Master’s Thesis Engineering Technology

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Analysis of pump pressure ripple as a source of noise in a hydraulic roll control system

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Introduction

At Tenneco Automotive Europe BV, research is done concerning suspension for cars. A result of this research is the CVSA2-Kinetic® system (Continuously Variable Semi-Active). This system uses semi-active dampers that allow for more control and combines these with the more advanced Kinetic® system. The Kinetic® system **provides roll control** without the need of anti-roll bars. The system is used in supercars as well as performance SUVs [1]. The main components needed for this system are shown in Figure 1:

- Semi-active dampers
- **Pump unit**
- Sensors
- Hydraulic manifold and lines

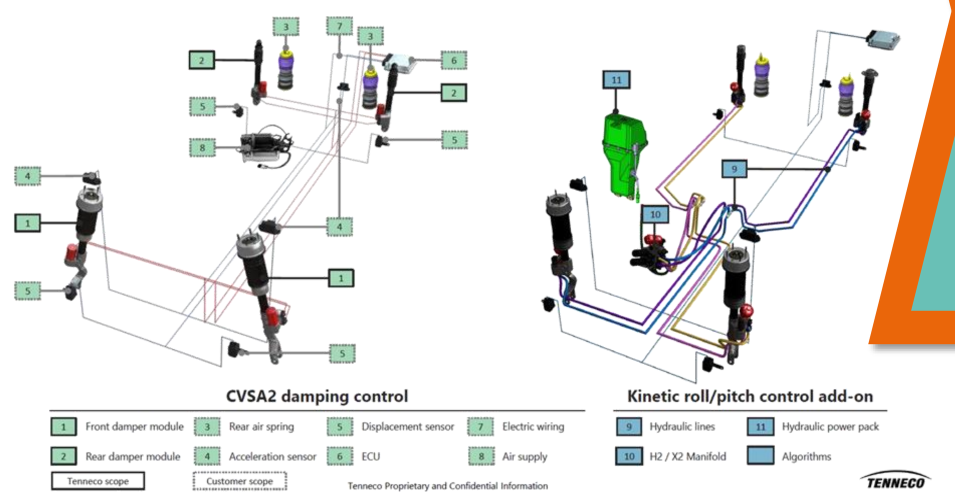

Figure 1: CVSA2-Kinetic® System [2]

Problem statement

The pump that is currently being used in this system, is expected to **cause pressure ripples that causes noise** in the vehicle. Because car manufacturers are tightening noise restrictions, a solution for this problem needs to be found.

A first step in solving this problem, is to **define the magnitude** of the problem. In this thesis, a **test setup** is **developed and built** to measure the pressure ripple created by the pump. To explore the subject and studies that are already carried out on similar problems, a literature study is performed.

As a second step, the literature study continues to propose **solutions** to **reduce the pressure ripple**. Once possible solutions are found, they can be implemented in the test setup, or prepared to be used in future research.

Literature study

This literature study explored two main topics:

- the development of the test setup,
- a search for different methods to reduce pressure ripples in the system.

Development of the test setup

To be able to measure the pressure ripples in the system, a first aspect is the **generation** of the pressure ripples. The main cause for pressure ripples are **flow pulsations**. These flow pulsations cause a cyclical component that is superimposed on the magnitude of the flow [3]. It is also discovered that the generated noise may be caused by mechanical impacts within the pump, but this phenomenon is mainly observed in gear pumps [4].

Next, the literature study focuses on the **practical realization** of the test setup. In this section, multiple similar test setups are examined, together with the ISO-norm. **ISO 10767-2** specifies the determination of pressure ripple levels generated in systems and components [5]. Subsequently, the **influence of pipe systems** and other components was examined [4]. Finally, with the information from these sources, a **hydraulic scheme** is designed and shown in Figure 2.

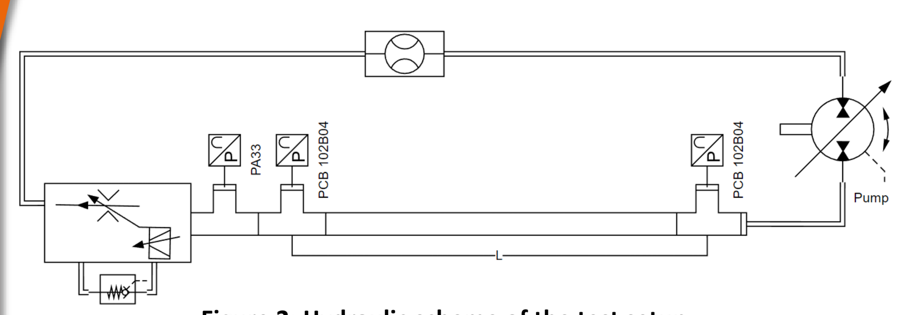

Figure 2: Hydraulic scheme of the test setup

Reducing the pressure ripple

The second part of the literature study searches for possibilities to **reduce the pressure ripple** in the system. The most suitable methods are:

- Reducing noise at the source
  - Increasing the number of pistons
  - Applying a visco –elastic coating
- Reducing noise in the transmission path
  - An in-line nitrogen silencer [6]
  - An accumulator with a flow direction unit

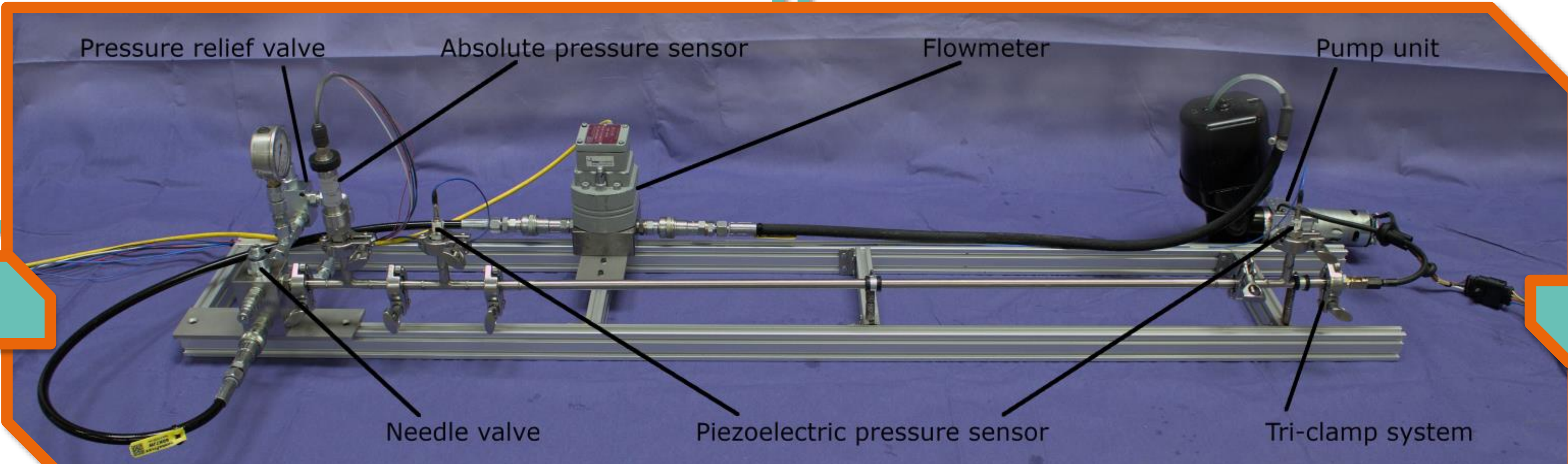

Figure 3: Test setup

Results

The results that are received from the CompactDAQ are **processed using LabView**. In LabView, they are displayed in real-time to monitor the measurement. When a measurement is done, the data is saved to a CSV file that can later be post-processed using MATLAB. The **resulting graphs** are shown in Figure 6.

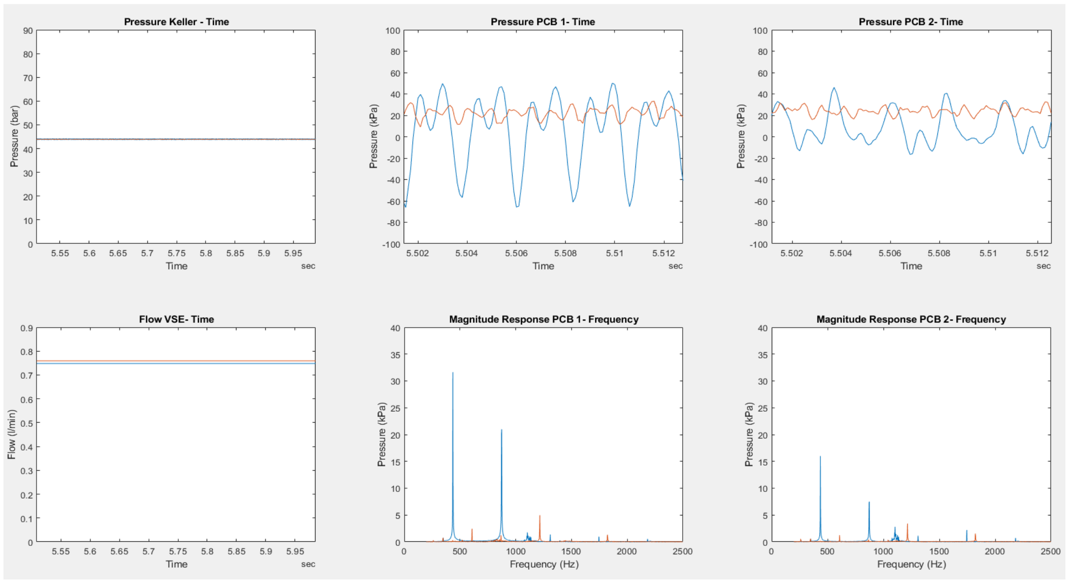

Figure 6: Results post-processing in MATLAB

Legend Figure 6

- Top left corner: the Keller PA-33X sensor.
- Top center and top right corner: the PCB 102B04 sensors.
- Bottom left corner: the VSE Flow flowmeter.
- Bottom center and right corner: FFTs of the PCB 102B04 sensors.

The results in Figure 6 are obtained by following a **test procedure** that describes all the steps to perform repeatable measurements. To verify this **repeatability**, multiple tests are carried out using the exact same settings for all the components. Following these tests, the **influence of the different components** is examined.

In Figure 6, the **difference** between a **5-piston pump and a 7-piston pump** is shown. It is clear that the pressure ripple generated by the **7-piston pump** (shown in orange) has a **much smaller magnitude** than the one from the 5-piston pump (shown in blue). This **confirms** the research on the reduction of pressure ripples. The pressure ripple of the 5-piston pump has a magnitude of ±100 kPa, while the 7-piston pump reduces this ripple to ±20 kPa. In Figure 6, the FFTs show a clear **shift in the fundamental frequency** from ±440 Hz to ±600 Hz.

Realization of test setup

To develop the test setup, possible layouts and sensors are explored. Eventually, the sensors that meet the requirements the best are selected. Additionally, the setup has to be expandable to give the possibility to test the noise reduction solutions. Partly because of this, the setup does not strictly follow ISO 10767-2.

Another reason for not following ISO 10767-2, is that **all the characteristics** of the hydraulic system want to be known. To achieve this, an absolute pressure sensor and a flowmeter are added to the system. Additionally, a second piezoelectric pressure sensor is added to **measure the influence of the pipe** that connects the pump unit to the manifold in the vehicle. The components used in the setup are listed below and shown in Figure 3.

• Absolute pressure sensor:	Keller PA-33X (0 - 100 bar)
• Piezoelectric pressure sensor:	PCB Piezotronics 102B04
• Flowmeter:	VSE Flow VSI 0,02
• Needle valve:	Parker FV102KV
• Pressure relief valve:	VMP ¼”L
• Connections:	Tri- clamp system (Following DIN 32676)

To **acquire the data** from this setup, a National Instruments CompactDAQ is used. A cDAQ-9189 chassis is used in combination with a NI-9220 analog input module (Figure 4, left). The PCB sensors are connected to a PCB 482A20 ICP sensor **signal conditioner** (Figure 4, right). The power to the pressure sensor and flowmeter is provided by an AFX-9660SB power supply (Figure 4, center), while power to the pump is provided by a Delta Elektronica SM 60-100 power supply (Figure 5).

Figure 4: Data acquisition setup

Figure 5: Pump power supply

Conclusion

The main objective of this master’s thesis was to develop a method to quantify the pressure ripple caused by a hydraulic pump for a hydraulic roll-control system in vehicles. To achieve this, a test setup was developed with pressure sensors for the absolute pressure in the system as well as pressure sensors to measure the smaller pressure ripple. In the setup, the flow of the hydraulic oil is also measured to completely identify the hydraulic behavior. To carry out these test In a repeatable way, a test procedure was composed, describing all the steps in the process. The results of the measurements clearly show the pressure ripple that needed to be measured. In the comparison between the 5-piston pump and the 7-piston pump, it is clearly visible that the 7-piston pump generates a pressure ripple with a significantly smaller magnitude.

Supervisors / Co-supervisors / Advisors

ir. Frank Gommans, ing. Stein Slootmaekers, ir. Gert Vanhees, prof. dr. Jeroen Lievens

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