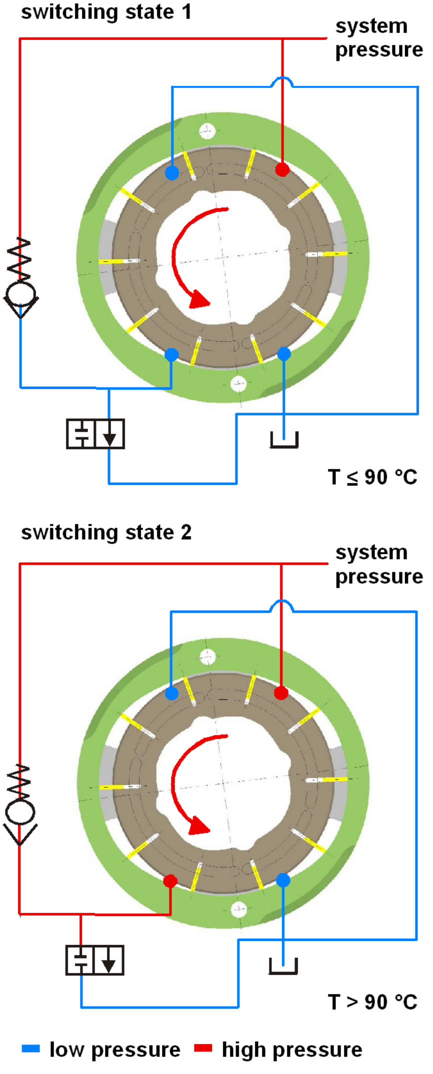

Fig. 9: Principle of a Switch Pump

Below the switching temperature, one of the two flows is switched in circulation to the suction channel (switching state 1). Only after the valve has been switched, is the second flow channeled to the system pressure (switching state 2). The motor design makes it possible to design the pump so that only one flow is pumped in normal driving operation (T_{oil} = 90 °C). The advantage of this principle is a compact pump, which, due to its small friction radii, also has low drag torque.

This simple construction has the lowest manufacturing costs of all of the concepts presented. Its reliability is ensured due to its direct connection to the engine. The disadvantage is the fact that the pump is still slightly oversized for low temperatures, which means that it does not ideally approximate the pressure requirements in this range. However, this over-dimensioning is certainly less than that of the existing fixed-displacement pumps, so that the remaining loss of efficiency is very low. For clarification, Figure 10 shows the change in the displacement volume over the cycle time. Here it can be seen that only in the first third of the cycle is there a clear difference between the switch pump and an optimal variable-displacement pump.

By contrast, the difference between these and serial pumps is quite distinct. The design of the switch pump (switching point volume distribution 50:50) is adapted for everyday operation. Optimizing it for the NEDC would result in a different design.

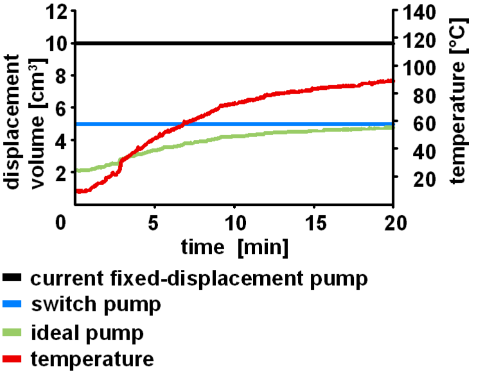

Fig. 10: Displacement Volumes in the NEDC

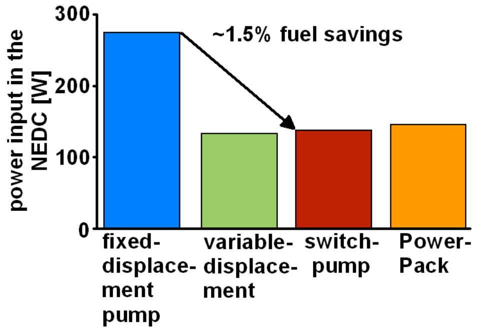

Fig. 11: Power Consumption in the NEDC

concept	PowerPack	variable displacement	switch pump
close to pressure demand	🙂	🙂	😐
power consumption	🙂	🙂	🙂
operating safety	😐	🙂	🙂
installation space	☹️	😐	🙂
cost	☹️	😐	🙂

Fig. 12: Evaluation of the Design Concepts

To evaluate the design concepts the power consumption in the NEDC was determined by using a simulation model. The results are shown in figure 11. The power consumption of all of the concepts are significantly below those of the state of the art pump. For a mid-sized vehicle with a power requirement of 10 kW in the NEDC, this reduction corresponds to a fuel saving of approximately 1.5%.

Figure 12 shows a summary of all of the concept evaluations.

The concept with the best cost-benefit ratio was selected for design implementation. Another deciding factor was the ability to implement the concept quickly in production. The dual-flow switch pump was selected for implementation based on this evaluation and on the positive trials with switch pumps.

Design Implementation of the Switch Pump

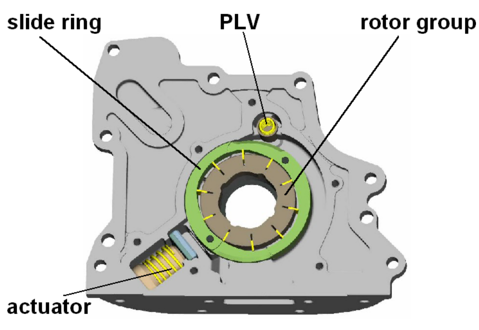

Fig. 13: Pump Design

Figure 13 shows how the switch pump is integrated in a current oil pump housing, in this case built as an on-axis pump. The pump sits on the engine block between the main bearing and the belt pulley for the power take-off. The crankshaft drives the rotor directly. The rotor group is designed as a two-stage vane cell with 10 vanes. The stroke contour reflects the LuK standard for power steering pumps, as is the hydraulic vane extension known from the high-pressure pumps, to minimize leakage. The pump is designed so that the channel guide is optimal for the dominant switching state 1 (only one flow active). The pressure limiting valve can be made considerably smaller than in the current production unit, since the maximum volume flowing through the valve has also been reduced.

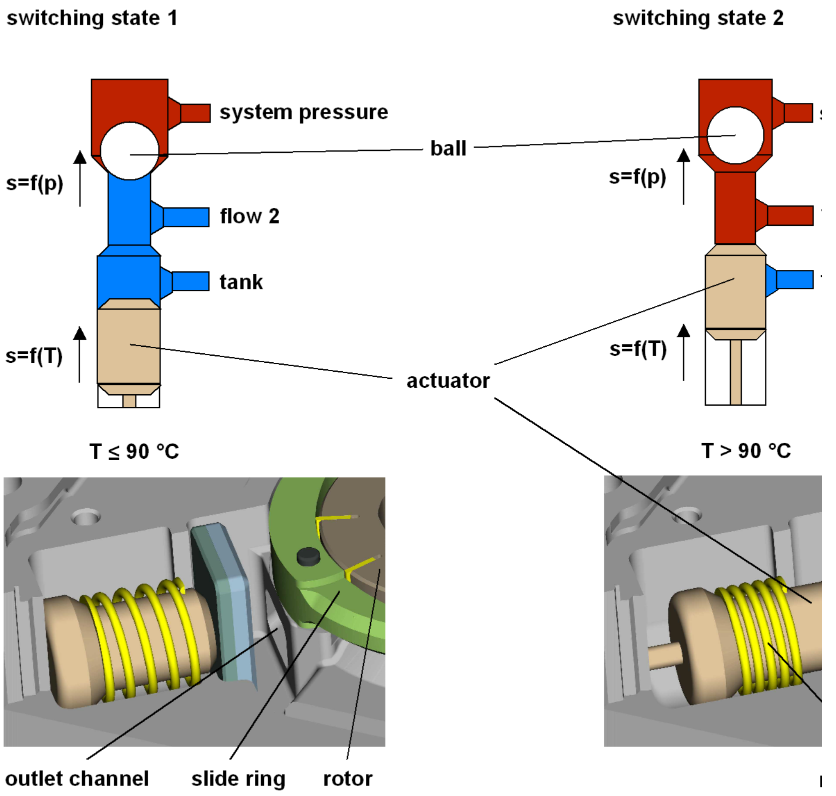

Fig. 14: *Switching Principle*

Figure 14 shows the selected switching principle. At low temperatures, the second flow is connected to the tank by means of an open seat valve. The connection between the second flow and the pressure outlet is closed by a check valve. When the oil temperature increases, the actuator shuts off the connection between the pressure outlet of flow 2 and the tank. As a result, pressure builds at the pressure outlet for switch stage 2. As soon as the pressure exceeds the system pressure, the check valve is opened and the second flow is also connected to the system.

For the actuator, an element was sought, which could be completely integrated in the pump. Electronics were avoided to minimize the complexity. Likewise, the actuator had to work without additional energy from the pump, since this would cause additional losses. There are several different temperature-sensitive materials that are suited in principle for this task [5].

An expansion element was used in the design shown here. When the switching temperature is exceeded, the piston is extended from the element. This piston is supported on the pump housing and moves the actuator with the valve plate against the bore (figure 14, bottom). When the oil has been cooled to below the switching temperature, the spring moves the actuator back to its initial position.

The cross-section of the bore and the valve plate were designed as large as possible to generate a low flow resistance in the open state. The actuator must be designed so that the amount of oil pumped into the engine is more than required at all engine speeds and temperatures. Figure 15 shows a simulation of the closing process during idling. At temperatures of up to 35 °C, some of the oil is still sent through the pressure limiting valve (PLV). Above this oil temperature, the full flow volume is pumped to the engine. The pressure buildup decreases as the temperature rises. Before it can fall below the minimum pressure, the pump switches to the second stage and supplies sufficient oil to the engine even at higher temperatures.

Due to the expansion element, there is a hysteresis between the temperatures to switch the second stage on and off. This also increases safety during the transition between hot and normal operation. The simulation shows that the requirement set in the beginning is fulfilled.

The channel guide and the placement of the elements are optimized using CFD simulations. For this purpose, calculations for the different operating conditions have been made. The best concept is selected based on the percent of time in which the individual states occur during practical operation.

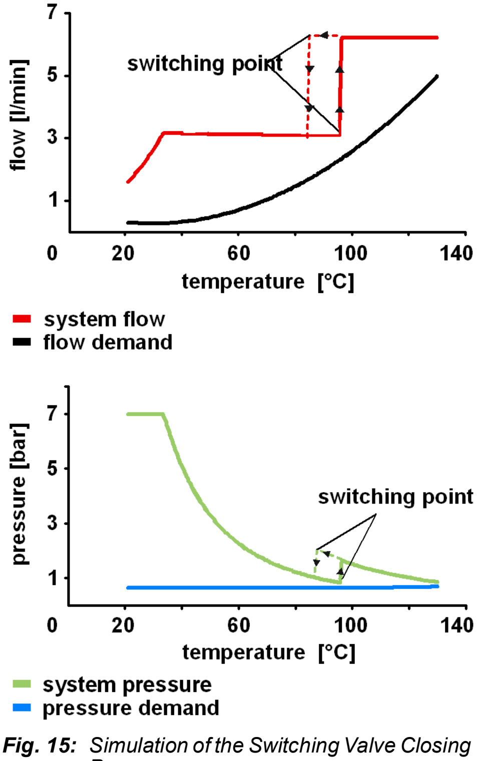

Fig. 15: Simulation of the Switching Valve Closing Process

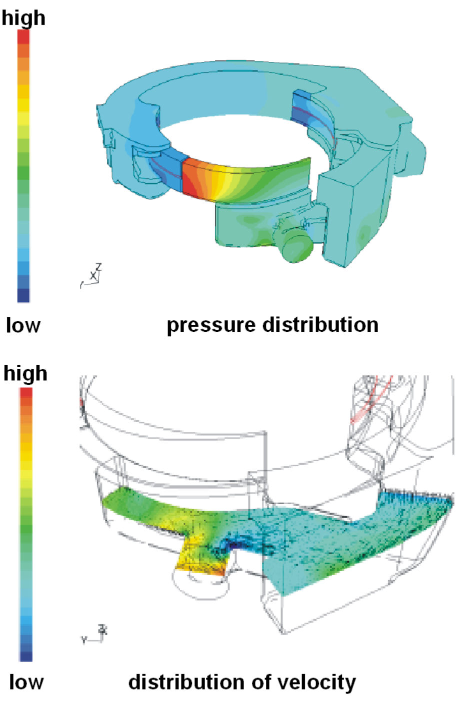

Fig. 16: Flow Conditions at the Switching Valve

Figure 16 shows an example of the final calculation of the channels in the region of the seat valve for the maximum flow rate.

Results

The results from the initial prototypes confirm the simulations. The current prototype was able to show a power reduction of 35% for the oil pump in the NEDC. This corresponds to approx. 1% reduction in fuel consumption.

Summary

Of all auxiliaries, the oil pump has the greatest potential for savings, since the current pumps must be designed for an operating condition, which rarely or never occurs in the vehicle. A requirement-oriented oil pump is both logical and necessary to reduce fuel consumption. It emerges that an oil pump that is temperature controlled best meets the requirements of the system. With such a pump, it is possible to realize a reduction in fuel consumption of 1 - 2% in the NEDC, depending on the vehicle.

The development presented here of a switchable, dual-flow vane pump can be integrated in the existing space and does not require expensive electronics. Even the initial prototype showed a fuel saving of 1%. The ratio between energy savings and development costs is highly attractive for the OEM.

References

[1] Köhler, E.: Verbrennungsmotoren: Motormechanik, Berechnung und Auslegung des Hubkolbenmotors, Vieweg 1998, p. 41 ff.

[2] Braess, H.-H.; Seiffert, U. (Ed.): Handbuch Kraftfahrzeugtechnik, Vieweg 2000, p. 157 ff.

[3] Koivunen, E. A.; LeBar, P. A.; Green, R.J.: Variable Capacity Pumps, Design Practices: Passenger Car Automatic Transmissions SAE 1994, p. 685 - 688.

[4] Murrenhoff, H.: Grundlagen der Fluidtechnik, Institut für fluidtechnische Antriebe und Steuerungen 1997, p. 149 - 154.

[5] Nußkern, H.: Thermische Stellelemente in der Gerätetechnik, Zeitschrift F&M Feinwerktechnik Mikrotechnik Meßtechnik, Carl Hanser Verlag 1995.

[6] Aral Aktiengesellschaft: Das blaue Buch von Aral, Firmenschrift der Aral Aktiengesellschaft 1992, p. 50 ff.