

CONSIDERATIONS REGARDING HYDRAULIC PUMPS WEAR AND MODERN MANUFACTURING AND REMANUFACTURING TECHNIQUES

Cătălin DUMITRESCU¹, Cătălin VIȚELARU², Liliana DUMITRESCU¹, Ștefan-Mihai ȘEFU¹,
Radu-Iulian RĂDOI¹, Adriana-Mariana BORȘ¹, Magdalena NEACȘU¹,
Stefano-Andrea MANTOVANI³

¹ National Institute of Research & Development for Optoelectronics – Subsidiary Hydraulics and Pneumatics Research Institute (INOE 2000 – IHP)

² National Institute of Research & Development for Optoelectronics INOE 2000

³ National Institute of Research & Development for Machines and Installations Designed to Agriculture and Food Industry – INMA

Abstract: *The wear of hydrostatic pumps negatively influences their operation and results in a decrease in volumetric efficiency, a reduction in service life and, ultimately, pump failure. The occurrence of the phenomenon of boundary or dry friction, at the contact between different component parts, extreme operating conditions, the lack of a lubricating film or fluid contamination increase pump wear. Currently, in order to improve the contact behaviour and increase the service life of a pump, new techniques and methods are used to treat the surfaces of the parts that intervene either in the manufacturing phase or in the maintenance phase.*

These techniques refer to the use of superior materials, the implementation of surface treatments (thin layer coatings), the use of machining processes (surface texturing) or 3D printing, and most of the time they are combined with each other to reduce the effect of wear.

Keywords: *Wear, hydrostatic pumps, metal coatings, thin layers*

1. General considerations regarding hydraulic pumps

Hydraulic pumps convert the mechanical energy generated by the drive motor into hydraulic energy. The transmission of energy from the motor to the pump is usually carried out through a flexible coupling that compensates for misalignment; in some cases, to make the drive speeds of the two components compatible, a gear or reduction unit must be interposed, especially in the case of endothermic engines. With a few exceptions, the standard rotational speeds for three-phase electric motors are compatible with direct connection to the pump; the speed is usually 1400 or 2800 rpm, but if the system is equipped with an electronic device known as an "inverter", the number of revolutions can be adjusted from the minimum limit (approx. 500 rpm) to the maximum. In the case of thermal engines, the drive speed is maintained within the same limits.

The pump receives energy to transfer a liquid; thus, a flow rate is generated at the pump outlet, which can be measured as a given volume passing through it per unit of time. In contrast, pressure results from the interaction of the pumped fluid with an obstacle, such as a reduction in the flow section, the piston of a cylinder or the blades of an engine. Pumps do not generate pressure, but are designed to support the pressure needed by the system. Hydraulic pumps, in general applications, are actually used either to move a fluid that encounters low resistance (e.g. systems that transfer water or similar fluids), or in systems where the fluid transmits energy, through its flow and pressure.

The most common types of pumps [1] are shown in Figure 1.

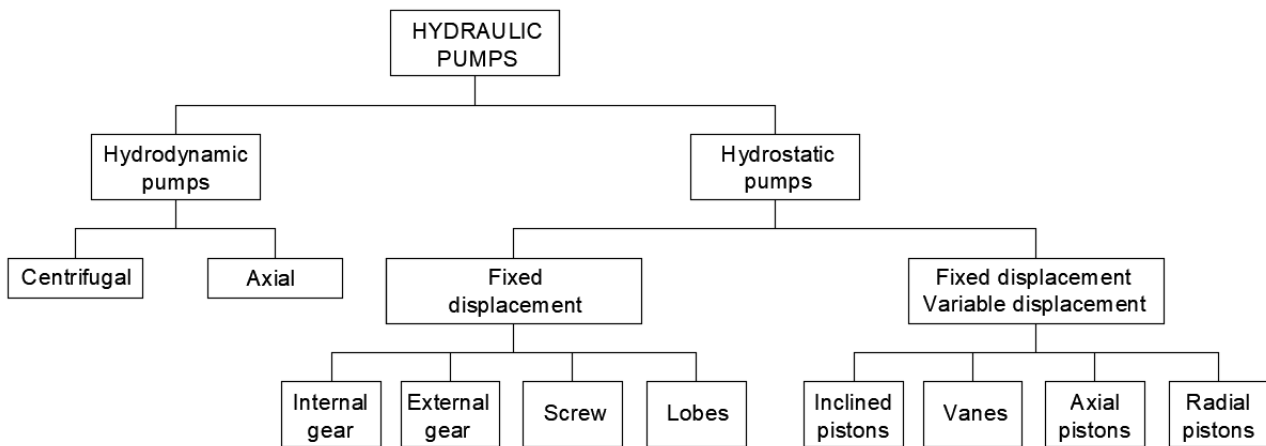


Fig. 1. The main types of hydraulic pumps

The physical principle falls under **hydrodynamics** in the first case, and **hydrostatics** in the second (Figure 1). Hydrodynamic pumps - usually called "rotodynamik pumps" - suck a liquid at rest and simply move it to another point; hydrostatic pumps - or "displacement pumps, volumetric pumps" - also suck a liquid from the tank, but move it to the drive system, characterized by high pressure. In this case the fluid is an intermediary through which energy is transferred, by means of the pressure that is installed in the system.

A major difference between the two types of pumps refers to the pressure level; if in hydrodynamic pumps the pressure that is installed in the circuit is of the order of a few bars, sufficient to move the fluid from one place to another, common hydrostatic pumps can support pressures of the order of a few hundred bars, and certain types of pumps can reach pressures of the order of thousands of bars.

When designing hydrostatic pumps, there are 2 important issues: the mechanical strength of the components, so that they operate at the pressures with which the pump is compatible, and respectively the tightness of the chamber in which the pressure is generated at the pump level.

Typically, hydrostatic pumps are based on the sealing of a chamber that reduces its volume; in this chamber the pumping effect is generated, the working fluid being forced by the tightness of the chamber to move towards the hydraulic circuit and thus transfer the energy generated at the pump level. Typically, in the hydraulic actuator (linear or rotary hydraulic motor) we also encounter one (e.g. hydraulic cylinder) or more sealed chambers (e.g. hydraulic piston motor).

Paradoxically, the tightness of a working chamber, which is key to the functioning of hydraulic systems and is achieved through the smallest possible clearances between the parts in contact, has a negative influence when the fluid in the system contains impurities; these reach the sealing area, where the clearances between the parts are very tight, and can damage the sealing surfaces.

2. Types of wear that occur in hydraulic systems

The main cause of wear in hydraulic systems is the absence of lubricant in the area where solid parts are in contact. Under the effect of pressing force, the parts come into contact and **adhesive wear** occurs. When there is a lubricant film, but it is insufficient, a less severe wear occurs, called **fatigue wear**. If the lubricant film loses some of its properties, **corrosive wear** can occur, and if the contact area of the parts comes into contact with oxygen, it evolves into **oxidative wear**.

If the lubricant contains hard particles that interpose between the two contacting surfaces, and the size of these particles is comparable to that of the distance between the parts, they produce **abrasive wear**. If the hard particles flow at a significant velocity and interact with the surfaces, they produce **erosive wear**.

Another type of wear, which occurs between parts with very small relative displacement, which can be from a few micrometers to a few millimeters, is **fretting wear**. In this case, under the action of

the load that brings the 2 parts into contact, local joining and detachment of the parts occur alternately, resulting in particles that subsequently lead to other types of wear. Depending on the contact pressure and the temperature in the interaction area, we can also have **impact wear** or **melting wear**.

Cavitation in hydraulic systems is an undesirable phenomenon that, among other inconveniences, causes **cavitation wear**; the result of operating in a cavitation mode is the detachment of particles from parts, which cause abrasive, erosive wear, etc. downstream.



Fig. 2. Main types of wear in hydraulic systems

Figure 2 shows the main types of wear in hydraulic systems. Below are some considerations related to the wear of the most common types of pumps.

3. Wear in axial piston pumps

This type of pump is the most complex and therefore the most complex situations regarding wear and its effects can be encountered here. Wear in axial piston hydraulic pumps is caused by friction between components such as piston/cylinder, piston shoe/swash plate and cylinder block/valve (distribution) plate pairs, and is accelerated by factors such as abrasive contaminants in the hydraulic fluid, high operating pressure and poor lubrication. This wear can lead to decreased volumetric efficiency, reduced service life and, ultimately, pump failure. Reducing wear involves using appropriate materials, maintaining fluid cleanliness and ensuring adequate lubrication [2, 3]. The main wear mechanism is three-component abrasive wear between the piston block and the valve plate, due to the removal of coarse carbides from the valve plate surface. The removed carbides and debris contaminate the hydraulic fluid and cause significant wear on other components that are not designed to withstand such harsh abrasive particles.

3.1. Causes of wear

- Friction: The main source of wear is friction between moving parts in the absence of a consistent film of lubricating fluid, especially the piston-cylinder pair and the piston shoe/swash plate pair.
- Hydraulic fluid contamination: Abrasive particles such as sand or dirt in the hydraulic oil are a major cause of wear, as they can scratch surfaces and cause damage.
- High pressure: Excessive discharge pressure can lead to high contact pressures, which increases the wear of the piston/cylinder pair.
- Poor lubrication: Degraded oil does not create the necessary film between the surfaces; friction, corrosion, oxidation, etc. occur.

3.2. How wear and tear manifests itself

- Reduced efficiency: As a result of component wear, clearances between the contacting parts increase, increasing internal losses; therefore, the pump will deliver a reduced flow rate.
- Increased wear: The wear of a part with the detachment of particles can lead to accelerated wear of the part with which it is in contact, creating a cascading effect.
- Component failure: Severe wear can cause parts to jam or fail completely.

In axial piston pumps, hydraulic fluid fills the pump housing and acts as a lubricant for some components. The piston/shoe and shoe/swash plate contacts are better lubricated by a hole in the pistons and pads that allows a small amount of pressurized fluid to escape from the cylinder block and reach the pad/plate contact area.

Although these pumps have a high power density and relatively high efficiency, they can become unusable after a few thousand hours due to wear of their components, compared to a normal lifespan of 10...20,000 hours.

4. Wear in vane pumps

In high-pressure vane pumps, whether fixed or variable flow, wear occurs on the internal surface of the housing (stator ring), at the radial grooves of the rotor, as well as on the side and tip of the vanes, as a consequence of the sliding contact between the rotor, stator ring and the vanes (see Figure 3).

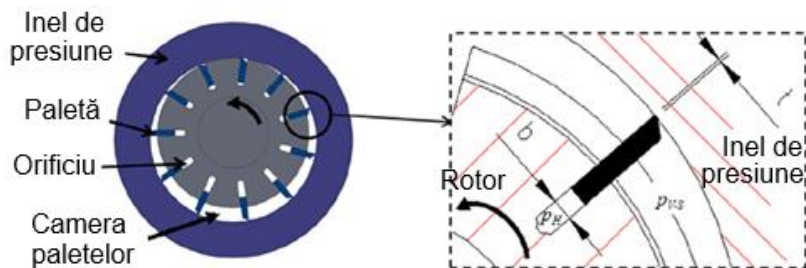


Fig. 3. Vane pump [4]

To achieve minimal wear, it is desirable to have an appropriate selection of materials and a design of the stator and blades taking into account the relative movement existing between them and the type of lubrication that exists in that area.

Thus, wear reduction can be achieved by improving the performance of the surface material if there is a boundary lubrication regime or by modifying the surface geometry in the case of a hydrodynamic lubrication regime.

As with other types of pumps, the parts in motion (impeller, vanes) wear out the most and are available in the form of repair (replacement) kits. Housing wear, which is slower but also more expensive, most often requires pump replacement, unless there is adequate remanufacturing technology.

5. Wear in gear pumps

The causes and effects of wear presented above (e.g. in axial piston pumps) are largely similar for all pump types; the most important difference is in the parts of the pump structure that wear out.

For **gear pumps**, the main wear occurs as a result of the pinion-housing and pinion-bearing block contact [5]; since the maximum pressure that develops in the pump housing is in the discharge area, a radial force occurs simultaneously and is transmitted through the driven pinion to the suction area of the housing. Since the pinion is in relative motion with respect to the housing, wear of the housing, which is most often made of aluminium alloy (duralumin, etc.), occurs in the contact area. Less wear is also found in the discharge area of the housing, as well as on the lateral faces of the bearing blocks. The side blocks can be replaced, their reconditioning not being economically

profitable. On the other hand, the wear of the casing most often requires the replacement of the pump; this is not possible in all situations, and when there is the option of remanufacturing the casing, this solution is preferable.



Fig. 4. Gear pump housing with wear evident in the suction and discharge area

In the case where the working fluid is heavily contaminated, wear occurs much faster than in the case of normal operation, and in this case it can also occur in the discharge area of the pump. The same phenomenon occurs in the case of long-term use, even if the conditions regarding oil quality, working pressure, etc. are met. Depending on the damage to the housing due to wear, the pump can be reconditioned or replaced.

6. Methods for increasing the service life and remanufacturing of hydraulic pumps

Recently, various methods have emerged to improve pump reliability, including the use of superior materials, surface treatments [6], or machining processes that improve contact behavior [7, 8]. These methods can be used in the initial design phase or for component reconditioning when economically justified. The category of surface treatments can include the deposition of thin layers, which is done in order to increase the resistance of the treated surfaces; the deposited film can have thicknesses from a few micrometers to a few tenths of a millimeter. If it is desired to compensate for wear occurring during operation, a previous deposition of a thicker layer can be made, over which the final film will be deposited.

The use of thin layers in hydraulics is in its infancy, this technique being used to date in other fields; however, it is starting to be found in this field as well, in response to requests for increasing the operating life or for remanufacturing some components [9] in order to reduce material consumption. The main methods of depositing thin layers:

a. Physical Vapour Deposition (PVD): thermal evaporation, sputtering, and vacuum ion plating.

b. Chemical Vapour Deposition (CVD): electrochemical deposition, chemical reduction, chemical vapour deposition, anodization

Depending on the state of aggregation of the deposition material and the physical and chemical processes of generation, transport and adhesion of the layers to the base material, there are different layer deposition technologies that use one or more methods.

Modern technologies used to deposit thin layers on metal surfaces are mainly: cathodic arc, magnetron sputtering (or DC-direct current)/ RF-radio frequency).

One of the more recent developments in magnetron sputtering is high-power pulsed sputtering, known as **High Power Impulse Magnetron Sputtering (HiPIMS)**, and is superior to DC magnetron sputtering techniques.

Another relevant technology for depositing starts is the one called **DLC (Diamond-Like Carbon) coatings** which consists of a PVD/CVD coating with exceptional hardness and lubrication properties.

To create extremely thin and uniform layers on surfaces, **ALD (Atomic Layer Deposition)** can be used, which takes place at the atomic level and is extremely precise.

Some of these processes are used in applications where the requirements are close to those in hydraulics; for example, the DLC process is currently adopted by most automotive manufacturers to create the working surface in engines, instead of the classic cylinder liners made of steel. In this case, the requirements are close to those of axial piston pumps: reduced roughness, resistance over time under friction conditions with a lubricant film, etc. The thickness of the deposited layer has values of 0.1...0.2 mm in this case.

7. Conclusions

Knowledge of the operation of hydraulic devices at the level of contact between the main parts, especially pumps, is essential for understanding the wear mechanism and, consequently, for obtaining the longest possible operating life for pumps, which represent the most important components of a hydraulic system. On the other hand, currently there are techniques that allow the remanufacturing of component parts whose failure, in the past, would have led to the complete replacement of the respective hydraulic device. The thin layer technique is one of these, which ensures the improvement of surface quality from the initial manufacturing phase or the reconditioning in the event of wear within certain limits. Even if this technique is still in its infancy in hydraulics, it is encountered in other fields, where it responds to similar requirements in terms of roughness, wear resistance under oil lubrication conditions, low friction coefficient, etc.

Acknowledgments

This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CCCDI - UEFISCDI, project number PN-IV-P7-7.1-PTE-2024-0618, within PNCDI IV.

References

- [1] Assofluid. *Hydraulics in Industrial and Mobile Applications*. Brugherio (Milano), Grafiche Parole Nove s.r.l. Publishing House, 2007.
- [2] Schuhler, Guillaume, A. Jourani, Salima Bouvier, and J.-M. Perrochat. "Multi technical analysis of wear mechanisms in axial piston pumps." *IOP Conf. Series: Journal of Physics: Conf. Series* 843 (2017): 012077. doi:10.1088/1742-6596/843/1/012077.
- [3] Liang, Yingna, Wei Wang, Miaomiao Shen, Zhepeng Zhang, Hao Xing, Cunyuan Wang, and Dianrong Gao. "Study on friction and wear characteristics of axial piston pump valve plate pairs modified with different surface energies." *Coatings* 14, no. 3 (2024): 328. <https://doi.org/10.3390/coatings14030328>.
- [4] Mucchi, Emiliano, Alessandro Agazzi, Gianluca D'Elia, and Giorgio Dalpiaz. "On the wear and lubrication regime in variable displacement vane pumps." *Wear* 306, no. 1-2 (2013): 36–46. <http://dx.doi.org/10.1016/j.wear.2013.06.025>.
- [5] Novak, Nejc, Ana Trajkovski, Marko Polajnar, Mitjan Kalin, and Franc Majdič. "Wear of hydraulic pump with real particles and medium test dust." *Wear* 532-533 (2023): 205101. <https://doi.org/10.1016/j.wear.2023.205101>.
- [6] Schuhler, Guillaume, A. Jourani, Salima Bouvier, and J.-M. Perrochat. "Efficacy of coatings and thermochemical treatments to improve wear resistance of axial piston pumps." *Tribology International* 126 (2018): 376–385. <https://doi.org/10.1016/j.triboint.2018.05.007>.
- [7] Schneider, Johannes, Daniel Braun, and Christian Greiner. "Laser Textured Surfaces for Mixed Lubrication: Influence of Aspect Ratio, Textured Area and Dimple Arrangement." *Lubricants* 5, no. 3 (2017): 32. doi:10.3390/lubricants5030032.
- [8] Antoszewski, Bogdan, and Piotr Kurp. "Effect of surface texture on the sliding pair lubrication efficiency." *Lubricants* 10, no. 5 (2022): 80. <https://doi.org/10.3390/lubricants10050080>.
- [9] Wang, Maolu, Xinjian Wang, Junyan Liu, Jiacheng Wei, Zhangwen Shen, and Yang Wang. "3-Dimensional ink printing of friction-reducing surface textures from copper nanoparticles." *Surface & Coatings Technology* 364 (2019): 57–62. <https://doi.org/10.1016/j.surfcoat.2019.02.080>.