PLENARY SPEAK

FLUID POWER TECHNOLOGY AND DEVELOPMENT TRENDS

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Fluid power represents one of the possibilities of controlled energy transfer. Although nowadays especially political actors on a global level strongly push electric drives, hydraulics is still unavoidable. Fluid power also impacts the carbon footprint, so reducing this impact is a very important trend. From a hydraulics perspective, this can be achieved by improving the efficiency of individual components. The average overall efficiency of hydraulic systems is between 23 % and 30 %, so it is necessary to analyse in depth the causes of this situation and take action. Users of hydraulic components want to calculate the service life of each hydraulic component, similar to bearings. It is also a modern trend to set up digital twins, i.e. numerical models and measurement and control systems that use machine learning to tell the user the current state of the system. The use of computer simulations and 3D printing is also very important.

Keywords:
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soft robotics,
digitalisation,
alternative
technologies

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1 Introduction

Fluid power is the generation, transmission, and control of power through the use of pressurised fluids. Fluid power technology is continuously developing according to all other technical improvements from digitalisations, low energy consumption, to full diagnostic, green and smart. For decades there has been competition between electric and hydraulic drives, today the electric ones are particularly exposed. Global political trends are trying to convince that electric drives are the only solution for our future, which will be green and progressive. Despite all this, hydraulic drives have remained and will remain, as they are constantly improved and adapted to global trends. Today, it is impossible to imagine heavy construction, agricultural, forestry, mining, marine, aviation, iron, woodworking and other machines without hydraulic drives. They are particularly suitable for heavy loads, fast and precise positioning, etc. Advantages of fluid power – hydraulics are: high power density – small volume of components, good damping of dynamic loads, simple and reliable protection of the system against overload, easy change of the direction of movement, simple adjustment of force or moment, fast response, large rigidity, etc.

Fluid power is evolving in multiple ways: fluids, components, materials, technologies, alternative technologies - 3D printing, mechatronics, digitalization, engineering diagnostics, carbon footprint, soft robotics, humanoid robotics, remote learning, internet of things, etc. In hydraulics, there are other obstacles on the road to improvement: higher production costs, high system complexity, implementation effort, incomplete use of digital solutions, etc.

The field of fluid power is also linked to the effects of climate change, which indirectly cause natural disasters such as higher temperatures, hurricanes, tornadoes, floods, etc. From 1890 to today [1], the ambient temperature in Europe has risen by an average of 1,6 °C (Fig. 1).

The environment, therefore, requires quick and effective action so that we do not suffer even greater disasters. Experts warn that an increase in the average environmental temperature of only 2 °C in the next ten years can cause a complete melting of the Arctic ice (Fig. 2) [2], that up to 99 % of tropical coral reefs can disappear, that river floods can increase by 170 % (as was the case in Slovenia this August), that sea levels can rise by more than a meter.

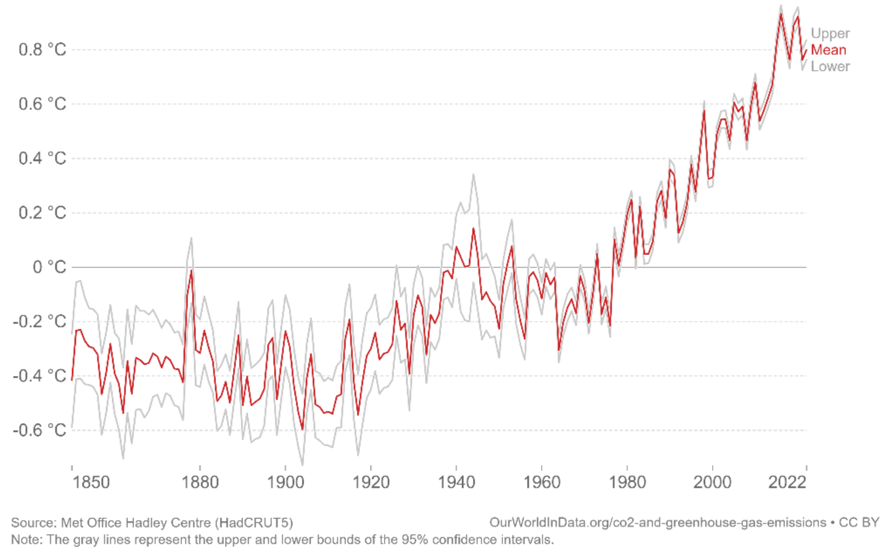

Figure 1: Change of global average land-see temperature during the years [1]

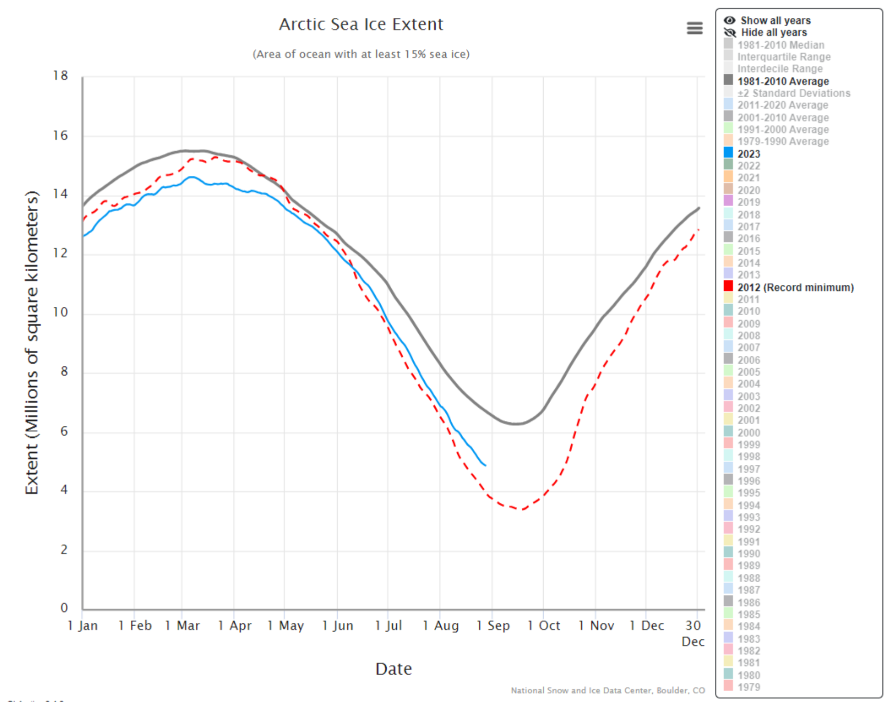

Figure 2: Change of Artic Sea Ice [2]

2 Increasing energy efficiency

Fluid power consumes between $66 \cdot 10^{10}$ kWh and $88 \cdot 10^{10}$ kWh annually, of which 40 % is used by mobile machinery, 56 % by industrial hydraulics and 3 % by aviation. With the above amount of energy consumed annually, hydraulic systems produce between 310 and 380 million metric tons (MMT) of carbon dioxide. According to the British Fluid Power Association, the efficiency of downstream fluid power systems ranges from 23 % to 30 % [3].

Hydraulic systems produce kinetic energy in the form of flow and potential energy in the form of pressure. Internal tribological contact between movable and stationary elements inside of hydraulic components (mostly pumps and valves) do not have sealings, but very low gap. Pressure difference in gaps occurs internal leakage, where hydraulic pressure energy converts into higher fluid temperature. Inadequate, degraded cleanliness of the hydraulic fluid affects more wear and increases the gap between two elements. As internal leakage through the gaps increases, the volumetric efficiency of the observed component decreases [4].

Digital hydraulic valves enable energy-efficient use in position and pressure control [5]. Such digital valves can be found in many industry branches. They are characterised by fast regulation and little or no internal leakage because a seat valve is used (Fig. 3). It also allows energy recuperation and can be used in many applications, such as cranes, forklifting trucks, etc.

Due to internal leakage in hydraulic components and pressure differences in flow through hydraulic lines and components, hydraulic energy is converted to heat. Heating the hydraulic fluid changes its properties, which is not desirable. Therefore, high-quality heat dissipation is very important. New high-quality cooling solutions are constantly being developed for this purpose. of heat dissipation from the hydraulic fluid to the environment [6].

3 Improving system reliability

Reliability for hydraulic **fluids** include viscosity, wear protection, thermal stability, corrosion inhibition, foam resistance, demulsibility (ability to release water), oxidation life and cleanliness. Pressure-dependent fluid properties, which include bulk modulus, density and traction, can have a large effect on hydraulic system efficiency [4, 7, 8].

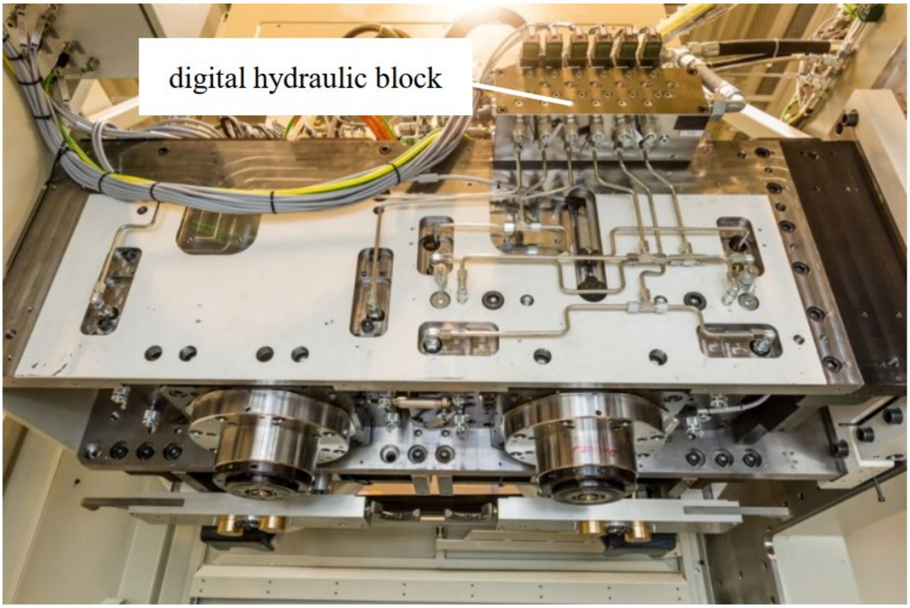

Figure 3: Micro-positioning system with digital valves [5]

3.1 Predicting of lifetime components in connection with cleanliness of hydraulic fluid

The reliability and service life of hydraulic components depend heavily on their working conditions, especially on the cleanliness of the hydraulic fluid used. Many experts worldwide are engaged in determining the service life of individual hydraulic components as a function of cleanliness. Real wear particles with their technical properties (hardness, toughness, ...) migrate with the hydraulic fluid and wear the sealing sliding surfaces of the components. Because it is difficult to obtain real wear particles and because such tests take a long time, research is currently underway to determine the acceleration factor of sustained wear tests using an abrasive-aggressive standard test powder (MTD) [9] (Fig. 4). Novak et al. for the first time investigated the wear of a hydraulic gear pump with external gearing separately with test dust and with wear particles [10].

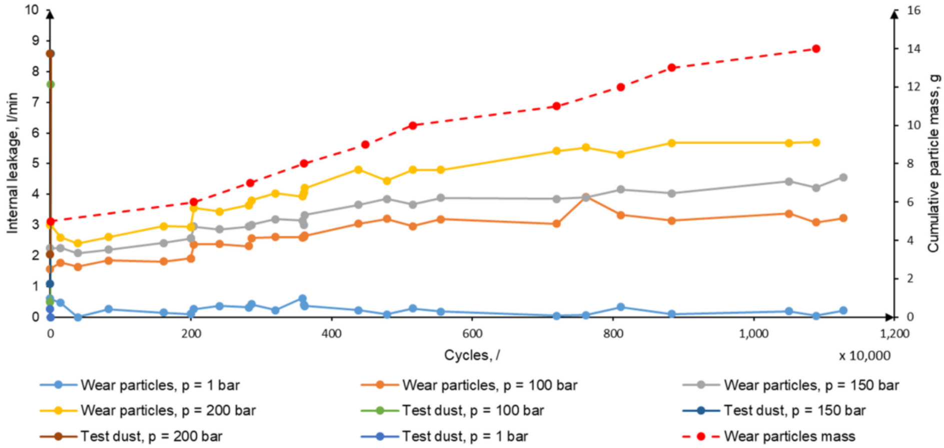

Figure 4: Comparison of volumetric efficiencies of hydraulic pump at different operation pressure, test dust and wear particles [9]

3.2 Opportunity for condition monitoring and predictive maintenance over digital twins & virtual sensors

Monitoring the condition of hydraulic components and systems can save a lot of money due to the high probability of avoiding failures. Damage/wear can be detected at an early stage so that early action can be taken on this basis to prevent the worst from happening. With proper condition monitoring, we can detect failures of individual parts of the observed hydraulic component. American researchers [11] have developed a method for detecting a worn valve plate (Fig. 5) of a variable displacement axial piston pump that reduces the number of sensors required to five.

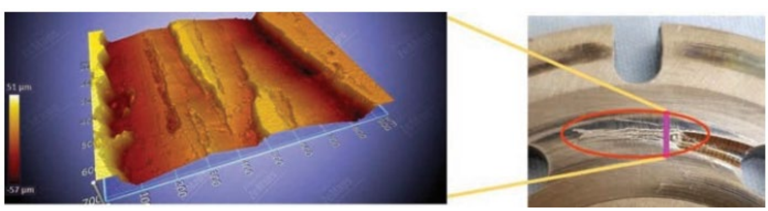

Figure 5: Valve plate with severe damage [11]

To successfully detect the valve plate failure, they measured the inlet and outlet pressures, drain pressure, the number of revolutions of the drive shaft, and the actual flow rate at the pump's outlet pressure port.

4 Building intelligent systems

Trends in the development of fluid power are strongly oriented toward complete digitization in several areas [4]:

- Industry 4.0 (cyber-physical systems, IoT)
- Fusion of physical machines and embedded systems
- Digital twin / digital shadow of machines, systems, processes
- Big Data and advanced data analytics, etc.

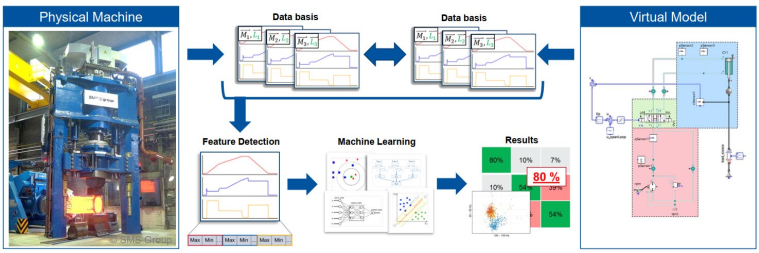

Figure 6: Hydraulic press digital twin [4]

5 Reducing the size and weight of components

Size and weight of materials can be reduced by various approaches. To name a few:

- new, alternative materials,
- shape optimization and iterative processes,
- 3D printing.

New and alternative materials

First, the tendencies of using new materials are divided into groups according to their definition or application. Here we divide them into base materials and materials used for coating. Since most hydraulic components are made of metals and metal alloys, the tendencies focus on improving the chemical structure of existing materials. This is achieved by creating the perfect mix of raw materials and combining them (melting) to create more durable materials that can better withstand stresses and, if possible, reduce the weight of the final structure [12]. In relation to metallic structures, many studies and thus development of coating layers have been carried out recently. The main function of coatings is to better resist corrosion, erosion and cavitation. Different materials and alloys bring a wide range of different coating properties, which must be very well understood in order to select the right coating for a particular application. Coatings can be classified according to the initial state of the coating material:

- Vapor phase: chemical vapor deposition (CVD) and physical vapor deposition (PVD) (Fig. 7) both use a plasma as the main energy source for depositing materials
- Solution state: electrochemical deposition, salt-gel, …
- Molten (or partially molten) state: laser deposition, welding, …

Materials used for coatings include hard and soft coatings, which are mostly polymers. Metals used for coating applications: molybdenum disulfite, titanium nitride, nickel, chromium, copper, silver, gold, cadmium, platinum, indium and others. As mentioned earlier, some coatings that are highly wear resistant are not based on metals, but are mostly polymers. To name a few: PTFE, polyamides, elastomer coatings and others.

Figure 7: PVD coated gear [13]

Some polymer materials can also be used as stand-alone materials: Polyamides, polyester resins, PEEK, UHMWPE, POM, PTFE, and others.

We can hardly talk about new materials without talking about carbon-based materials. The widely used carbon fibers combined with polyester resins can be either in an organized form as a fabric or in a chaotic state with fibers randomly distributed in the volume, which is called forged carbon fibers. Carbon allows structures to withstand large loads while keeping weight to a minimum. Many studies have also been conducted on carbon nanostructures in the form of nanotubes [14]. These studies have shown that nanotubes can withstand the highest loads measured up to now, more than any other known materials.

Shape optimization and iterative processes

Shape optimization is an old process of removing unnecessary volume of initial material to reduce the mass of the structure. This can be, has been, and in some cases is done by hand. However, knowing how much material can be removed to make the structure withstand the applied loads and strains is a very complex numerical process. Basically, it's a question of "how much is too much". Human instinct is incapable of such operations, so computers have had to be used to achieve optimal results. The use of modern software to determine the optimum shape and mass to be removed based on loads and constraints with a known initial volume is called topology optimization. In this type of shape optimization, finite element methods are used to calculate the stresses that occur in the volume of material to determine where and how much material can be safely removed so that the object can still perform its intended tasks [15].

In a slightly different approach, the iterative methods are not limited by the initial volume and can produce a variety of different solutions to the same problem, allowing the designer to choose the optimal one. Typically, different solutions are compared based on strength, the material used, and the overall shape that must meet the requirements or constraints. One such process is generative design [16]. Generative designs are also distinguished by their purpose. Solutions can be purely structural, but in some cases it is the internal structure that needs to be optimised for fluid flow. This is then generative design, which incorporates CFD as part of the solution to reduce the pressure drop through the structure through which the fluid flows.

3D printing

Directly related to the previous subsection on optimization, some structures are impossible or to complex to produce using the subtractive manufacturing techniques known and used so far [17]. For these structures, 3-dimensional printing of materials is used. Since firstly introduced and patented 1970, 3D printing has become almost an industry in itself (Fig. 8), supporting other processes where possible and where other processes fall short [18]. Printing a wide variety of polymers and metals, this type of manufacturing can be used to produce complex internal geometries and closed structures, which is important in the field of hydraulics [19].

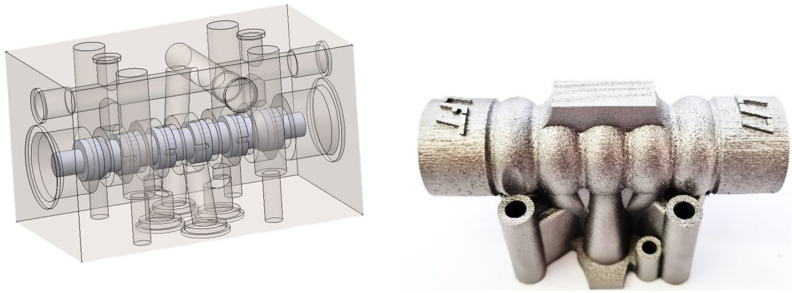

Figure 8: Comparison of conventional (left) and 3D printed (right) Hydraulic valve [20]

6 Reduction of negative impacts on the environment

It is almost impossible to define all the impacts that hydraulic systems have on the environment during and after their life cycle. However, it is important that engineers are at least aware of the main pollutants that affect the environment of hydraulic systems. In this way, it is possible to reduce these impacts in order to minimize them and, consequently, the negative consequences for the environment [21].

In the context of hydraulics, there are several influences that have a negative impact on the environment:

- Reduced air quality,
- Noise and vibration,
- Soil and ground pollution,
- Ground and underground water pollution, etc.

Since all of these environmental impacts are directly related to human health and well-being, engineers should consider environmental impacts when designing new hydraulic systems. While vibration and noise reductions are related to system operation, soil contamination and contamination of the earth are due to improper disposal of fluids and structures. Recycling as many materials as possible can only be achieved if the system is designed for reuse in the first place. For example, the automotive industry has begun to reduce the use of non-recyclable materials, especially plastics [20].

Dealing with noise and vibration normally requires some type of enclosure. However, this is changing in the case of hydraulic systems as they present new challenges in terms of maintenance, retrofitting, heat dissipation, etc…

Improving air quality has become an ongoing debate about "how to", but we have yet to move from words to action. Similar to soil and land pollution, air pollution is not only associated with equipment when it is in operation. The manufacture, transport of parts and the improper disposal of components and fluids can also have a major impact on the environment, so we must always look at the entire life cycle to understand the big picture.

7 Conclusions

This paper provides an overview of the current state of development and guidelines for fluid power. One of the biggest global problems is the warming of the atmosphere, to which fluid power also contributes. It produces an average of 345 million metric tons of carbon dioxide per year. The situation can be improved by lower consumption and better hydraulic efficiency, which averages only 26%. The main trends in hydraulics are digitalization, digital twins, advanced automation, reliability improvement, ability to predict component life depending on operating parameters, advanced numerical simulations, building intelligent self-learning hydraulic systems, Big Data management and storage, green technologies, advanced green hydraulic fluids, new advanced materials, additive technologies – 3D printing, etc.

With further development in the above directions, fluid power will by no means die out, but will continue to be used in the future and compete with electric and other drives.

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