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TRENDS IN DESIGN OF WATER HYDRAULICS - MOTION CONTROL AND OPEN-ENDED SOLUTIONS

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ABSTRACT

The paper presents and discusses a R&D-view on trends in development and best practise in design of both low-pressure and high-pressure tap water hydraulic components and systems for motion control as well as open-ended solutions various industrial applications. The focus is on the advantages using ordinary tap water and the range of application areas are illustrated with examples, in particular within the food processing industry, humidification operations, water mist systems for fire fighting, high water pressure cleaners, water moisturising systems for wood processing, lumber drying process and mobile machines and equipment that operate in environmentally sensitive surroundings. Today's progress in water hydraulics includes electro-water hydraulic proportional valves and servovalves for design of motion control solutions for machines and robots. The remarkable property is that the components operate with pure water from the tap without additives of any kind. Hence water hydraulics takes the benefit of pure water as fluid being environmentally friendly, easy to clean sanitary design, non-toxic, non-flammable, inexpensive, readily available and easily disposable. The low-pressure tap water hydraulic systems cover up to around 50 bar, and 2-4 kW having a strong potential to compete with pneumatic and electrical solutions in many applications. The high-pressure water hydraulic systems cover typically up to 160 bar pressure from pump and to motors and actuators 140 bar. Recently, dedicated pumps and accessories running with sea-water as fluid are available. A unique solution is to use reverse osmosis to generate drinking water from sea-water, and furthermore for several off-shore applications. Furthermore, tap water hydraulic components of the Nessie® family and examples of measured performance characteristics are presented and the trends in industrial applications and need for future are discussed.

KEY WORDS

Water hydraulics, Actuators, Motion Control, Robot Manipulator, Open-ended Systems, Water Mist.

INTRODUCTION

Globally, the benefits for industries and societies are based on the nature of water due to the following properties: environmentally friendly fluid, non-flammable, fire and explosion proof, easy to clean sanitary design, non-toxic, inexpensive, readily available and easily disposable. The remarkable property is that the components operate with pure water from the tap without additives of any kind, [1] and [22]. The business sales history confirms that the use of modern water hydraulics shows a growing turnover as for Danfoss High-Pressure Water Solutions in Figure 1.

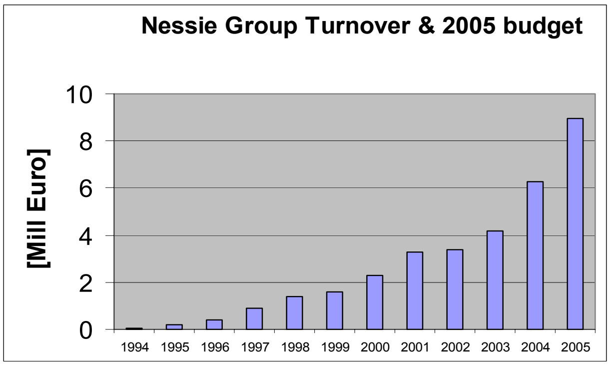

Figure 1 Trend in turnover of Danfoss Nessie Group

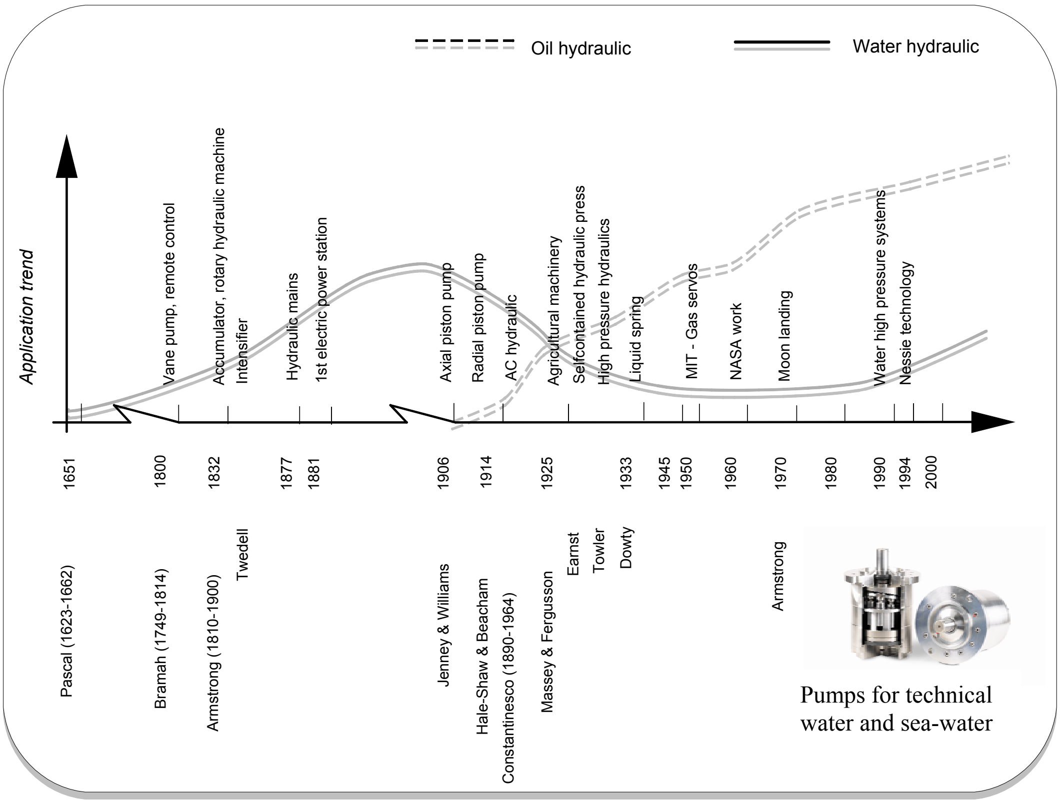

Figure 2 Hydraulics application trends and key milestones,[2]

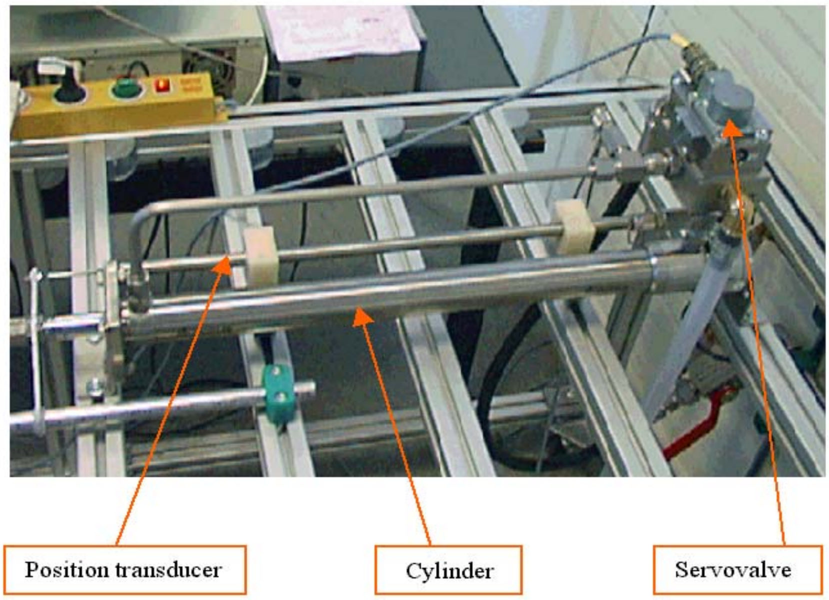

Figure 3 DTU Test water hydraulic servo actuator with a Nessie power supply

Figure 2 illustrates the development and applications of water hydraulics versus oil hydraulics, [2]. The Century BC Ctesibus invented a two-piston pump designed for pumping water. Later in 1795 Joseph Bramah was the inventor of the unique *the hydraulic press*. In 1994 Danfoss introduced the first generation of modern tap water components known as the Nessie® family of products for high-pressure tap water hydraulic systems that operate typically up to 140 bar. Since 1997 Danfoss has introduced such a second generation of low-pressure and low-power tap water hydraulic components that operate up to 50 bar. Figure 3 shows a running R&D test water hydraulic servo actuator for motion control since 1997 at Technical University of Denmark, DTU. The benefits of water relative to mineral oil, bio oil and water-oil emulsion are illustrated in Figure 4.

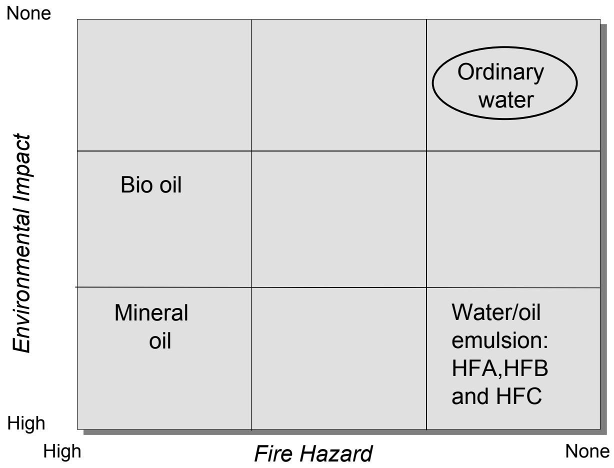

Figure 4 Water versus bio oil, mineral oil and emulsions

The significant advantages and benefits:

- No pollution of the environment (since most processes create leakage and fluid spills)
- Low operational and power media costs, i.e. purchase, storage, disposal
- Non-flammable explosion-proof fluid, safe and suitable for use in hazardous applications (lower insurance costs, etc.)
- High fluid power density, high power efficiency and high torque to inertia ratio compared to electric drives and pneumatic drives
- Workers do not breathe harmful oil vapours or risk exposure to skin and eyes.

The compressibility gives the liquid its ability to store and transfer energy with a remarkable power density, i.e. a very high torque to inertia ratio. However the bulk modulus of pure ordinary water is 2.4 10^3 MPa, approximately 50% larger than that for mineral oil (1.6 10^3 MPa), and the velocity of sound in water (1,480 m/s at 20 ^oC) is around 10% faster than the velocity of sound in mineral oil (1,300 m/s at 20 ^oC). Thus a water hydraulic robot could be significantly faster than an oil hydraulically or an electrically driven robot.

A group of frontrunner companies as Danfoss High-Pressure Water Solution have their water hydraulic products and systems on the market, and the number and the areas of application are increasing since shown at the exhibition area '*The World of Water Hydraulics'* at the Hanover Fair 1997 and 1999.

Today's R&D trends strengthen development and best practise in design of both low-pressure and high-pressure tap water hydraulic components and systems for motion control as well as open-ended solutions for customers within various industrial applications. The advantages using ordinary tap water and the range of application areas are illustrated in this paper with examples, in particular within process industries, the food processing industry, pharmaceutical industry, humidification operations, water mist systems for fire fighting, high water pressure cleaners, water moisturising systems for wood processing, lumber drying process, mining, steel and cobber industry, nuclear industry, and mobile machines and equipment that operate in environmentally sensitive surroundings. Today's progress in water hydraulics includes electro-water hydraulic proportional valves and servovalves for design of motion control solutions for machines and robots. Many industrial applications required particulars cautions that water hydraulics can provide [1]. On the other hand, water has low viscosity relative to mineral oil, and can in general only be recommended applied for supply pressure up to 160 bars.

Water is the most natural fluid in the world and nothing in nature is more closely associated with cleanliness, freshness, and purity that pure water. Therefore the use of pure water form the tap without any kind of additives for hydraulic systems suited for motion control and power transmission for machines and equipment, and water mist systems is a *natural approach.*

RESEARCH AND DEVELOPMENT

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, [2]-[26]. Briefly, the main specific problems to overcome are

- avoid *corrosion*, using right combination of materials and surface finishes
- avoid *flow erosion* due to very low viscosity and turbulent flow
- control of *lubrication* with water; *tribology*, design internal parts and gaps
- surface treatment, tribology, achieving low friction surfaces with water lubrication

- control of *internal leakage* to secure satisfaction of high power efficiency
- control of *external leakage* to secure satisfaction of high power efficiency
- optimisation of the water nozzle performance for generation of water mist and moisturising units.

These challenges have been undertaken by Danfoss and other companies and by researchers. Today, 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 turnover in Figure 1 and Figure 2.

TEMPERATURE AND PRESSURE RANGE

The permitted operational temperature range is +3 ^{0}C to +50 ^{0}C max. due to the nature of pure water, Figure 5. Today, as an example the pressure range of the Nessie® products is up to 160 bar. Furthermore, the range for components and water pressure up to 50 bar and for medium power range up to 4 kW are available.

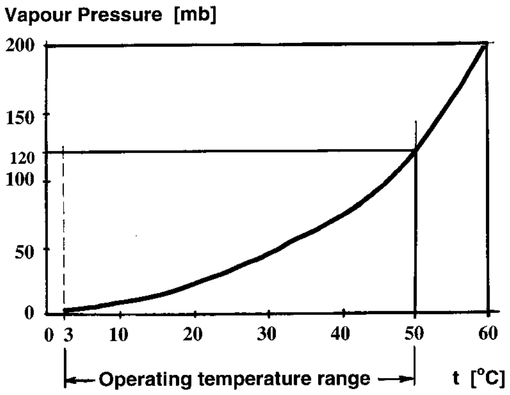

Figure 5 Vapour pressure characteristic of water

The maximum temperature of +50 ^{0}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.

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 6. The dynamic viscosity of mineral oil (30 cSt at 55 ^{o}C and atmospheric pressure) is around 30 times that of pure water (1 cSt at 20 ^{o}C and atmospheric pressure).

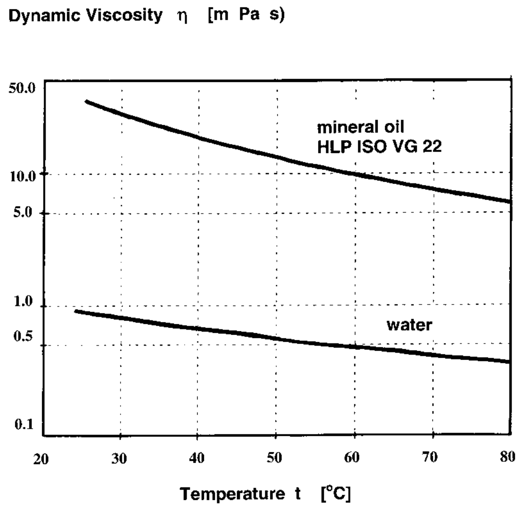

Figure 6 Viscosity of water and mineral hydraulic oil

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

$$Q_L = \frac{bh^3}{12L\eta}\Delta p \tag{1}$$

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 (e.g. gap between piston and bore), the ratio of leakage water relative to leakage of a typical hydraulic oil is

$$\frac{Q_{L,W}}{Q_{L,O}} = \frac{\eta_{Oil}}{\eta_{Water}} \cong 30 \tag{2}$$

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

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

In most cases, the radial gap, for example in piston pumps, cannot be reduced in practise, because there is a risk for locking the pistons due to thermal expansion caused by friction between mechanical parts. In design of water piston pumps, the gap clearance between piston and bore can be reduced to less than 10 μm without difficulties. Further, according to the inverse Reynold's equation, the spot underneath an elastic seal relative to a rod where $\frac{dp}{dx} = 0$ then the height of the gap is h_0 is proportional to $\sqrt{\eta}$. Comparing this value for water hydraulic relative to oil hydraulic gives the ratio

$$\frac{\mathbf{h}_{0,water}}{\mathbf{h}_{0,oil}} = \sqrt{\frac{\eta_{Water}}{\eta_{oil}}} = \frac{\mathbf{1}}{\sqrt{\mathbf{30}}} = \mathbf{0.18} \qquad (4)$$

The global gaps for oil hydraulics is in the region of around 1/10 μm. That means, for the same given conditions the gap for water hydraulics should be a factor 0.18 less against the seal.
Due to the lower viscosity of water the dynamic pressure that builds up is significant lower compared to the same conditions with oil in wedge gaps. Assuming equal length of the wedge gap, the mean gap width has to be reduced according to the ratio

$$\frac{h_{m,water}}{h_{m,oil}} = \sqrt{\frac{\eta_{Water}}{\eta_{oil}}} = \frac{1}{\sqrt{30}} = 0.18 \qquad (5)$$

The same assumption could approximately holds for the micro-hydrodynamics at the wedge gaps of the surface structure. This implies that gaps have to be much smaller to build up the same hydrodynamic bearing forces as with oil. In this case it is important to avoid the risk of contact between solid parts and risk of higher wear.
Use of *hydrostatic bearing* is an efficient solution for separating the bearing surfaces. Furthermore, use of materials with low friction and resistant to wear is important. Stainless steel W. No. 1.4057 and reinforced polymer PEEK from the polyetherketone family are used by Danfoss 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. The trend shows the increasing number of application areas for modern tap water hydraulic components, in particular the used for design of environmental friendly industrial machinery, robots, and systems.

SOLUTIONS FOR WATER HYDRAULICS

Due to the significant advantages of tap water hydraulics, water hydraulic system solutions can often compete with pneumatic and electrical solutions in many industrial areas and with oil hydraulics in situations where machines and equipment have to operate in environmentally sensitive surroundings. Typical important application areas for tap water hydraulic solutions are:

- open-ended systems
- closed loop hydraulic systems
- combined open-ended and closed loop systems
- food processing industry
- chemical and pharmaceutical industry
- mining industry
- steel industry
- nuclear industry
- wood processing
- lumber drying processes
- humidification (energy saving, HVAC)
- water mist fire protection and fighting systems
- high pressure water cleaners

During the last few years Danfoss High-Pressure Water Solution developed dedicated APP pumps and accessories for sea-water and technical water to be available on the market. A unique breakthrough is the process called

- *Reverse Osmosis* (drinking water from sea-water)

Super Duplex stainless steel to operate with sea-water.

It is not more difficult to design water hydraulic systems than oil hydraulic systems as long as the required guidelines and design rules recommend for water hydraulics are followed by the design engineers, the technicians and service personnel.

WATER HYDRAULIC MACHINES

Today, water hydraulics is applied in design of modern mobile machines that have to operate in environmentally sensitive surroundings. In the following paragraphs two examples are presented.

Environmental waste packer lorry

All hydraulic functions for lifting and filling on the designed Waste Packer Lorrys for the Gothenburg Municipal are shown one of them in Figure 7.

Figure 7 Water hydraulic waste packer lorry

The functions are controlled and operated by water hydraulics to protect the environment in the city. The benefits are no risk of oil spill drops or product contamination, and easy to clean. The vehicles have el-hybrid motors.
A water hydraulic axial pump drives the hydraulic system, PAH 80, providing a flow of 115 l/min @ 140 bar. A water hydraulic motor MAH 12.5 drives the winch. All the linear motions such as open/closing tail gate, ejector plate, skip shaker, bin lift, carriage plate and packer plat are controlled by the 36 water hydraulic valves that drive the 11 water hydraulic cylinders. The control system includes a PLC. In order to operate degrees below freezing points, harmless propylenglycol has been added (sugar based glycol that a.o. is use in the food industry ad sweetener). A significant benefit is no risk of hydraulic oil spill drops on roads, and do reduce the use of annual around 18,000 hydraulic oil for machines per year in Gothenburg. In Sweden around of 40,000 ton of oil hydraulics are coming from leaks, and 1 litre of hydraulic oil can spoil a farmer area for crops or 25,000 drinking water reservoir. In many cases water hydraulics are solutions for environmental areas.

TAP WATER HYDRAULIC MACHINERY DESIGNED FOR HYGIENE IN FOOD INDUSTRY

Some typical examples of design for hygiene are presented in the following to illustrates application areas where tap water hydraulics can offer a design for hygiene solution in the food processing industry, which can not been solved by use of a bio-oil based hydraulic system. Compared with pneumatic solutions, water hydraulic solutions have the significant advantages of easy to flush and clean according to the requirements and regulations in the food processing industry, lighter weight of cutting tools (saws etc.) due to higher power density, much higher efficiency and saving energy costs. A tap water hydraulic driven meat burger-machine is shown in Figure 8. A motor is driving the spindle for the meat cutting of beef meat, and two water cylinders for motion control are used to form the five meat burgers in one row, and one cylinder for moving the forming tool horisontally. The machine is very environmentally friendly and very easy to clean daily.

Figure 8 Tap water hydraulic driven burger-machine

Figure 9 Ice fill machines for 400 ice per minutes with one motor, 3 linear servo cylinders and 3 end cylinders

An automatic controlled ice fill machine for Tetra Pak Hoyer in Denmark with a capacity of 400 ice per minutes driven by electro water hydraulics with one motor, 3 linear servo cylinders and 3 end cylinders is shown in Figure 9.

An automatic control tobacco cutter machine for Universelle Germany is shown in Figure 10 with two water hydraulic cylinders to avoid no risk of pollution, easy cleaning and save energy.

Figure 10 Automatic control tobacco cutter machine driven by water hydraulics with two cylinders

A water hydraulic drive unit for wing press equipment for the aero plane factory of Palamine in UK want to avoid no pollution on ground, no fire risk and no oil is shown in Figure 11.

INDUSTRIAL HIGH PRESSURE WATER CLEANING

A very important industrial application of tap water hydraulics is high-pressure water cleaners. A typical example is cleaners for malt reservoirs in beer breweries shown in diagram in Figure 12. A pump, PAH 32, generates a pressure up to 160 bar. The pump supplies the two high-pressure clean guns connected to a main water supply ring net via quick couplings. The installation supplies the user with a very flexible and effective high pressure cleaning system.

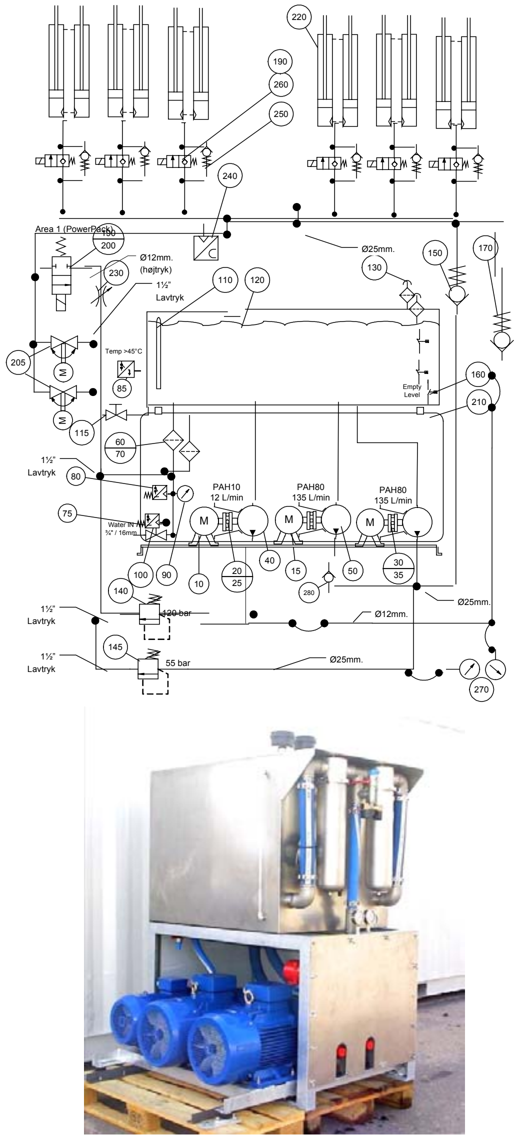

Figure 11 Water hydraulic drives for wing press equipment for an aero plane factory

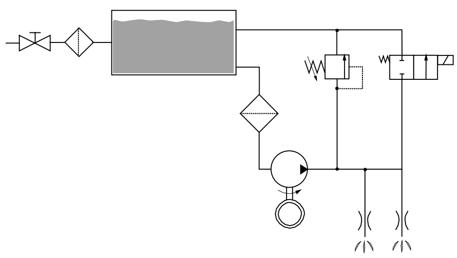

Figure 12 Diagram of a high pressure water cleaner

The high power density gives a very compact cleaner unit. Further advantages are no oil lubrication due to lubrication of the components by the tap water itself, and the system requires minimum maintenance.

HUMIDIFICATION

Today's several installations of humidification units with pumps, nozzles and accessories are in use for high-pressure water mist. It is needed indoor such as in super markets selling fruits and in textile industry. Indoor air quality is determined by a number of factors. Humidity is one of the most important measures directly affecting human beings as well as animals, plants and almost any material. Therefore, the ability to adjust humidity, both humidifying and dehumidifying, is of importance and found in numerous applications and industries.

Human beings, for example, feel most comfortable at humidity between 40 and 60% rH and a temperature of 22°C / 72°F. Correct humidity minimizes risk of infection with contagious disease, growth of bacteria or fungi, as well as impacts on performance of man and machine. There are hundreds of examples of how humidity affects productivity of manufacturing processes and the quality of products.

A high-pressure pump boosts water to a pressure typically between 70-100 bar. Specially designed water nozzles atomize the water in billions of extremely small droplets. The water mist jets are injected either directly into the open space or into the duct system of an air-handling unit as shown in Figure 13. A humidification controlled green house for crops is shown in Figure 14.

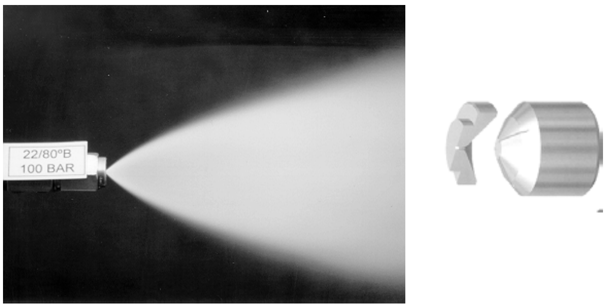

Figure 13 A nozzle and generation of water droplets

The principle works adiabatically, which means that the evaporation heat required for transferring water from liquid state into gas is obtained by the surrounding air, resulting in a temperature decrease called adiabatic cooling effect.

WOOD PROCESSING

Special designed water mist solutions are installed for wood processing, in particular for sawmills to avoid dust and to improve lubrication and cooling of saws as shown in Figure 15 as well as for lumber drying shown in Figure 16.

Figure 14 Humidification control in green house

Figure 15 Wood processing for sawmills

A new water hydraulic based Lumber Drying Concept has been developed and tested, see Figure 16. This concept offers faster drying of lumber in a kiln with substantial benefits to capacity, wood quality and the overall economy.

Figure 16 Control of process for lumber drying in a kiln

Optimum profitability in the lumber business depends on the knowledge and experience of handling lumber as living wood material. Automation has become an indispensable tool for optimising the lumber drying process. A newly developed high-pressure water moisturising unit, making up the core of this concept (Nessie® Wood Concept) that improve the control of the lumber drying process. The new high-pressure water moisturising unit operates at pressures between 80-100 bar and special design nozzles generate extremely small water droplets evaporating immediately.

A vital part of the system is the nozzles that distribute the water droplets into the kiln. In Figure 13 is shown a nozzle and generation of water droplets. The system consists of a tank, a pump, a motor, valves, nozzles and a control system. The evaporated water quickly covers the total surface of the lumber in a kiln. The results are tangible

- Shorter payback time of the kiln plant: a markedly shortened drying period increases capacity.
- Increased wood quality thanks to a more lenient drying process.
- Reduction of waste.
- Higher product selling price.

The high-pressure unit provides these benefits by ensuring optimum controlled climatic conditions in all phases of the drying process: *heating, drying and conditioning*:

In the *heating phase* air humidity must be increased in order to obtain intense heating of the lumber – otherwise the danger of cracking and deteriorating is immediate. The humidity supplied by the Nessie high-pressure water moisturising unit condenses evenly on the surface of the entire pile, thus providing lenient heating of the lumber. Moreover, the heating phase can be reduced to 4-6 hours, compared to the 14-24 hours typically required by traditional moisturising of softwood. Applying the high-pressure water moisturising unit furthermore renders the widespread sprinkling of heat exchangers superfluous. The accurate process control ensures that the exact water amount for optimum climatic conditions in the kiln is optained, leaving out any need for additional evaporation. This cuts down maintenance and replacement costs for otherwise rapidly corroding heat exchangers.

In the *drying phase* the climatic conditions in the kiln are likewise controlled by means of high-pressure water. The technology is superior to steam applications that may cause increased energy supply and thus undesirable increase of temperature. Experience from some 200 applications already running world-wide shows that accurate and quickly reacting temperature control can be obtained when utilising high-pressure water technology in the drying phase. Additionally, water consumption is as low as 1 litre per cubic metre softwood per drying hour if you replace a traditional low-pressure water application with a high-pressure water moisturising unit.

In the *conditioning phase* lumber is moisturised with water in order to reduce tension and to equalise the humidity quotient throughout the lumber. Using high-pressure water, an even distribution of droplets on the lumber surface is achieved.

Steam applications make up an alternative to the Nessie high-pressure water moisturising unit. However, supplying steam may cause undesirable heating at the beginning of the conditioning phase. This adverse effect cannot occur using the high-pressure application, since it works on cold water exclusively.

A key advantage is that lumber drying with the new high pressure water moisturising unit only requires one system for the entire process: heating, drying and conditioning. The range of droplets before steam generation is 70 times shorter compared to traditional low-pressure systems (on identical temperature conditions). The drop size is 7 times smaller. The system is the most even and all-embracing evaporation on the market.

FIRE PROTECTION AND FIGHTING SYSTEMS

Very effective tap water hydraulic fire protection and fighting systems have been developed and taken in use. Figure 17 shows an typical fire fighting application.

Figure 17 Fire fighting by high pressure water hydraulics for generation of water mist

The water pressure is generated by a PAH 32 pump (max. 160 bar and max. flow 44 l/min) and a pressure relief valve secure protection against excessive pressure. The water mist system replaces Halogen systems (CFC) that have the disadvantage of damaging the ozone layer. The water mist is generated through special designed nozzles and small quantities of water can be used to extinguish fires, including those involving hydrocarbons and electrical controls

WATER HYDRAULIC MARITIME MACHINERY

Novel Boatscrubbers, a developed automatic boat washer to control and drive by high pressure water hydraulics for motion control and rotation of the brushes to clean the boats is shown in Figure 18.

Figure 18 Automatic water hydraulic boat washer

The benefits are significant due to the solution means that the boat-body can be paint with a silicone process to eliminate the pollutions from traditional boat painting that contains dangerous particles that seriously pollute the seabed of the harbours and sea-water.

REVERSE OSMOSIS
- DRING WATER FROM SEA-WATER

Recently, a unique breakthrough with the success of development, design and implementation the process called

- *Reverse Osmosis* (drinking water from sea-water)

by novel dedicated pumps and valves using Super Duplex stain steel to operate with sea-water. A dream of generation drinking water from sea-water by reverse osmosis process is today reality by using dedicated APP pumps and VCM valves from Danfoss.

Figure 19 Drinking water from sea-water by reverse osmosis process by APP pumps and VCM valves

Figure 19 illustrates drinking water from sea-water from an installation from Lanzarothe has resulted in an overall low as 2.65 kW/m^3 fresh water production and saving running costs.

TRENDS IN R&D FOR WATER HYDRAULICS

The novel developed DTU robot manipulator with three joints, each controlled by a servovalve for a water hydraulic rotary vane actuator, has three links and is able to sustain a maximum load of 85 Kg with 1.9 m of extension, shown in Figures 20, 21, and 22. For a dexterous use, a load of 50 Kg has not to be exceeded. The slave arm weighs around 90 Kg and the actuators generate 2156 Nm, 1056 Nm and 448 Nm, respectively.

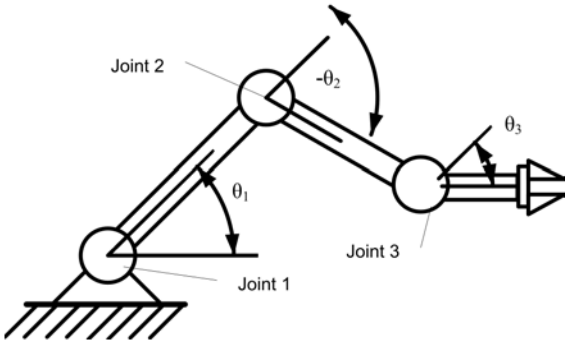

Figure 20 Schematic of the 3 DOF robot manipulator

The robot arms have servovalves to control flow rates. This solution allows the use of rigid connection between the servovalves and the actuator.

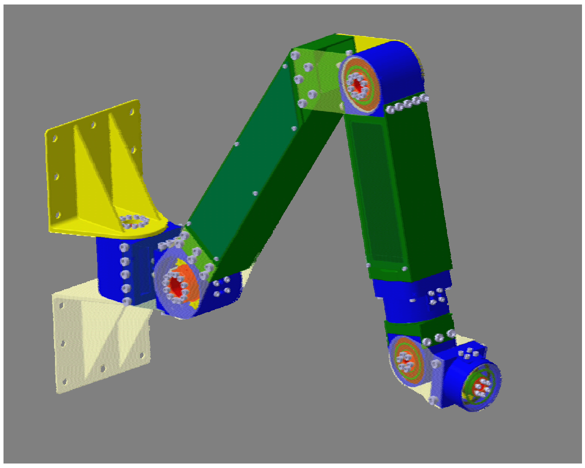

Figure 21 CATIA model of the arm 1 and arm 2 of the 6 DOF robot manipulator

The results [26] include engineering design and test of the proposed simulation models compared with IHA Tampere University's research measurements from a similar robot manipulator driven by tap water hydraulic components, Rameda, 2004, [24].
Simulation results behaviour of the tool point centre (TPC) of the slave manipulator arm with 3 DOF is shown in Figure 23.

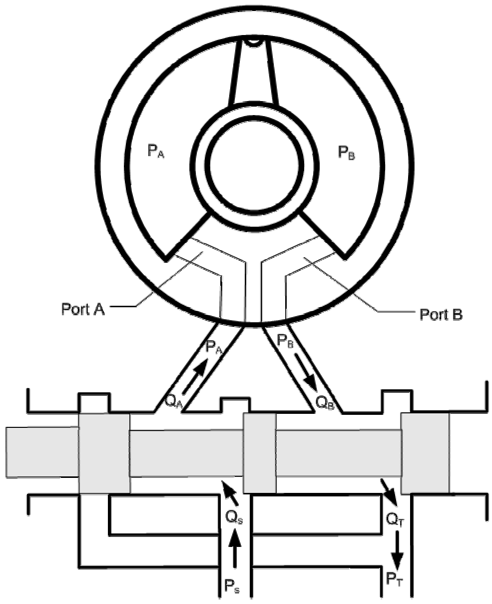

Figure 22 Schematic of water hydraulic vane actuator

A typical motion control application the slave arm was tested by defining the following complete test path trajectory build up by geometric elements as part of circles, strait lines, corner and ramp as reference input to the robot controller.

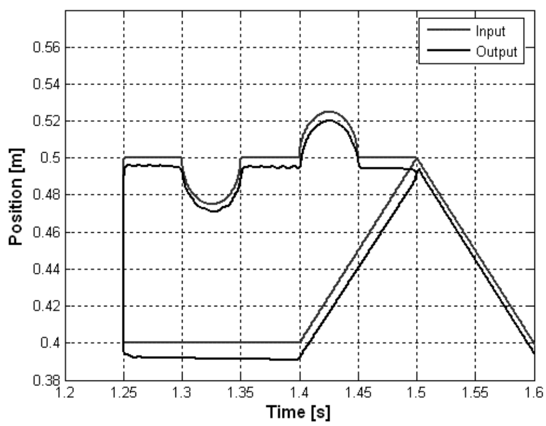

Figure 23 Tool point centre trajectory following a complete reference input path shape

The CUT's water hydraulic test rig facility with actuator operates arm, water hydraulic valves and cylinders shown in Figure 24 was built for R&D activity. It includes power supply, input signals generator, sensors for pressure, temperature, flow rate and position measurement system. As applied for the DTU water hydraulic test facility similar hydraulic components for the CUT test rig are mainly Danfoss Nessie products, including proportional valves, [23 and 25].

Figure 24 A CUT water hydraulics test manipulator

CONCLUSION AND OUTLOOK

Trends confirm that design of water hydraulic application is a *natural approach* to solve many of the major environmental pollution problem and problems in industries, which cannot accept contamination of products and problems of fire and explosion risk.

The contributions presents and discusses a R&D-view on trends in development and best practise in design of both low-pressure and high-pressure tap water hydraulic components and systems for motion control as well as open-ended solutions various industrial applications. The business sales history confirms that the use of modern water hydraulics shows a growing turnover per year. Important industrial applications and the benefits are presented with focus on process industries such as food industry, pharmaceutical processes, water mist fire fighting systems, high water pressure cleaners, water moisturising systems for a humidification, wood processing (sawmills and lumber drying processing), and industrial mobile machines and municipal machines working in environmentally sensitive surroundings.

Recently, a unique breakthrough with the success of development, design and implementation the process called *Reverse Osmosis* (drinking water from sea-water) by novel dedicated axial pumps and valves using Super Duplex stain steel to operate with sea-water.

Today's challenge is to include design of water hydraulic systems and industrial solutions in education of engineers, and research for PhD students. Several universities have undertaken the challenge, and more and more universities do include water hydraulics as an important technology complementary to oil hydraulics, pneumatics and electrical power engineering to best practice for design of solutions for the future.

ACKNOWLEDGMENTS

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