Nenad Todić[1)]
Slobodan Savić[1)]
Dušan Gordić[1)]

1) Faculty of Engineering, University of Kragujevac, Serbia, ntodic@gmail.com {ssavic, gordic}@kg.ac.rs

DEVELOPMENT AND DESIGN OF WATER HYDRAULICS COMPONENTS

Abstract: *The paper presents modern water hydraulics technology, commencing from its early development to its current applications. This paper will also present the factors that resulted in the decline of water hydraulic applications and the factors that have contributed to the re-emergence of water hydraulics today. The advantages of using water in hydraulic systems are discussed, various important properties of water are presented, and some of the recent research works done by various investigators in water hydraulics are also highlighted.*

Keywords: *Water, Hydarulic Technology, Piston Axial Pump*

1. INTRODUCTION

The earliest hydraulic systems used water as hydraulic fluid. This restricted the working temperature range and caused corrosion as well as lubricating problems. It was not until the late 1920's that mineral hydraulic oils were introduced. Consequently, the oil became the main pressure medium of hydraulic applications. Recently, the demand for using pure tap water as a pressure medium in hydraulic applications has increased due to its availability, easy maintenance, its low cost and its high safety levels against pollution and fire hazard.Water hydraulics can be used in new application areas such as food processing, pulp and paper industry, medicine, glass making, coal mining and nuclear industry.

Water is characterized by very low viscosity in comparison with mineral hydraulic oils. Key problems should be considered in water hydraulic system. First, the very low viscosity must increase the difficulty of developing hydrodynamic film between friction pairs, and the very small change of water's viscosity with pressure means that elastohydrodynamic lubrication with hard materials is unlikely to occur. The low viscosity is accompanied with poor lubricities of water. Poor lubricities can cause corrosive wear and erosion problems. Secondly, it is to be noted that water (especially seawater) is electrically conductive and may act as an electrolyte when impurities or certain additives are present. In such cases the electrolyte corrosion may arise. Metallic materials to be used in connection with the water pressure medium should comply with the electrochemical series [1-4]. Water piston pump (motor) has been developed in some developed countries, such as USA, UK, Japan, Denmark, Germany and Finland, etc.

In water hydraulics a lot of interesting applications have been developed and researched. The application mentioned below makes clear that water hydraulics is no longer restricted to stationary applications.

(a) Ocean exploration engineering
When seawater hydraulics is used in the subsea control system, the power source and seawater pump could be positioned near the working place, requiring only electrical power from the surface. There would be no need for the flow and return of hydraulics fluid, and possibly no need for the expensive umbilical at all if the system were controlled remotely. The financial benefits would be significant.

(b) Metallurgical industry and mining
Non-flammability is of paramount importance in high-temperature and mining applications The use of water hydraulics instead of conventional fire resistant hydraulics in metallurgical industry (converter, furnace and aluminum productions), plastics processing facilities, nuclear industry and power in mine, not only avoid the risk of fire, also reduce operating cost and pollution to environment.

(c) Paper cutting
Quite a new development is a water jet cutting system for the paper machine. In the paper machine, the edge of the fast paper line has to be cut. Traditional way is to use steel cutters, but due to their unreliable operation, the use of

water jet for cutting is raising more and more interest.

In other words, the problem is that the steel cuttings are wearing quite much and have to be changed very often. Other alternative is to use water jet cutting. 80 Mpa cutting system has been developed in Finland, which is now on the market.

(d)Waste packer lorry

In Sweden there is an interesting mobile application operated with water hydraulics. That is a waste packer lorry. The waste lorry is a daily operated vehicle and the hydraulic system must be designed for outdoor temperatures of –10 to +40°C. Therefore, the tap water is frost protected by 35% food grade propylene glycol. This fluid is classified as a non-hazardous to humans and the environment [5-6].

2. DEVELOPMENT, RESEARCH AND DESIGN OF WATER HYDRAULICS COMPONENTS

The research and development challenges were to find engineering solutions to the specific problems in design and manufacturing of water hydraulic components and industrial systems suitable for using pure tap water as the pressure fluid. Companies have water hydraulic components, systems and solutions on the market, and the number of products and the areas of application are increasing as illustrated in Figure 1. Current technological efforts for water hydraulics are far less than those for oil hydraulics. The experience gained from oil hydraulics is very important for future water hydraulics research. Engineering relationships between water and oil are significantly different and cannot be overcome

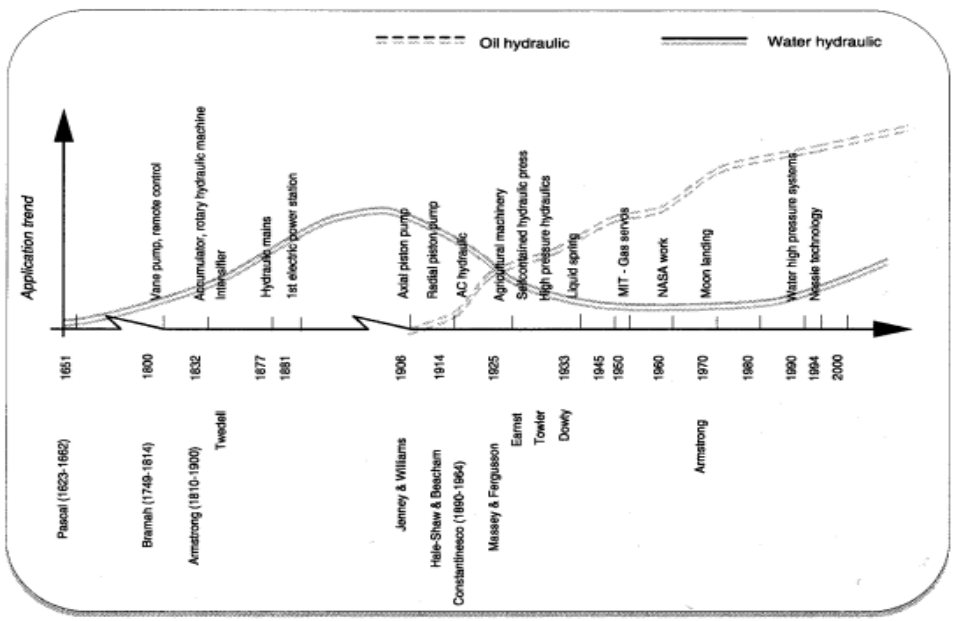


Figure 1. *The historical development of oil and water hydraulics*

or trivialized by simple modification of design parameters from oil hydraulics. Water hydraulics should be regarded as a new evolving technology. It has certainly brought in challenges as well as opportunities for the engineers and manufacturers. When the current drawbacks are resolved through advances in technology, modern water hydraulics will have a wider range of application fields than the oil hydraulics presently has. Presently, water

hydraulics is more expensive than its oil counterpart, due to the fact that it is an evolving or new technology and naturally comes with a lower volume and higher price. Moreover, the production technology is not widespread yet or well established and this resulted in higher unit production cost which the user has to consider. Moreover, the use of water hydraulic systems has not developed as fast as expected due to the lack of common goals and the components developed are scattered over a very large range of power levels, and missed sizes and types of components. The current market share of water hydraulics is believed to be less than 5%. As long as the quantity produced is small and one is still at the bottom of the learning curve, the price of the final component will be unfavorable. Hence, while water is cheap, water hydraulic components are not. This will be resolved when more engineers and companies join in the development and use of this new technology. Recent sales growths are 50% to 100% per year. It is expected that water and oil hydraulics will co-exist in the near future with water filling in the niches where environment, health, fire and safely, product compatibility, etc. are important considerations. In the longer term, it is expected that water hydraulics will take over many of the existing oil hydraulic applications besides having new applications of its own.

If a system is going to be utilized, it needs a driving force of which water hydraulics has one - the environmental lobby. A technology will not be used unless it offers an ultimate financial advantage over other technologies or unless it is required by law. National legislation on environmental protection will certainly increase the application of water hydraulics.

Some nations are beginning to change not only their environmental regulations but also the enforcement and Sweden is one exampl. As the demand increases from both users and regulatory agencies, more manufacturers will begin putting the resources towards the development of water hydraulic components and systems. Water hydraulic actuators will become both smaller and larger - smaller in size and larger in power output due to the increasing pressure range that is being made possible. Just like oil hydraulics dominated power transmission and control in the last few decades, water hydraulics technology could well supercede oil hydraulics technology and revolutionize the power transmission industry in the years to come. One area not discussed was nano-technology level components for biosensors and biotechnology.

2.1. Temperature and pressure range

The permitted operational temperature range is +3°C to +50°C max. due to the nature of pure water, Figure 2.

The maximum temperature of +50°C is in many cases not a strong constraint because thermal conductivity of water is 4-5 times that of mineral oil! This means, that water hydraulic systems tend to require less cooling capacity. Heating is often a consequence of flow losses due to flow resistance.

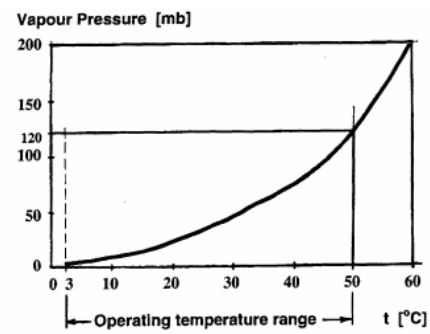


Figure 2. *Vapour pressure characteristic of water*

2.2. Viscosity and materials for design

In that respect need of cooling, water benefits from its much lower viscosity when compared to mineral oil, bio oil and oil/water emulsion, Figure 3. The dynamic viscosity of mineral oil is around 30 times that of pure water. That means using water the diameter of pipes, hoses and cooling systems is smaller size than that for oil hydraulics for the same power range. The specific heat of water is 2 times that of mineral oil, that means water has the double ability to absorb heat. The viscosity of water is significant lower than the viscosity of hydraulic oils; with a factor of one to two orders depending of the actual oil.

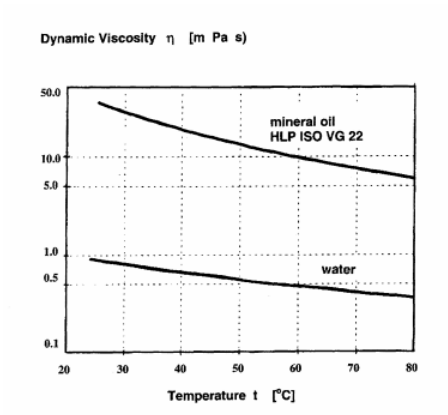


Figure 3. *Viscosity of water and mineral hydraulic oil*

Assuming conditions for laminar volume flow according to Hagen-Poiseuille's law the leakage flow QL through the gap can calculated from the following equation

$$Q_L = \frac{bh^3}{12L\eta}\Delta p$$

where b is the width, L is the length, h is the high of the gap, η is the dynamic viscosity and Δp is the pressure drop. For equal gaps in a water hydraulic machine the ratio of leakage water relative to leakage of a typical hydraulic oil is

$$\frac{Q_{L,W}}{Q_{L,O}} = \frac{\eta_{Oil}}{\eta_{Water}} \cong 30$$

In order to reduce the leakage flow of water hydraulic components to the same level achieved for oil hydraulic components, the size of the gap has to be reduced according to the ratio

$$\frac{h_{water}}{h_{oil}} = \sqrt[3]{\frac{\eta_{Water}}{\eta_{oil}}} = 0.32$$

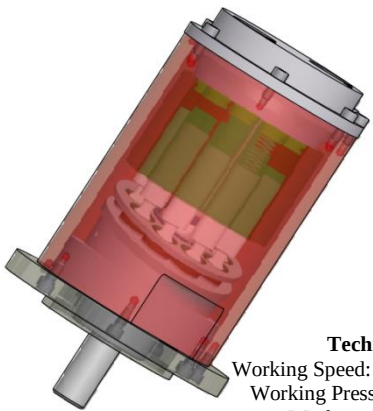
Use of hydrostatic bearing is an efficient solution for separating the bearing surfaces. Furthermore, the use of materials with low friction and that are resistant to wear is important. Stainless steel W.No.1.4057 and reinforced polymer PEEK from the polyetherketone family are used for the sliding and sealing gaps of pumps and motors. An increasing numbers of engineers and managers are considering water hydraulics as an emerging technology that can offer significant advantages to solve motion and force control tasks as a single technology and/or combined with other technologies. There is an increasing number of application areas for modern tap water hydraulic components. In particular, they are used for design of environmental friendly industrial machinery, robots, and systems [7-8].

3. WATER HYDRAULIC AXIAL PISTON PUMP RESEARCH AND DEVELOPMENT

The challenges of hydraulic pumps create a need for continued tribological research. One research area is the use of water hydraulics, especially the use of variable displacement axial piston pumps in the hydrostatic transmission of mobile machinery. Axial piston pumps and motors are commonly used in hydraulic applications because of their compact size, wide operating range and controllability. On the other hand these types of pumps and motors are quite complex. To increase the overall efficiency of the system, variable displacement axial piston units are widely used as basic components in oil hydraulics nowadays. Axial piston type units are also very useful in modern water hydraulic pumps and motors. In mobile machines most of the units are axial piston design at the moment. However, there are not commercial variable axial piston pumps or motors for water hydraulics, which is a significant problem in certain applications. The aim of the pump research is to study basic effects caused by the adjustment of the swashplate angle. At first, the attention is focused on measuring the water film thickness between the swashplate and the slipper fipad and the forces affecting the piston while tilting the swashplate [9-11].

There are several different water hydraulic pumps on the market at the moment. Most of the pumps are oil lubricated piston pumps, which are driven by crankshaft mechanism. Only a few of the pumps are totally water lubricated. Water lubricated pumps are usually axial piston pumps with non-adjustable

swashplate, Figure 4. Water as a pressure medium requires that all materials should be non-corrosive and all clearances are smaller than in oil hydraulic units.



Technical data:
Working Speed: 1000 min^{-1}
Working Pressure: 80 bar
Working fluid: water

Figure 4. *Water hydraulic axial piston pump*

Developments of water hydraulic axial piston machines have been made around world during the past three decades. The research involved material research, pump design and pump tests, including life time tests. The changes in design, material selections and power pack development are discussed. The design of the pumps, material of the pumps and test results are also discussed. The combination of stainless steel and coal fibre reinforced PEEK has proven to be successful in water hydraulic pumps [12-14]. Material selection, optimizing structure and manufacturing are recognized as the key problems. Material research is an important part of water hydraulic component research. The wear mechanism of ceramic-ceramic contact is fatigue and surface fracture. In stainless steel polymer combinations, the wear mechanism of the PEEK composites is fatigue when the load is lighter and micro-cutting and plastic deformation when the load is heavier. The conclusion is that metal-polymer combinations are more suitable to be friction pairs in water hydraulic piston pumps, but that ceramic-ceramic combinations also have potential. Companies have some patents concerning water hydraulic axial piston pumps. Key elements of the patents are the structure and materials of the slipper. Stainless steel and industrial plastics combinations are used in all the inventions [15].

4. CONCLUSION

Water hydraulics is a versatile technology, which can be applied in various applications. That makes it interesting technology area to research and develop. In water hydraulic system, the first objective should be to develop piston pump and motor using raw water as pressure medium. The poor lubrication, wear, and erosion in water piston pump (motor) are more likely to happen than in oil hydraulic one election. The experience gained from experimental study on the friction pairs in a pump (motor) will provide good basis for design and development of water hydraulic axial piston pumps and motors. Modern water hydraulic technology is still new and there are a lot of problems to be solved in order to make the technique more widely available for power transmission.

REFERENCES:

[1] Dong, W. (2006). *Research on key problems in water hydraulic piston pump and its experiment*, 4th FPNI-Symp. Sarasota, 171-179.

[2] Trostmann, E., Frolund, B., Olesen, B. & Hilbrecht, B. (2001). *Tap Water as Hydraulic Pressure Medium*, Marcel Dekker, New York.

[3] Krutz, G.W. & Chua, P.S.K. (2004). *Water Hydraulics -Theory and Applications 2004*, Water Hydraulics, Agricultural Equipment Technology Conference (AETC '04), February 8-10, Louisville, Kentucky.

[4] Bech, T., Olsen, S. & Klit, P. (1999). *Design of Pumps for Water Hydraulic Systems*. 6th Scandinavian International Conference on Fluid Power, SICFP'99, Tampere, Finland.

[5] Vilenius, J. (2001). *Water and Mobile Hydraulic Research in Finland.* The Fifth International Conference on Fluid Power Transmission and Control, April 2-7, Hang Zhou, China.

[6] Rydberg, K. (2001). *Energy Efficient Water Hydraulic Systems*. The Fifth International Conference on Fluid Power Transmission and Control, April 2-7, Hang Zhou, China.
[7] Riipinen, H. *Life in the water hydraulics system.* Dr Tech dissertation. Tampere University of Technology. Tampere University of Technology Publications 716, 54 p.
[8] Conrad, F. (2005). *Trends in design of water hydraulics motion control and open-ended solutions*, 6th JFPS International Symposium on Fluid Power, Tsukuba.
[9] Takashima, M. (1996). *Development of High Performance Components for Pollution Free Water Hydraulic System*. Third JHPS Int Symp on Fluid Power, Yokohama'96, November 4-6, 465-471.
[10] Koskinen, K.T., Leino, T. & Riipinen, H. (2008). *Sustainable Development with Water Hydraulics-Possibilities and Challenges.* 7th JFPS International Symposium on Fluid Power, Toyama.
[11] Sairiala, H., Koskinen, K.T. & Vilenius, M. (2004). *Proportional Valves in Low-pressure Water Hydraulics*. 3rd FPNI-PhD Symposium on Fluid Power, Terrassa Spain, June 30-July 2, s. 501-508.
[12] Rokala, M. (2012). *Analysis of Slipper Structures in Water Hydraulic Axial Piston Pump*, Tampere.
[13] Backe, W. (1999). *Water- or oil-hydraulics in the future*. 6th Scandinavian International Conference on Fluid Power, SICFP'99, Tampere, Finland.
[14] Ivantysyn, J. & Ivantysynova, M. (2001). *Hydrostatic Pumps and Motors*. First English Edition, Akademia Books international, New Delhi, India.
[15] Bergada, J.M. & Kumar, S. (2014). *Fluid Power, Mathematical Design of Several Components*. Nova Science Publishers, Inc., New York.

Acknowledgements: The research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Grant III 42013.