Variable Displacement Pump Design Optimization

by Anders Järpedal

Fuel economy, emissions and performance are today more important than ever in the automotive industry. New design concepts are constantly being investigated in the pursuit of the highest efficiency. At BorgWarner in Landskrona, one line of attack is to try a new, variable design for an oil pump.

One of the central components in the company's all-wheel drive products is a hydraulic piston pump. The pump's job is to supply oil at a specific pressure to the system. The required power to drive such a pump is proportional to the pressure difference between the intake and the outlet, the speed of the pump and the so-called displacement – that is, the amount of oil that is pumped each revolution. In other words, the energy consumption of the pump can be reduced at high pressures and speeds by choosing a lower displacement. On the other hand, by using a higher displacement at low pressures and speeds the reaction time of the pump can be improved since more fluid is pumped each revolution.

The benefits with being able to vary the displacement is clear. A prototype pump with variable displacement was therefore developed by BorgWarner. However, the prototype had two problems that would affect the in-vehicle experience and therefore have to be reduced: It shows unwanted pressure variations – ripples – and have a high sound level. But why?

Before answering this question the basic principle for the variable displacement pump has to be explained. As can be seen in Figure 1, it is the inclination of the swash plate that controls the movement of the pistons. Thus, the swash plate angle controls the amount of oil being pumped each revolution. A larger angle gives a higher oil flow, and a smaller angle gives a lower flow. The prototype is also designed so that the current swash plate angle is dependent on the pump pressure.

So what was then the underlying causes for the problems with the prototype? The answers were found by applying fluid dynamics theory, by studying the frequency content of sound recordings, and by using a new, detailed simulation model of the pump where each cylinder could be studied individually. It showed that the pressure ripples are actually caused by variations in the pump flow. The flow variations were found to be especially large when the swash plate is in transfer between its upper and lower angle limits, and it was soon discovered that the swash plate angle vibrates severely in this interval. No wonder that the pressure is unstable! Regarding the sound generation, the main contributor is believed to be the rapidly changing pressure in the cylinder chambers. There are pressure spikes when the cylinders link up to the intake and outlet ports, and these will create noise.

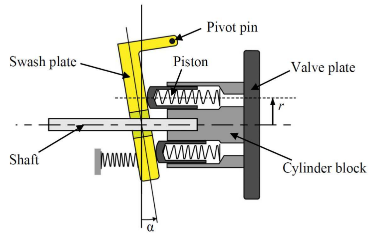

Figure 1. The displacement is varied by changing the inclination of the swash plate, α.

There are several parameters in the design that can be altered in order to improve and tune the behaviour of the pump. For example the pivot pin of the swash plate can be moved or the geometry of the pump ports can be changed. To find the best parameter combination a design optimization was carried out. The objectives were to minimize the pressure spikes and flow variations, and over 4 600 different designs were simulated and evaluated. The most promising designs made it on to a thorough performance comparison where they were compared to the original prototype design.

The most optimal design shows up to 30 percent lower flow variations thanks to the reduced swash plate oscillation, seen in Figure 2. In addition, over 50 percent reduced cylinder pressure change-rate was achieved! Apart from reducing the noise, the improved design hopefully will take this new, efficient pump concept one step closer to realization.

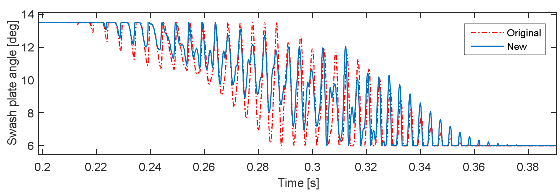

Figure 2. Swash plate oscillations.