ELIKA, VARIABLE FLOW WITH FIXED DISPLACEMENT HELICAL PUMP

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Electrification and hybridization have reduced engine noise in industrial vehicles, making hydraulic circuit noise the dominant source. Variable displacement pumps can lower noise but often at the cost of efficiency. The Elika gear pump, developed with the University of Bologna, uses patented helical gear technology to deliver low noise and high efficiency across a wide speed range, particularly when paired with Variable Frequency Drive brushless motors. Recent Marzocchi R&D tests showed it can deliver flows from 1 l/min to 20 l/min with the same displacement, maintaining over 90 % volumetric efficiency. These characteristics enable variable flow from a fixed displacement pump, offering a cost-effective, energy-efficient alternative to variable displacement designs, especially for electrified powertrains where noise reduction and efficiency are critical.

Keywords:
gear pump,
helical rotors,
Elika,
low noise,
Variable Frequency Drive

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1 Introduction

Standard external gear pumps provide high flows with high pressure and more over they can be small, lightweight and highly customizable. Their main issue is as the pressure and the speed rise then their noise becomes intrusive. Many new and modern applications are in high demand for low noise solutions; the main technical solutions developed over the years to reduce the noise of gear pumps are summarized below.

2 Development of external gear pumps

2.1 Standard external gear pump

It's well known that the major sources of noise of a gear pump are due to two different factors: a mechanical one, generated by the transmission of motion between the gear wheels, and the hydraulic one due to the volume of oil entrapped in the area in which the gears meshing (red area on Figure 1).

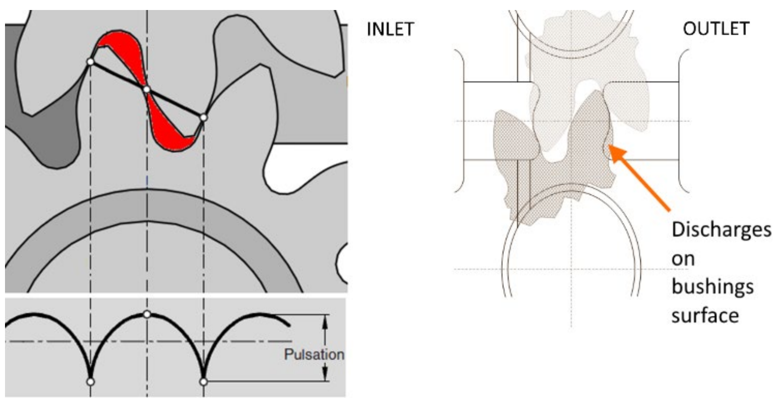


Figure 1: Standard external gear pump.

The encapsulation of this volume of oil generates high pressure pulsations and noise. The frequency of this phenomenon depends not only on the entity of the trapped volume, but also on the number of teeth of the wheels and their rotation speed; consequently, if the speed working range are wide, the frequencies with which these phenomena arise can be high, and noise generated can reach particularly annoying frequencies (>3000 Hz). In the standard external gear pumps, Figure 1, in order to reduce noise and pulsations, the optimization of gears and discharges on bushings surfaces gives only limited benefits.

2.2 Dual flank external gear pump

In order to reduce the volume trapped between the gear wheels, a technical solution is to use "double flank" profiles, Figure 2. Using this solution, thanks to the reduction of the trapped volume (red area on Figure 2), a considerable reduction of the pressure pulsation up to 75 %, and noise are reduced of about 3 dBA.

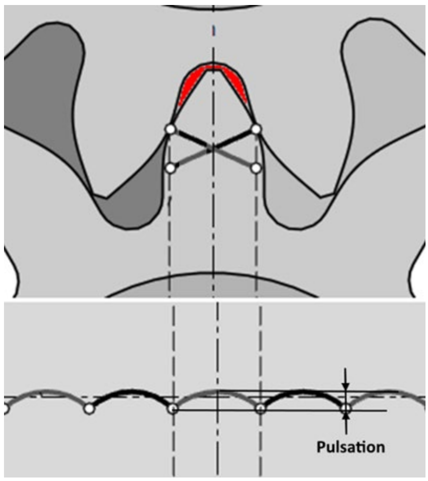


Figure 2: Dual flank external gear pump.

However, the double contact transmission has the effect of doubling the fundamental frequency of gear meshing, consequently the frequency spectrum of the emitted noise shifts towards higher, and consequently, more annoying frequencies.

2.3 Gear pump with helical gears

The mechanical noise of meshing of the gear wheels can be reduced using helical gears, Figure 3. Using this technical solution is a partial improvement, as it does not solve the problem related to the volume of oil trapped between the gear wheels. The helix angle used in any case is low to avoid oil seepage from the helical shaft in the meshing position; consequently, in order to limit the helix angle, these pumps often have to have a large number of teeth. This factor significantly limits the specific displacement of helical pumps, making them bulkier than the corresponding straight tooth pumps. Using this solution, a considerable reduction of the pressure pulsation up to 75 %, and noise are reduced by about 2 dBA to 10 dBA.

Figure 3: Gear pump with helical gears.

2.4 Gear pump with conjugated helical gears

This solution is able to eliminate both the hydraulic noise caused by the volume of oil that remains trapped between the wheels, which in this case is practically zero, and the noise typical of straight tooth transmissions. The absence of the trapped volume also removes any constraint on the helix angles, as the fluid can no longer seep between the gear wheels in the meshing area, Figure 4.

This technical solution, having eliminated the two main sources of noise (mechanical and hydraulic), is able to reduce the pressure pulsation up to 80 %, and the pump noise up to 15 dBA.

The idea of reducing the pump noise through elimination of the encapsulated volume, thanks to a special shape of tooth profile is not new. The idea was born precisely in the mobile market. His first documented application dates back to the power steering inventor Francis W. Davis. The inventor studied and applied, for the first time, a gear pump without encapsulation in order to reduce the noise in hydraulic power steering Figure 5.

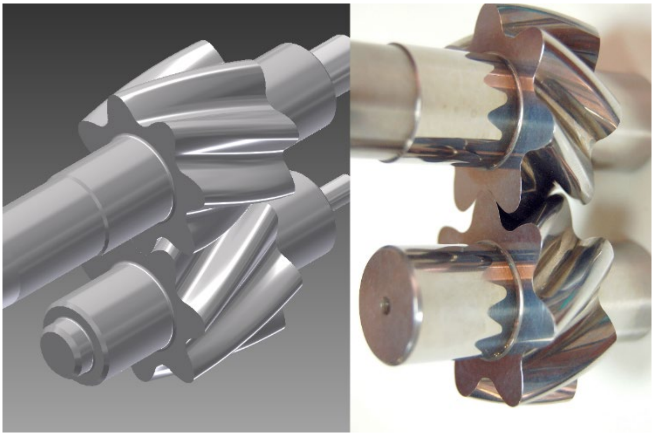


Figure 4: Gear pump with conjugated helical gears.

Figure 5: Drawings of the Pat. US2261143 – Gears - 18/08/1939 – Francis W. Davis.

A pump using a special tooth profile design was installed with success on the Pierce-Arrow in 1928 and moved to a Buick in 1932. In the original power steering the working pressures reached 70 to 100 bar, and the maximum rotation speed was about 1800 rpm. Despite the difficulty of manufacturing these special toothed wheels, in the following years, Francis W. Davis continued to study low noise hydraulic power steering and economic methods to produce non-encapsulated tooth profiles, collaborating with the major American automotive companies, and filing numerous patents. Unfortunately, in 1934 the Great Depression forced the inventor to suspend his research because of the high production costs. Later, the advent of Second World War moved the inventor attention towards military applications where low noise and comfort were not a priority. The interesting story of this American inventor is described in the book "The unreasonable American" published in 1968 by the academy of Applied Science. The profiles of the toothed wheels described in the patents were conceptually very simple, essentially composed of circular and involute arcs and obtained with shaped tools (Pat.US.US2261143, US2206079). The degree of accuracy obtained once, was just sufficient for applications at low to medium speeds and pressures.

Now, after more than 90 years, Marzocchi Pompe intends to bring again this technology in high pressure and mobile applications. The development of tooth grinding technology makes possible the economical production of high precision toothed wheels.

Analyzing the pump features globally, this is the pump that is able to allow the best performance in terms of pulsation noise and performance Table 1, making it competitive also with respect to internal gear pumps.

Table 1: Pump features

Features:	EXTENAL GEAR PUMP	DUAL FLANK GEAR PUMP	HELICAL GEARS not conjugated PUMP	HELICAL GEARS Conjugated PUMP
NOISE	☺ (red)	☺ (red)	☺ ☺ (black)	☺ ☺ ☺ ☺ (green)
PULSATIONS	☺ (red)	☺ (red)	☺ ☺ (black)	☺ ☺ ☺ ☺ (green)
EFFICIENCY	☺ ☺ ☺ (blue)	☺ ☺ (black)	☺ ☺ (black)	☺ ☺ ☺ ☺ (green)
Contamination RESISTENCE	☺ ☺ ☺ (blue)	☺ ☺ (black)	☺ ☺ (black)	☺ ☺ (black)
SIMPLICITY constructive	☺ ☺ ☺ ☺ (green)	☺ ☺ (black)	☺ ☺ ☺ (blue)	☺ ☺ (black)
COST	☺ ☺ ☺ ☺ (green)	☺ ☺ ☺ (blue)	☺ ☺ ☺ (blue)	☺ ☺ (black)

3 The Elika Pump

It is well known that the major source of noise of a gear pump is due to pressure pulsations and that the main source of this phenomenon is the area in which the gears mesh. Here the pressure pulsations originate from the encapsulated oil between the teeth of the pump's gears. In that small vein, symbolized by the red zone in Figure 1, the oil gets trapped, compressed and then makes noise at every engagement of the gear. Elika Pump was conceived and designed to be a low noise and low pulsation pump.

The heart of the Elika Pump is the particular patented shape of the tooth profile without encapsulation, which reduces considerably the pressure oscillations and vibrations produced by the pump, producing many advantages on the final application (Pat. EP2352921).

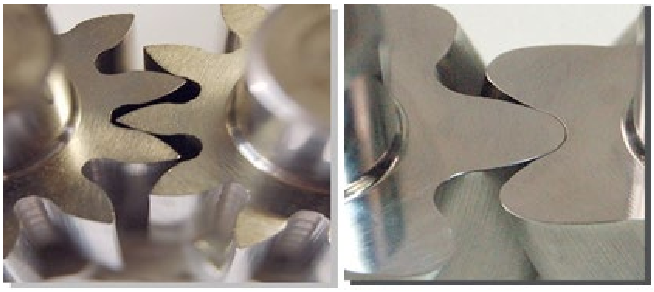


Figure 6: Left - traditional tooth profile (conventional external gear pump); right - Elika tooth profile (helical shape) with not trapping zone.

As can be seen from Figure 6, there is no space for the oil to get trapped between the teeth of the gear as the helically shaped teeth are completely matching each other. This helps to get rid of much of the hydro-mechanical noise coming from that encapsulation. The helical gear also has a lower number of teeth. The helical toothing ensures the continuity of motion despite the low number of teeth. The low number of teeth greatly reduces the fundamental frequencies of the pump noise and makes the sound particularly pleasant.

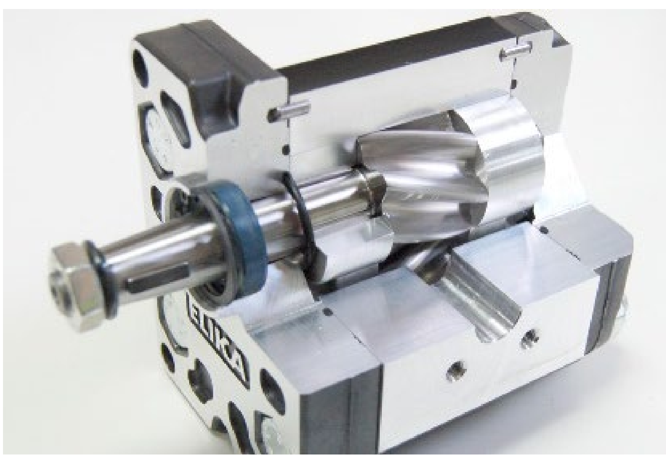


Figure 7: Elika Pump sectioned.

Elika is Marzocchi Pompe's response for all those applications that require low noise levels. It was designed to be completely interchangeable with a conventional Gear Pump. This pump reduces the noise emission up to 15 dBA compared to a conventional external gear pump. The maximum operating pressures are similar to those of the series Marzocchi GHP Series Pump (Cast-Iron Flange and cover Pumps) and reach up to 300 bar. From the outside Elika looks very similar to a standard Gear Pump. The difference is inside, Figure 7.

To ensure the correct continuity of motion with this special tooth profile without encapsulation, it was necessary to generate a helical toothing. Each pump has a gear with a right helix and another with left helix. The use of helical gears generates axial forces of magnitude proportional to the working pressure, which must always be balanced. The resulting of axial force is due to two different type of components: transmission components, due to the transmission of motion between the driving gear and the driven gear, that are opposite; pressure components due to the axial reaction of the pressure on the surface of the gear wheels on in the pump outlet area, that are in the same direction. The resultant forces of the axial thrusts induced by helical teeth are always hydraulically balanced in an optimal way, in every operating condition, by the axial compensation system integrated in the pump cover, Figure 8. The problem of axial thrust generated in pumps with helical gears was already studied in 1972 by Yasuo Kita (US3658452).

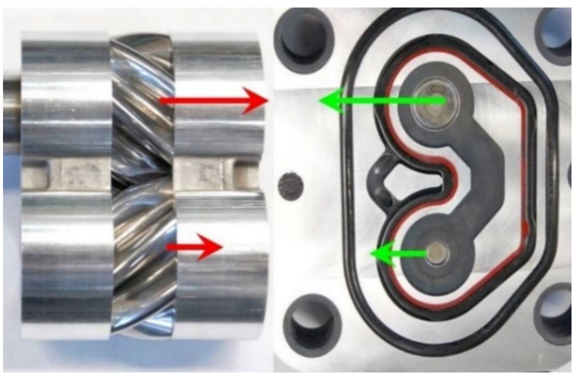


Figure 8: Hydraulic compensation system.

On the driving shaft, the components of the axial and hydraulic forces are concordant, on the driven shaft instead they are discordant, consequently the resulting forces are different, but both are directed towards the cover (red arrows).

The components are hydraulically balanced through compensating cylinders (green arrows).

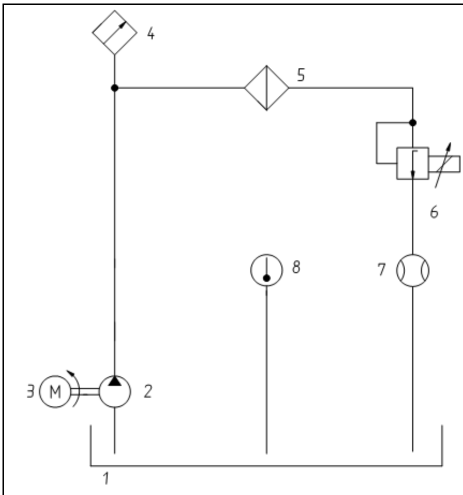
Today the Elika pump is available in 5 groups: Elika1P, ElikaK1P, Elika2, Elika3, Elika4. These groups range from 2.1 cm^3/rev all the way to 200 cm^3/rev. Elika is also available as multiple stack pumps. Elika's versatility and low-noise, low-ripple and high efficiency characteristics project this pump into many different end applications. Powerpacks and mini powerpacks, material handling machines, automotive, agricultural machines, municipality etc. In addition to the particular low-noise, there are other characteristics of this pump to be discovered. Due to the peculiar design, Elika pumps are capable of maintaining high overall efficiency over a high range of speeds. The high range on speeds translate into a high range of flows. The pump Type ELI1P-D-3.7-G (displacement 3.72 cm^3/rev), tested in Marzocchi R&D lab, allowed to deliver flow from 1 l/min to 20 l/min using the same displacement and maintaining high volumetric efficiency (>90 %) throughout.

4 Developing a new application

This feature, coupled with the ever-increasing diffusion of VFD brushless motors, leads to the possibility of obtaining a variable flow from a fixed displacement pump. This pump is particularly suited for electric vehicles (thanks to its high overall efficiency) where energy saving is a main driver. In these applications, it is required that even in the phases in which the vehicles operate only in electric mode, the hydraulic applications such as the steering that must remain in operation, must not be audible. This feature is particularly important in public transport to ensure maximum interior comfort.

Its features make this product very useful against variable displacement pumps. Marzocchi Pompe R&D Department has tested the following Elika Pump and Brushless Motor (Figure 9 Description of test circuit, Figure 10 Pump on test).

Marzocchi started testing the pump and then the pump and motor together. Starting from 250 rpm, the pump maintains a volumetric efficiency of more than 90 %. The Figure 11 graph shows that the pump could go all the way up to 5,000 rpm and achieve very high efficiency. The conclusion is that Elika's volumetric efficiency is almost independent of pressure.



1-Oil Tank, 80 l ISO VG 46
2-Elika ELI1P-D-3.7-G Pump; displacement 3.72 cm^3/rev
3-BLDC Motor; 4 kW max. power; voltage 24V DC; Max current 160A; Max speed 5000 rpm.
4-Pressure transducer Druck PTX 611 (max 400 bar)
5-High pressure filter 12 µm
6- Proportional valve Vickers KACG 3 L350D (max 350 bar)
7- Flowmeter VSE type VS 04 (max 40 l/min)
8-Thermocouple PT100

Figure 9: Test circuit.

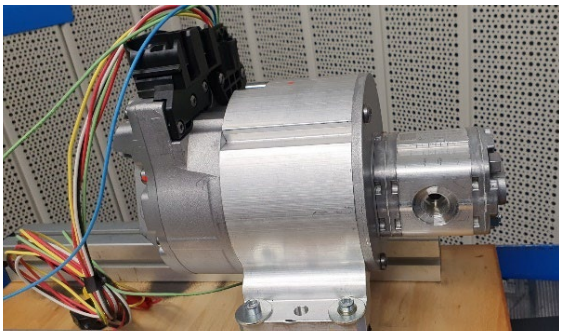


Figure 10: Motor – Pump on test.

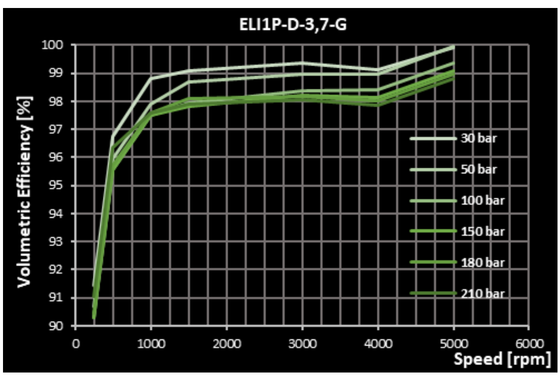


Figure 11: ELI1P volumetric efficiency vs. speed.

Starting from 50 bar, the pump maintains mechanical efficiency in excess of 80 %. At higher pressures, the mechanical efficiency is almost independent of speed (Figure 12).

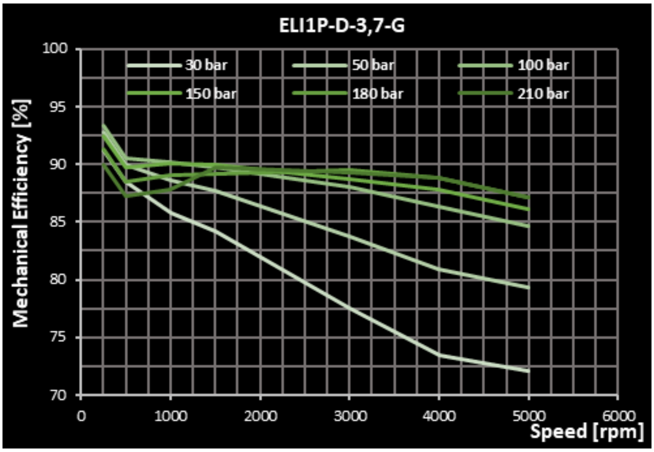


Figure 12: ELI1P mechanical efficiency vs. speed.

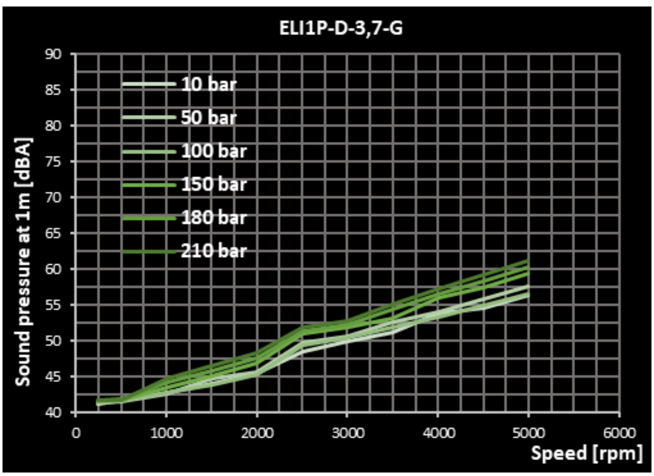


Figure 13: Elika ELI1P-D-3.7 pump sound pressure in dBA vs. speed.

The following two charts (Figure13 and Figure 14) show the noise comparison data between the Elika Pump and its corresponding, same displacement, Standard Gear Marzocchi Pump that has straight teeth and comes from the 1P Family of pumps (Figures 13 to 15). The noise tests were performed in a soundproofed chamber, with a background noise lower than 32 dBA, according to ISO 4412 standards, with a integrating sound level meter Type Delta Ohm HD 2110 L.

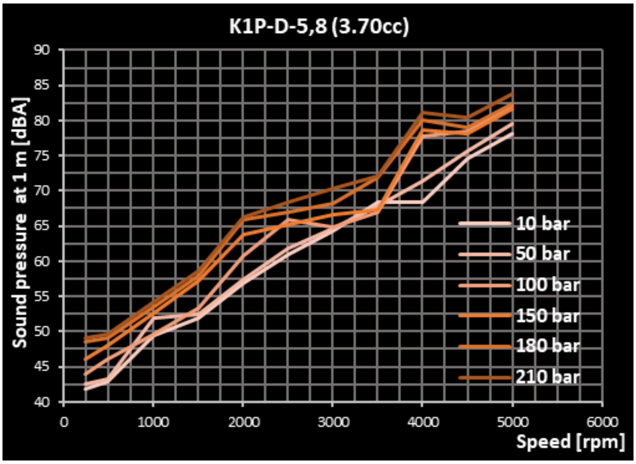


Figure 14: Standard straight teeth gear pump K1P-D-5.8 sound pressure in dBA vs. rpm.

At 5,000 rpm and at the highest pressure Elika Pump hardly reaches 62.5 dBA, on the other side the conventional Pump, K1P, reaches the mentioned peak at 2,000 rpm and 150 bar. Elika low-noise advantage on conventional straight gears pumps is even more evident in the following graphic showing their average data comparison.

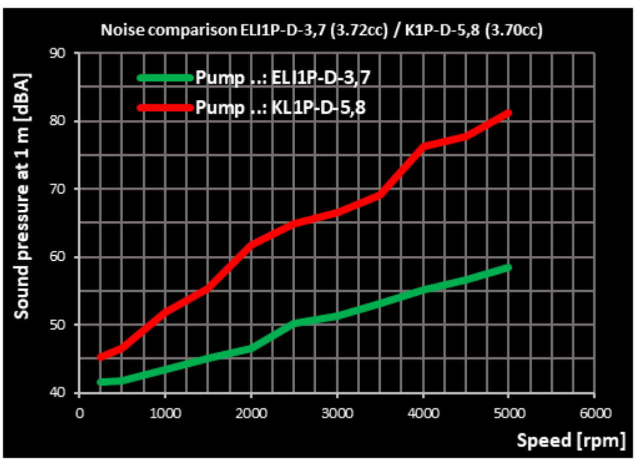


Figure 15: Average noise comparison between ELI1P (green) and K1P (red).

Elika is not only quieter but also the noise increases less steep. One particular aspect of the noise of this pump is its frequency. Looking at the graph in Figure 16 the Elika Pump in green shows the frequency spectrum shifted toward the lower frequencies. The lower frequency spectrum means that the noise is more pleasant. Standard gear pump has a pitch on high frequency which is, on the other hand, particularly unpleasant.

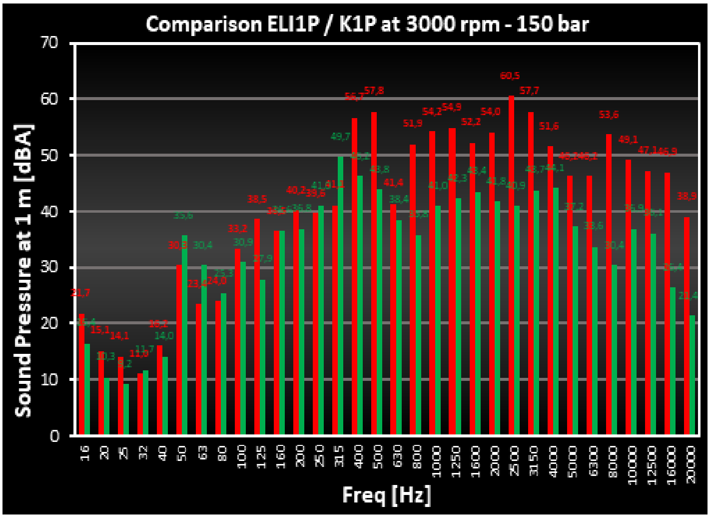


Figure 16: Noise spectrum comparison ELI1P (green) / K1P (red) at 3000 rpm and 150 bar.

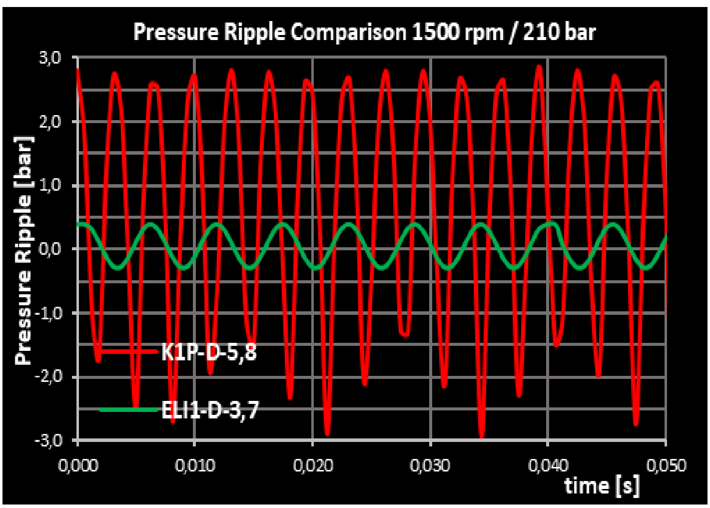


Figure 17: Pressure ripple comparison ELI1P (green) / K1P (red) at 1,500 rpm / 210 bar.

Looking at the chart in Figure 17, the Elika Pump has lower amplitude of the pressure ripple but also a lower frequency.

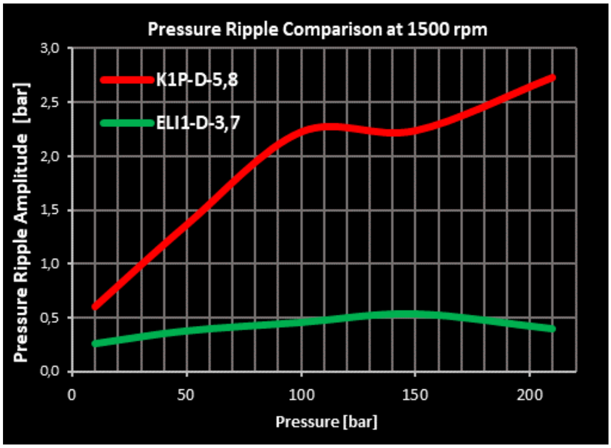


Figure 18: Comparison ELI1P (green) / K1P (red), pressure ripple comparison at 1,500 rpm.

The green line in Figure 18 shows us the summary of all the testing on the Elika range of pressures. The ripple, as the pressure increases, becomes a lot different between the two pumps showing its great distance from the standard pump and its red line. The Elika Pump is consistently lower than 0.5 bar.

5 Pump and motor combination

The chart on Figure 19 shows the relation between flow and current of the motor-pump combination at different pressures. It is clear how the relation is close to linear.

Figure 20 shows the combined Overall efficiency ηovr of the motor + pump calculated as:

$$\eta_{ovr} = \frac{\text{Hydraulic Power}}{\text{Electrical power}} \tag{1}$$

By looking at the graph in Figure 20, the efficiencies stay in the range of 60 % to 70 %.

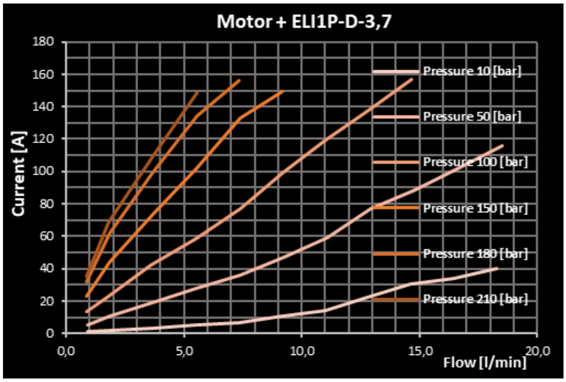


Figure 19: Relation between flow and current of the motor-pump.

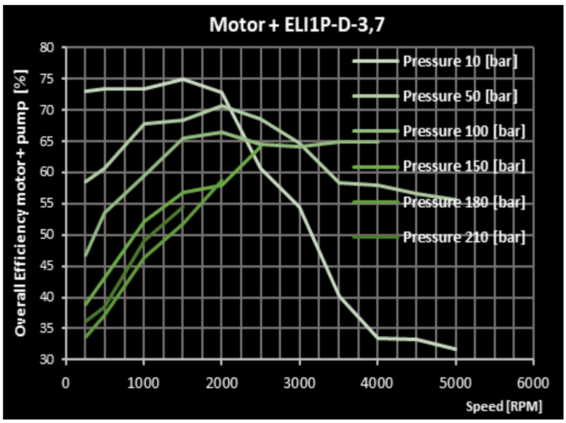


Figure 20: Overall motor-pump efficiency.

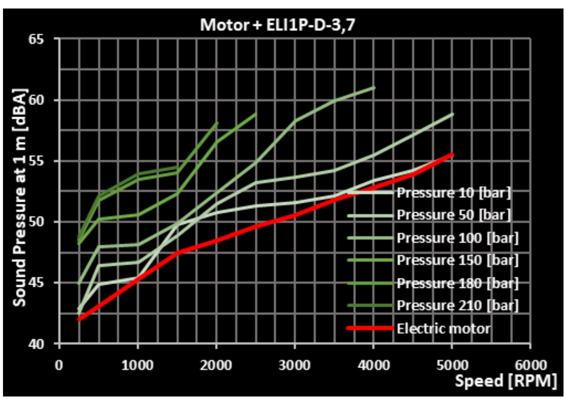


Figure 21: Motor-pump combined noise.

Figure 21 shows in green the overall sound pressure of the motor + pump combination. Red line shows the motor alone. It's clear that the pump adds just a small amount of noise over the motor which is already very silent. All the way to 150 bars the pump just adds 3 dBA to 5 dBA. The whole combination, pump plus motor, always stays below 60 dBA which is a very good target.

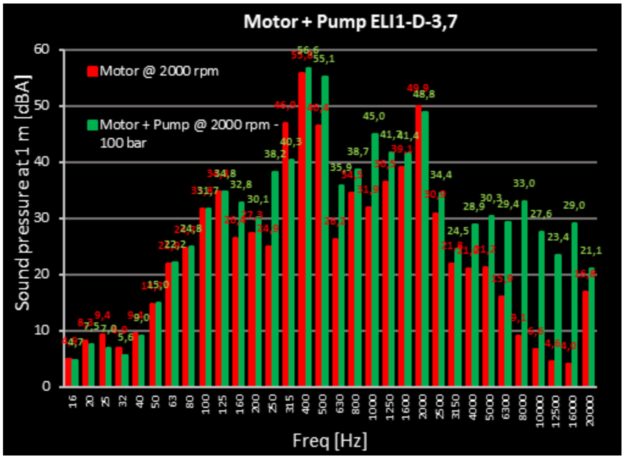


Figure 22: Frequency spectrum comparison with motor only (red) vs. motor+pump (green) at 2000 rpm, 100 bar.

6 Benefit of a VFD pump drive

Electrification and hybridization have dramatically reduced engine noise from industrial vehicles, making hydraulic circuit noise predominant. This feature, coupled with the ever-increasing diffusion of VFD brushless motors, leads to the possibility of obtaining a variable flow from a fixed displacement pump. In these applications, it is required that even in the phases in which the vehicles operate only in electric mode, the hydraulic applications such as the steering that must remain in operation, must not be audible. This feature is particularly important in public transport to ensure maximum interior comfort.

Elika pumps are particularly suited for electric vehicles (thanks to its high overall efficiency) where energy saving is a main driver. Its features make this product very useful against variable displacement pumps. The Elika gear pump has been co-developed with the Faculty of Engineering at the University of Bologna, using helical gear technology (Pat. EP2352921).

This technology delivers low noise with high efficiency across a high range of speeds and is particularly efficient when coupled with VFD brushless motors. Recent tests at the Marzocchi R&D lab demonstrated flow from 1 l/min to 20 l/min using the same displacement and maintaining high volumetric efficiency (>90 %) throughout. This presentation demonstrates how recently discovered additional benefits of helical gear technology can increase efficiency and reduce cost when deployed in electrified powertrains.

Major benefits both for the final user and the system of a Variable flow with fixed displacement helical pump Elika Drive are:

- Possibility to obtain high flow variation using variable speed.
- Less expensive than variable displacement pump solution.
- Higher efficiency reduces energy consumption (smaller pump displacement).
- Higher efficiency reduces oil heating (smaller reservoirs and coolers).
- Low noise thanks to the inherent design of Elika (-15 dBA on average).

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