An innovative external gear pump for low noise applications

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Abstract

The reduction of noise in stationary and mobile applications is becoming more and more important. In this paper a new type of an external gear pump is presented. In order to understand the design features of the pump, first an overview of the relevant sources of noise in an external gear pump is given. Subsequent to that different ways to reduce the noise are shown and finally combined to achieve the new SILENCE PLUS pump. Afterwards results of the new pump are presented, before the paper concludes with an outline which applications will benefit from the new type of pump.

KEYWORDS: external gear pump, low noise

1 Introduction

With increasing industrialization and automation also the generated noise increased. According to calculations by the German Federal Environmental Agency (Umweltbundesamt) about 16 percent of the population are exposed to noise levels exceeding 65 dB(A) during the day, solely due to road traffic - other noise pollution is added. According to the latest findings a permanent strain exceeding this value is an increased risk for cardiovascular disease. Therefore EU directives as well as the Occupational Safety and Health Administration (OSHA) set noise limits. Nevertheless, there is need to draw action, because noise interferes and causes illness burden - and increasingly so.

Therefore it is not surprising, that noise reduction has gained more and more focus in stationary as well as mobile hydraulic applications. The primary source of noise in a hydraulic system is the inherent noise of the pump(s) which depends on pressure and the speed of rotation. Valves with their switching surges induce aperiodic noise as well, but these are not dominant in the overall noise level. Therefore the main starting point in order to reduce the noise should be the permanent noise emission of the pumps.

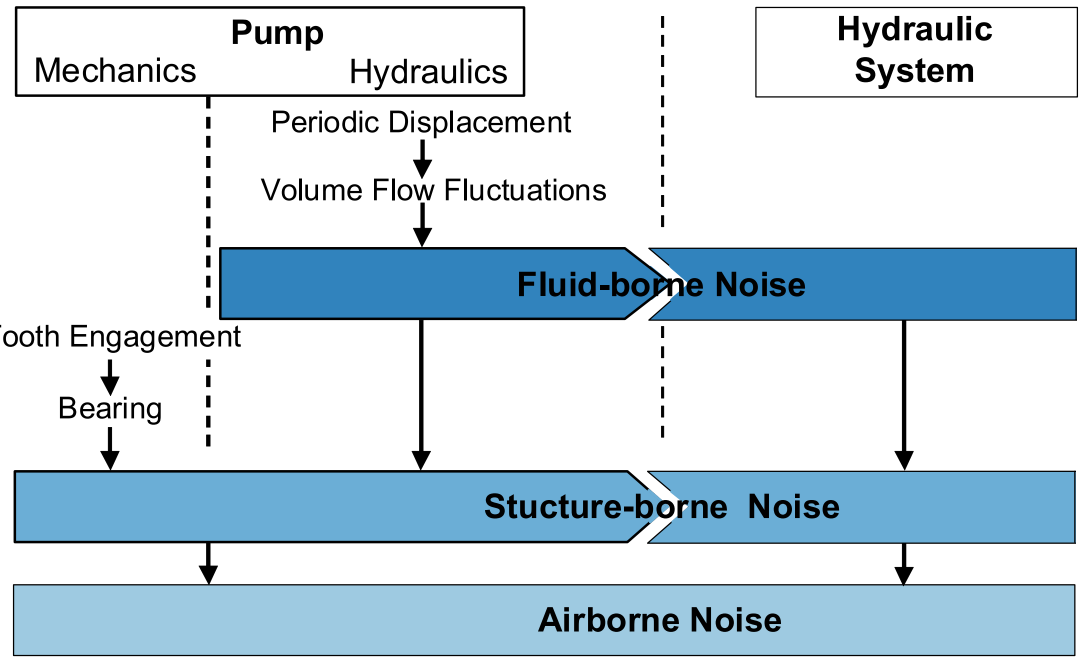

Figure 1: Vibration mechanisms and transmission of noise in hydraulic systems

Formerly this noise has lead to secondary measures like acoustic decoupling, insulation or encapsulation. A more direct way is to undertake primary measures, i.e. the design of quiet pumps.

External gear pumps are the workhorses in hydraulic systems, as they have proved their usefulness for decades. While being rugged, efficient and competitively priced their primary features – pressures up to 280 bar and extremely high efficiency have come to be taken for granted. But their relatively high level of noise and the unpleasant pitch also became something of a given. This was the reason to rethink the design of an external gear pump right from the start.

2 Generation of noise has multiple causes

In order to reduce the noise emission, one has to stop the noise right at its place of generation. To solve this task one has to understand the main influencing factors. Therefore, in this section the different mechanisms leading to noise generation in an external gear pump are described. **Figure 1** shows the different mechanisms how noise is generated and transmitted in a hydraulic system.

By the subjective perception of a hydraulic system, it seems to emit many types of noises. Therefore the user speaks e.g. of whining pumps and engines or whistling of steering systems and valves. But often the noise emittance of vibrant and sound radiating structures such as attachable frames or the entire body of the vehicle, can not that clearly be linked to the hydraulics. In general one has to distinguish between liquid-borne sound, solid-borne sound and airborne sound. The human ear as a receiver, however, responds only to the airborne sound.

2.1 Intrinsic noise

In all positive displacement pumps there are processes which are periodically repeated. In an external gear pump these processes are caused by the rotating gears and, to be more specific, by the meshing of the gears. The engaging gears generate oscillating forces on the bearings which in turn transmit to the casing where they are emitted as airborne sound. These changing forces are predetermined by the design of the gears.

Another source for intrinsic noise are the periodic pulsations of the flow caused by the periodical change of the tooth chamber’s volume. These changes induce fluid-borne noise inside the pump in the first place, which is then converted to audible airborne sound directly on the vibrating outer wall of the casing.

2.2 Pressure pulsation

Additionally to the intrinsic noise mentioned in the previous section, the pressure pulsation of external gear pumps stimulates vibrations in all components in contact with the pulsating fluid. This structure-borne noise then emits audible airborne sound directly or stimulates other solid structures to noise vibrations, which in turn ultimately create airborne sound. Therefore the pressure pulsation should be regarded as a separate source for the noise emitted by the whole system, as even a completely encapsulated pump could lead to a noisy system in the end, if its pulsation is too high.

2.3 Sound characteristic

The third important aspect of noise is the frequency. This property influences both noise sources mentioned before. It acts on the airborne noise that arises directly from the sound of the pump body as "pitch". Lower frequencies lead to a more appealing sound of the pumps intrinsic noise in general. In addition, the frequency of the liquid sound (pulsation) stimulates resonance of other system components in a frequency-dependent way.

3 Design features

In the development process of a low noise pump the effects mentioned in the previous section where analysed and different approaches where considered. As mentioned above the goal was not to use secondary measures but to address the real cause of the radiated noise. So design and structure of the casing and flange assemblies and therefore the possibility of insulation and damping are not part of this paper. Instead the focus lies on the heart of an external gear pump – the gears.

3.1 Helical gearing

In a first step the decision was made to use a helical gearing, a design commonly found in transmission construction. This has considerable impact on the pump's intrinsic noise since, due to the angular design of the teeth, the contact between one gear and the other no longer changes in just a single moment from one pair of teeth to the following over the total width of the gear. Instead, this step is smoothed into a continuous process of constantly changing contacts at different times. In other words, these events are distributed both spatially and in time, making for quieter running of the gear set.

However, in a direct implementation of this principle in the external gear pump, the following has to be taken into account: Maintaining the involute toothing may increase the flow pulsation depending on the specific choice of the helix angle. Additionally for any type of helical gearing the inherent additional axial forces come into play, which have to be considered in the bearings.

Figure 2 shows the noise level at different speeds of a gear pump with helical teeth, compared to a pump with straight spur gears. In the entire operating range a clear advantage for the helical teeth can be seen. The pulsation of the pump is shown in Figure 2 as well. Because of the small helical angles used no deterioration can be recognized.

The shown noise reductions due to the helical gears are only achieved by mechanical means and reduce the intrinsic noise of the pump. The hydraulic parts of the noise generation are not affected, so the impact on the entire hydraulic system is rather low. (An explanation why, will be given in section 4.1)

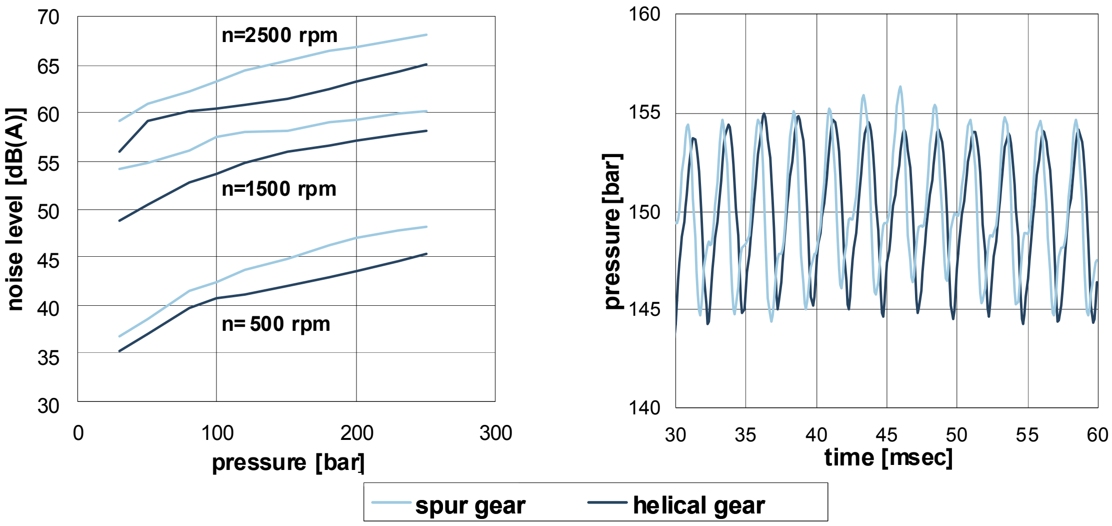

Figure 2: Comparison of an external gear pump with spur and helical gears, Left: noise level, Right: Pressure pulsation.

3.2 Double-flank contact

The gears in conventional external gear pumps make contact during rotation – and thus form a seal – only at the leading flanks. Therefore, in the last decade external gear pumps with double-flank contact have entered the market. These pumps exhibit very close tolerances for shaft spacing and the tooth profiles. The result is zero clearance between the two engaging flanks. The benefit is that the rear flank is also involved in sealing and contributes to moving the fluid. Thus flow is significantly more uniform and pulsation is reduced by about 75 percent. Less vibration and noise are induced in the hydraulic system as a whole.

3.3 Eliminating the trapped oil cavity

In external gear pumps using conventional toothing there is continuous alternation between one and two points of contact. Achieving uniform rotation necessitates to maintain contact – for a certain period of time – between the previous pair of teeth while the next pair is engaging. But in the absence of other engineering measures closed, fluid-filled spaces, the “trapped oil cavities”, will form between these points of contact on both, the intake and the discharge sides. The changing volume of this space leads to rapid and severe rises in pressure. These, in turn, can induce vibration. Flow noises can also be generated when this cavity opens toward the low-pressure side releasing its pressurized fluid. A gearing that excludes these trapped oil cavities inherently, allows therefore, a significant reduction of the intrinsic noise of a pump.

3.4 Non-involute gears

Despite their common use, involute teeth are not the only possible type of gearing in positive displacement pumps. The gerotor pumps, for example often use trochoidal shaped teeth. But there is another type of toothing which is completely different and has quite interesting properties: It is the kind of teeth used in screw pumps and lobe pumps.

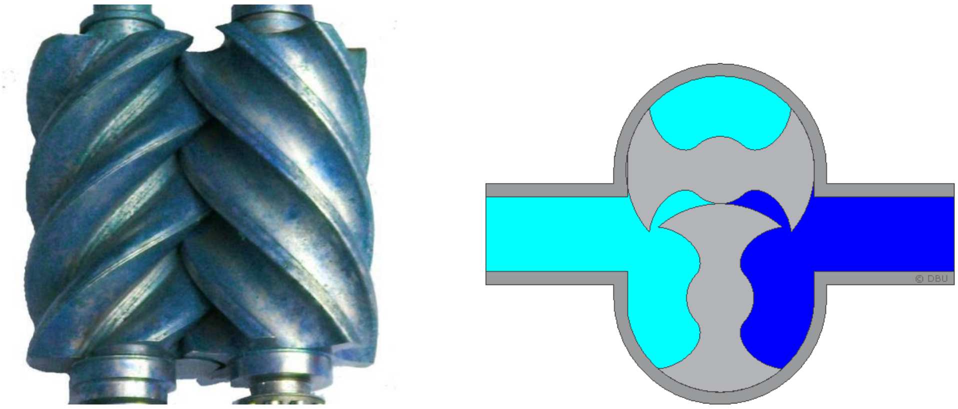

Figure 3: Sketches of gears of screw pump /9/ (left) and lobe pump /10/ (right).

These gears have non-involute gears which mesh in a continuous one point contact. Therefore, for example the rotors in screw pumps displace the fluid in axial direction in the way, that each tooth of one gear completely fills the tooth chamber of the accompanying gear. Thus the displacement volume is bounded by the thread roots, the thread flanks, and the pump casing. As the screws rotate, the entrapped fluid slides driven by the turns of the spiral towards the axial discharge space, while the next slug is being entrapped. Screw pumps exhibit nearly no pulsation. But due to the helical angle of the gears and the pressure gradient developing in axial direction the screw pumps are subject to great axial forces. Also the long sealing line between gears and casing of the pumps prevents high pressures, in general. As a third disadvantage two-screw pumps are normally equipped with a set of timing gears, as one gear cannot drive the other one directly.

Roots compressors on the other hand are a special kind of lobe pump. As they only possess two wings, in general no one would call them gear pumps, but in a way they are. Why they are of interest in the course of this paper is the way the sealing between the two gears is maintained. Like the screw pumps mentioned before the surfaces of the two gears are in contact not only at the flanks of the teeth but also at the top and bottom. Thus there is no abrupt transfer of contact pressure from one flank to the next. Instead there is always just a single contact point which moves continuously along a closed-loop engagement pattern in the form of a figure 8.

This kind of pump is also free of trapped oil cavities, still - depending on the pumps layout - show a great deal of pulsation. The two other properties which prevent this type of gears to be used in external gear pumps are: First, that the two gears have to be driven by timing gears, i.e. there is no direct transmission of momentum from one gear to the other. And second, due to a high backlash they can only be used at low pressures.

4 The combination of the different features

In the previous sections, different measures to reduce the mechanical and hydraulic vibrations where presented. The combination of different approaches lends itself quite well in order to fully optimize the product properties. Examples would be: “involute helical gears free of backlash” or “spur gears with optimized trapped oil cavities free of backlash”.

4.1 The gears

Conventional external gear pumps with involute teeth basically have a flow pulsation. This pulsation is caused by a non-constant change in volume of the displacement (tooth chamber) during the meshing of the gears.

In order to achieve a smoothing of the pulsation characteristics it seems quite obvious to displace two delivery cycles by a phase shift of half the transverse pitch angle and thus superimpose them. This idea has led to the development of the DUO pump with to gear sets. If one thinks out this idea, it seems straight forward to construct a pump with helical gears. Superimposing more and more periodic pulsations should yield a continuous flow in the end. However, two properties of the involute gearing prevent, that this approach leads to the desired success:

First, because of the involute teeth there is always a changing of one or two pair of teeth being in contact. In order to maintain hydraulic sealing one of these points has to define the sealing point. But at some moment the sealing point has to switch from the leading to the following pair of teeth in contact. This change leads to a discontinuity of the delivery volumes as the leading tooth chamber does no longer participate in the delivery process at the moment when it passes the end of the high pressure side’s pressure groove. Secondly, in the axial direction at some plane already an enlargement of the chamber’s volume occurs while other parts of the tooth chamber still shrink.

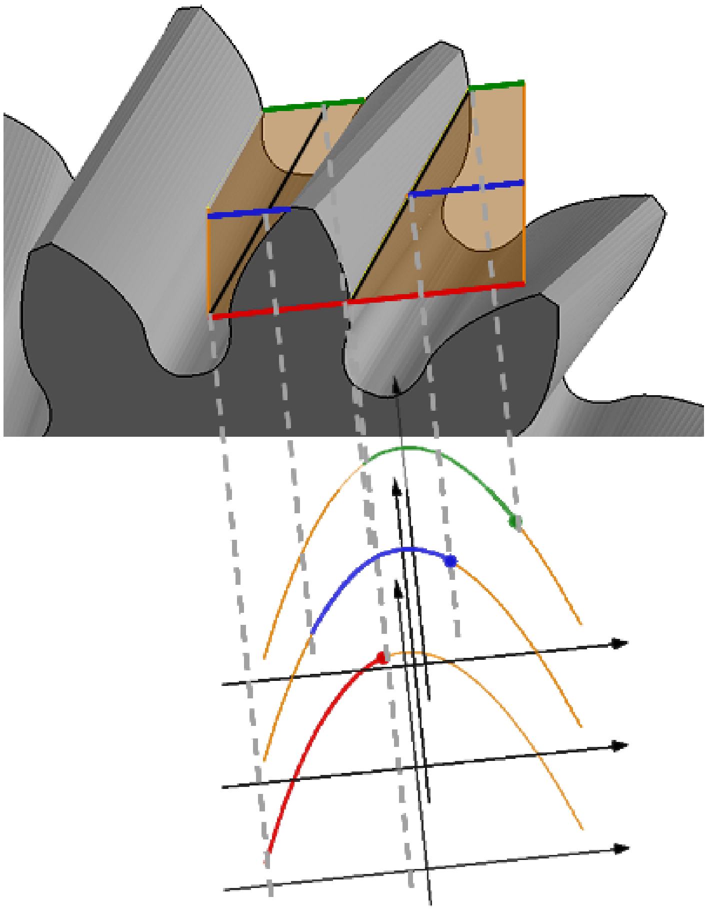

Figure 4: Sections of a helical gear and related parts of the delivery parabola

This is illustrated in **Figure 4**. The depicted slice of the tooth chamber at the front side of the gear is still displacing fluid. The slices in the middle and at the end of the tooth have already started to decrease the amount of fluid displaced. If the slice at the end of the gear now comes out of contact, i.e. the sealing ends and the chamber opens to the suction side, the whole delivery process has to stop, as otherwise there would be a hydraulic short-circuiting. This is displayed in **Figure 5**, where the left side shows the different parts of the parabola used by the different slices. The right side shows the resulting flow generated over time.

By using a helical gearing the phase shifted superposition of periodic processes works only for the mechanical excitations of vibrations. In the delivery process, in contrast, not the same but different sections of the delivery parabola are added. Therefore, the pulsation stays the same. In summary, helical gears can be beneficial when mechanical excitations are the problem, e.g. in the low-pressure and low speed regime.

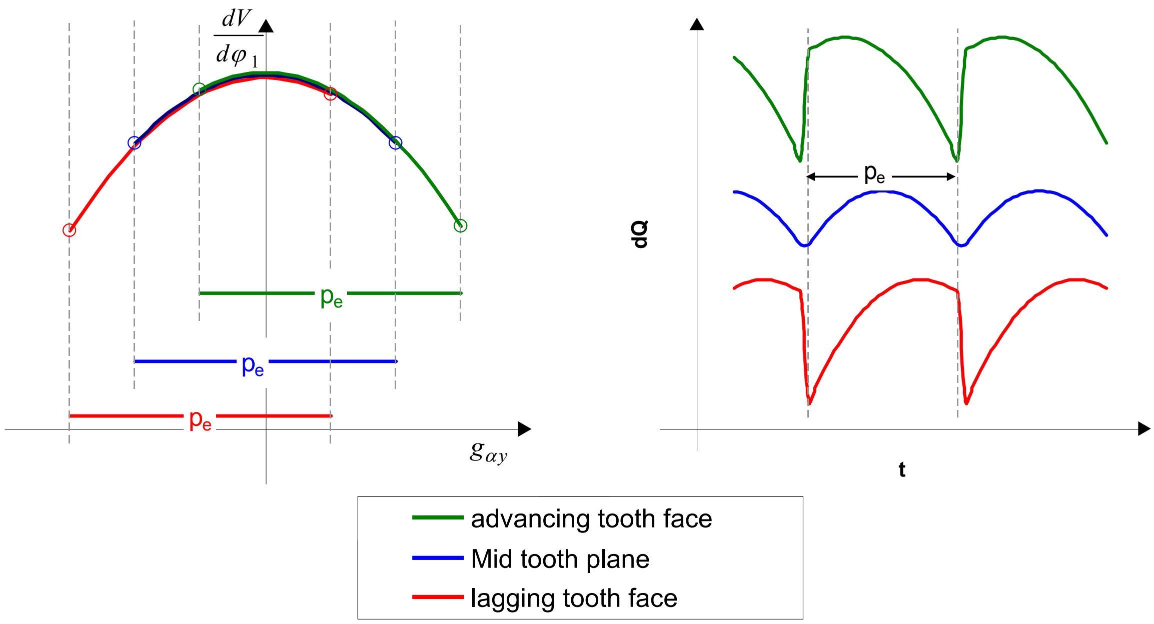

Figure 5: Sketch of the pulsation mechanism a) spatially and b) in time

To overcome this dilemma, the present approach uses a helical gear with a continuous line of action. In section 3.4 two types of gears using this principle where shown but also their disadvantages where mentioned. The presented gears expand the idea of a roots compressor in increasing its number of teeth.

Due to the eight-shaped form of the contact line also parts of the trailing flank contribute to the sealing line. As these parts can not transmit torque a helical gear is mandatory. By the use of a helical gearing no longer timing gears are necessary. With this type of tooth shape and its continuous line of contact, the volume of a chamber is completely displaced to the pressure side and then while opening to the suction side the tooth chamber is re-filled. However, unlike a helical involute gearing due to the continuous line of action at any time, a hydraulic sealing between shrinking and expanding parts of the tooth chamber exists. The tooth shape as well as the sealing line is shown in **Figure 6**. This process looks quite the same as in a conventional screw pump, but in contrast the delivery works in radial and not in axial direction of the pump. As a side effect, no compensation grooves are needed in the bushings to prevent trapped oil, as there are no trapped-oil-cavities because of the fully emptying of the tooth chambers.

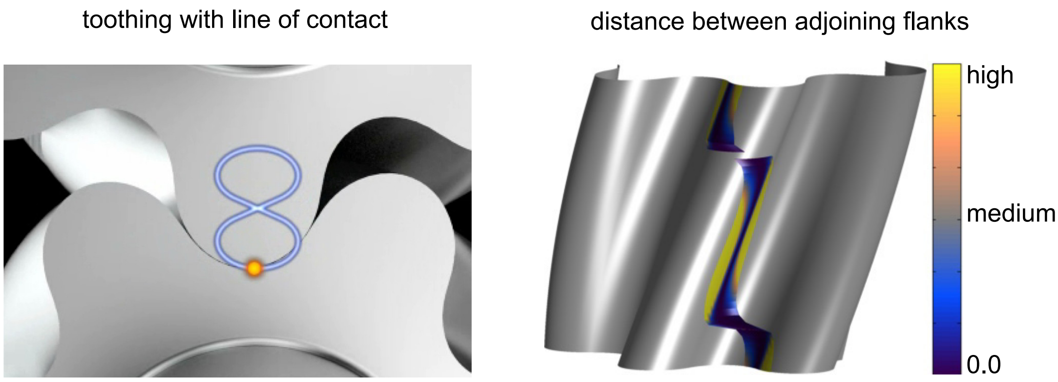

Figure 6: Left: Toothing with line of contact Right: Distance of tooth flanks

4.2 The axial force compensation

Due to the helical toothing axial forces impinge on the gears which act according to the skew and direction towards the front or end caps. These axial forces must be compensated in order to avoid increased wear at the front face of the gears and the bushing. As solution for compensation of these axial forces hydrostatic grooves are proposed. These grooves generate the compensating forces at the same place where the axial force develops its damaging effect; between the faces of the gears and the bushings located in the direction of force (see **Figure 7**). Because of the hydrostatic nature of the compensating force this takes place without wear.

The groove is manufactured into the bushes in a way that it communicates with the high pressure side. The size of the groove is designed so that the generated force equals the expected axial force.

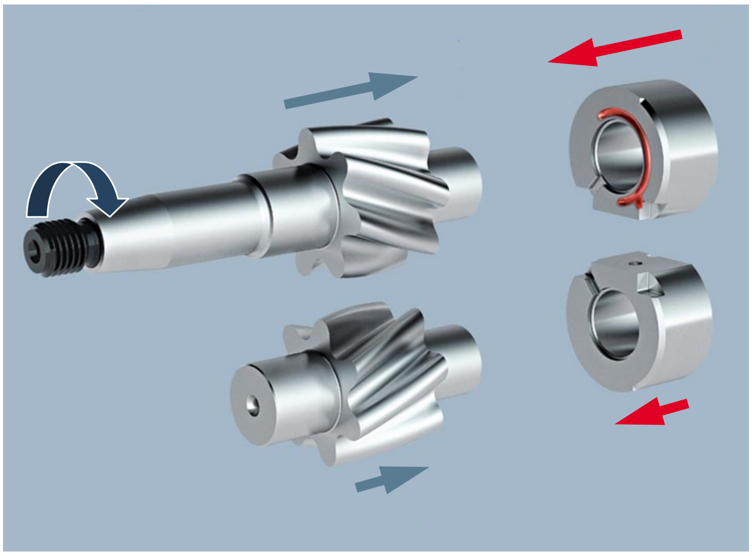

Figure 7: Direction of forces acting on the gears, compensation grooves

5 The results

In this section results of the new gear pump are shown. As the goal of the new pump was to address all three different sources of noise, intrinsic noise, pressure pulsation and the frequency, in this section we will also address this three topics.

5.1 Noise level

Extensive test series conducted by Rexroth in the noise measurement cell, show that the inherent noise of the SILENCE PLUS compared to conventional external gear pumps are lower by an average of 15 dB(A). The noise reduction is effective in the whole pressure and speed range.

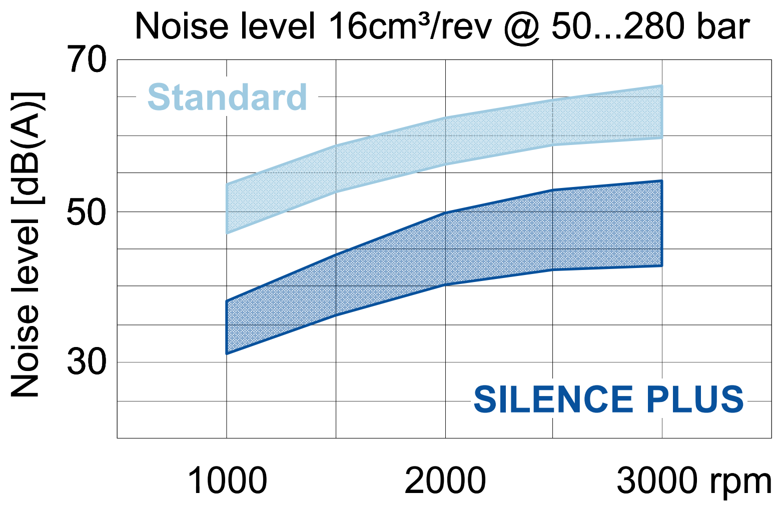

Figure 8: Noise level of a conventional gear pump and a SILENCE PLUS

Now, from a practitioner's point of view one could argue: measurements of components in the acoustic measurement cell are one thing, the effect on the system as a whole might be a different story. The effect of a SILENCE PLUS pump on hydraulic power packs was investigated. As an example: The sound of a simple power pack was first measured without the pump at 52 dB(A). Subsequently, a SILENCE PLUS was assembled and the noise of the unit with a circulating pump pressure of 10 bar was measured. The noise of the unit increased from 52 to 55 dB(A). The system's noise emission therefore only increased by 3 dB(A). This means that even with the hydraulic pump assembled almost only the sound of the electric motor could be heard.

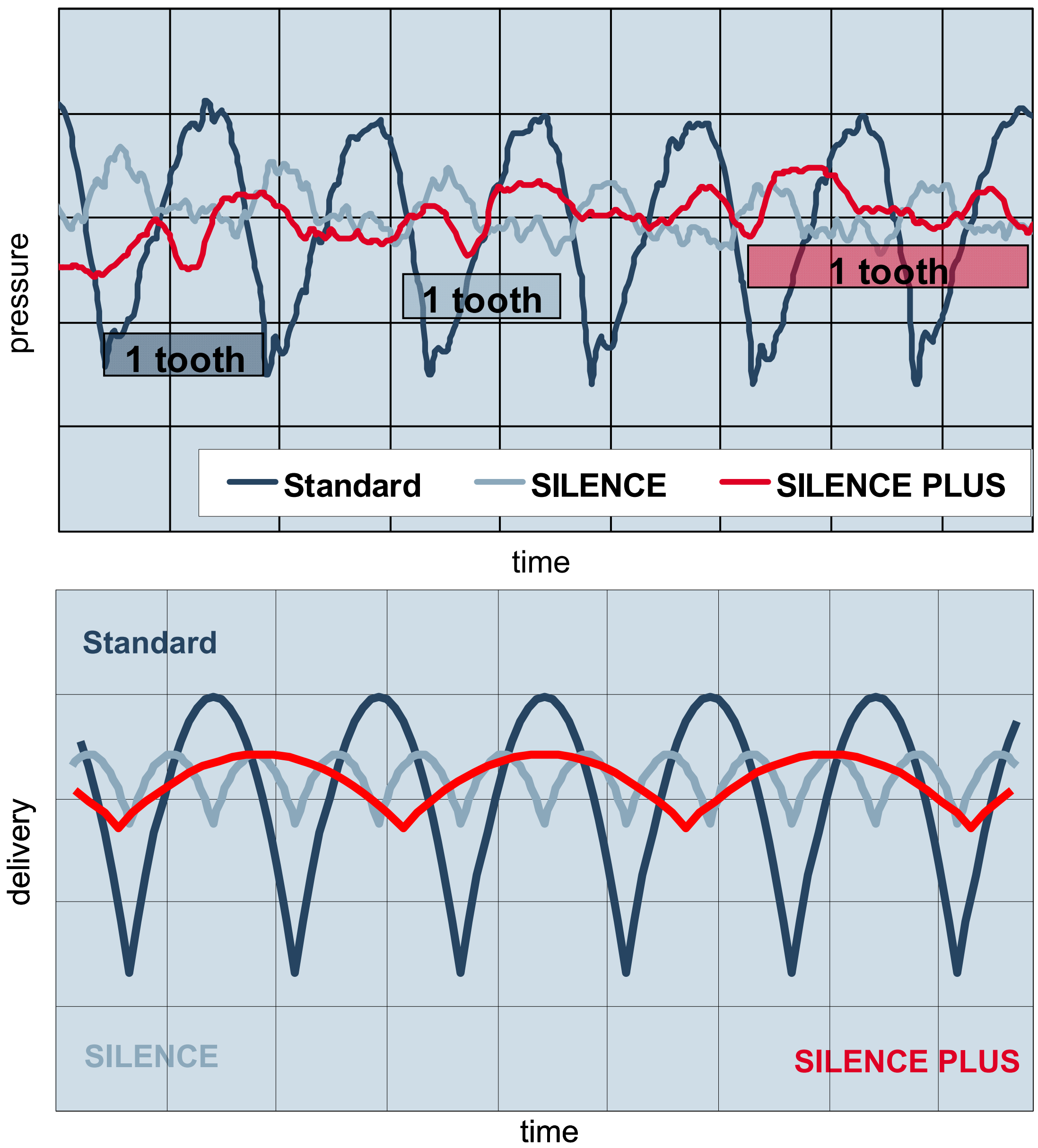

Figure 9: Top: Measured pressure signals in an anechoic setup
Bottom: Sketch of the predicted delivery behaviour

5.2 Pressure pulsation

As described in section 2.2 the pressure pulsation plays an important role for the hydraulic stimulation of the connected components. The SILENCE PLUS pump reduces the pressure pulsation by 75% and therefore effectively reduces airborne sound emitted by the system. This can be seen in the measurements of **Figure 9**. The measurements shown in Figure 9 were taken in an anechoic measurement setup and show quite a good agreement with the expected results shown on the bottom part of the figure.

5.3 Frequency

The frequency range of the intrinsic noise of the pump is lowered by 35% due to the low number of teeth. This can be seen in Figure 9 (top) and is also sketched in Figure 9 (bottom). The lower frequency is perceived by the human ear as more pleasant than the pitch of a standard external gear machine. With the new pump design the sound characteristic changes in a much less-intrusive "hum". As an additional effect the lower frequency has a positive impact on the pulsation too, e.g. in hydraulic steering.

6 Applications

The low intrinsic noise, low pulsation and the pleasant tone of the SILENCE PLUS make it suitable for multiple applications. Especially applications where the noise generated by the hydraulic system is dominant benefit from the use of low noise pumps as well as those used in noise sensitive environments (e.g. in residential areas).

The noise reduction is especially effective when the hydraulic pump is used in connection with an electric motor. In that case the hydraulic noise is usually dominant since the electric motor is much quieter than a combustion engine. Moreover, the frequency ranges of noise generated by the pump and the electric motor are similar, so that the noise adds up and by minimizing the pump's noise, a significant reduction of the overall noise is achieved. This can be beneficial to users of, for instance, turning-, milling and grinding machines or sawing machine tools.

The impact of the new technology is particularly positive in the field of mobile conveyor systems, for example in electric fork lifts, electric pallet trucks or truck-mounted forklifts. All applications of small mobile power packs such as lift gates of feeder trucks become significantly quieter.

Since the intrinsic noise of the pump is nearly inaudible at low pressures, the pump is predestined for use in all kinds of lubrication, filtering and cooling circuits. But even when used for lubricating transmissions in vehicles, the pumps noise reduction unfolds its full effect.

Pumps powered by electric motors, with virtually no hydraulic noise, are predestined for use not only in manufacturing plants and warehouses but also in supermarkets and beverage shops. Domestic applications such as passenger lifts, parking lifts and log splitters profit from the development. Trash presses behind supermarkets and hotels can be operated all day and it is acceptable for forklifts to load and unload even at night.

In the case of diesel-powered drives it is the internal combustion engine itself that creates most of the noise. At first glance, attenuating hydraulic noise would seem to make little sense. But the pump, too, produces a considerable amount of noise. Since this noise is in a higher frequency range it can be heard above the blend of lower-frequency sounds. The pitch of the intrinsic noise of the SILENCE PLUS, owing to the smaller number of teeth, is 35 percent lower. The human ear senses this as a significantly less intrusive, far more tolerable “hum”. Neighbours previously annoyed by noise from construction sites or garbage trucks in the early morning hours profit from such advances. The sanitation crew and the driver also appreciate the far lower noise level.

Direct airborne sound resulting from the pump’s intrinsic noise can be of some relevance for diesel-powered machinery. The blower drive on agricultural seeders, for example, represents a noise load for the operator and one that can be mitigated with the use of the SILENCE PLUS.

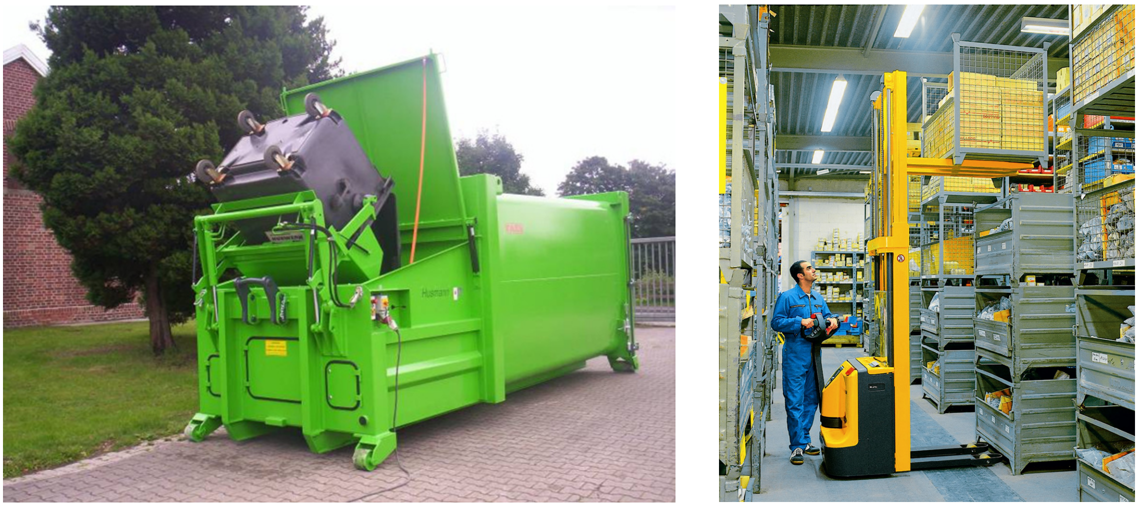

Figure 10: Examples of beneficial applications, Left: Self-pressing trash container, Right: Stacker

7 Summary

In this paper the need to develop low noise gear pumps was emphasized. The different sources for noise were outlined and the possible design features to tackle these causes for noise were described. It was shown how to combine the different features in order to achieve a new innovative type of external gear pump. Finally the results of the new pump were given in terms of noise level, pressure pulsation and reduced frequency. In the last section different applications for the new pump were pointed out ranging from pumps powered by electric motors in mobile forklifts to domestic applications such as passenger lifts. The future will show where else one could stop the hydraulic noise when using the right pump.

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