2012 Dutch Fluid Power Conference

FEDA aandrijven en automatiseren

Cartridge valve for use in seawater

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1. Introduction

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The application of water as a medium to transmit power is not new. It might surprise you to know that water was already being used in around 0 A.D. to open temple doors. The inventor of this ingenious system was Hero of Alexandria, an ancient Greek scientist, who made use of water pressure (combined with heat to create the required pressure differential) to automatically open and close temple doors. You can find a clever animation of this on Wikipedia (see figure 1).

Figure 1. The temple doors designed by Hero of Alexandria open and close automatically, partly through the use of water

1.1. Water-hydraulics in the 21st century

The use of water to transmit power is currently gaining popularity for a variety of reasons. Firstly, with the increasingly heavy focus on the environment, potential oil leakages from hydraulic installations are decidedly unwelcome. In addition, American research indicates that frequent physical contact with hydraulic oil can cause certain types of cancer. Obviously, this can be solved simply enough by preventive measures when handling and working with this oil, but it does raise the issue that this medium is not entirely harmless. Today there is research under way around the world, including in China and Japan, into water-hydraulics and its possibilities. The Netherlands must not fall behind.

1.2. *Offshore applications*

Water-hydraulics offer extensive possibilities, many of them in offshore applications. Hydraulics are increasingly being deployed to perform work below the water surface, sometimes at great depths, for purposes such as mineral extraction from the sea bed. Oil leakages in the marine environment are unacceptable, so it would be highly convenient if the same could be achieved using seawater. After all, this medium is on hand in adequate quantities, and when the work can be done using pure seawater, we no longer even need to include a return hose in the system.

2. Materials for manifold and cartridges

One of the companies that have made serious work of water hydraulics for offshore applications is IHC, with the development of the 'hydrohammer' (see more on this in the paper by Michael Schaap on page 183). The specific requirement is that the hydrohammer

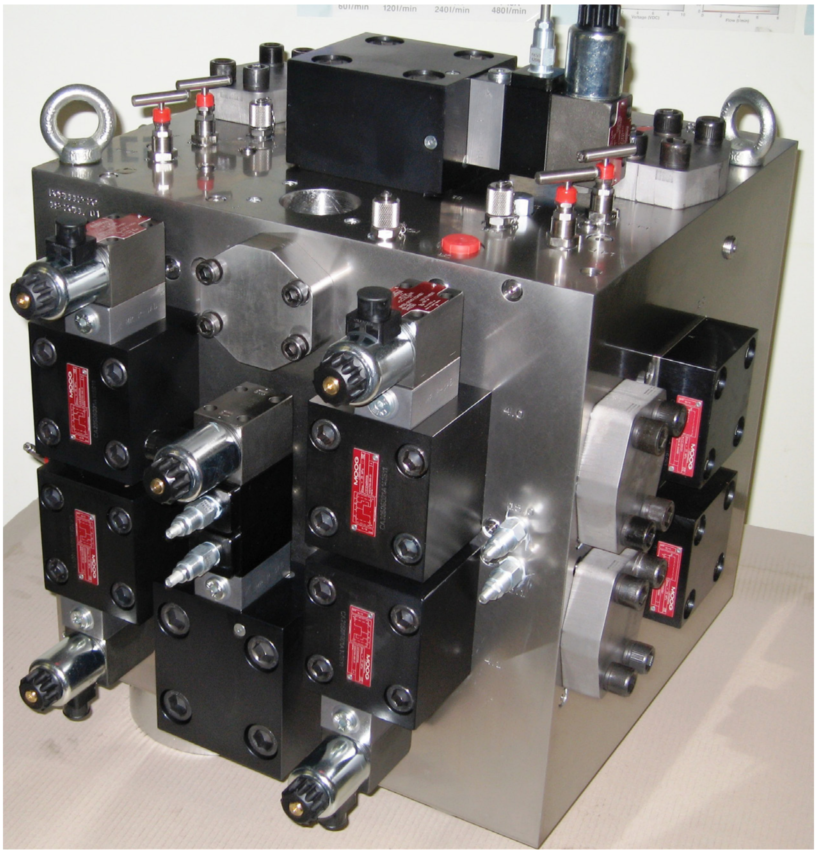

Figure 2. Manifold for the Hydrohammer

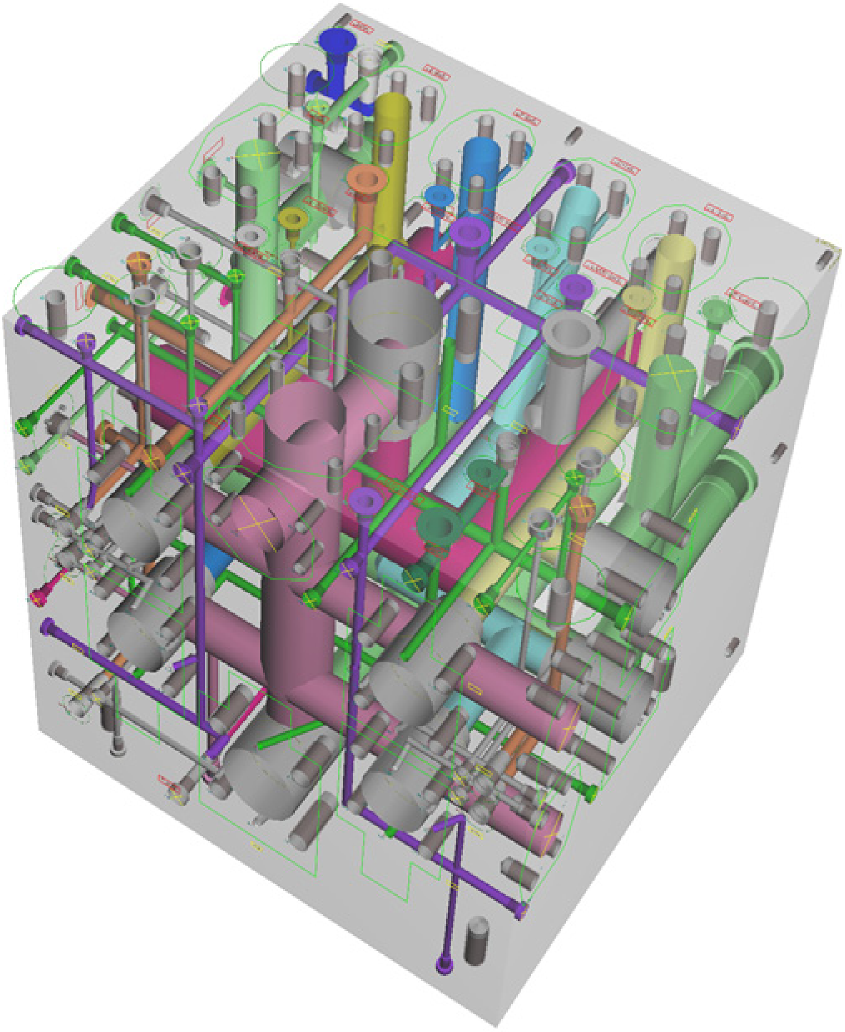

Figure 3. Manifold for the Hydrohammer

operates on seawater, and Hydroplus was asked to take responsibility for the pressure medium supply. Much as it always does for any other hydraulic installation, the company developed a manifold for this purpose, making use of cartridges (figures 2 and 3).
The main difficulties that arise when using seawater as a pressure medium are the lack of lubricating properties, and the both corrosive and erosive nature of water. Among other things, this means that stainless steel cannot be used for the manifold: the low compressibility of the water causes flows that lead to extreme wear in the material. The only option is to turn to more exotic materials.

2.1. Duplex steel

On the advice of IHC, which has conducted research into materials suitable for water-hydraulics, Hydroplus selected the material Duplex steel for the manifold. Duplex steel differs from other types of stainless steel in its special chemical composition, linked to a specific annealing procedure, [1]. This combination yields a metallurgical microstructure comprising 50% ferrite and 50% austenite, which possesses exceptional mechanical properties and a high resistance to corrosion.

Duplex steel is characterized by:

- excellent corrosion-resistance,
- high mechanical strength,
- high wear-resistance and
- good suitability for welding.

2.2. Cartridges

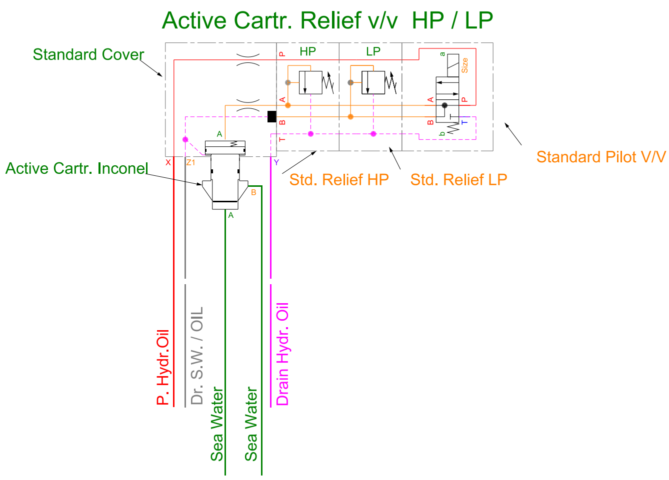

Figure 4. Schematic diagram of a system in which the control of the valves is achieved using oil, while the main flow consists of seawater

The required cartridges turn out to be more of challenge, especially when it comes to the price. For the cartridges to be controlled using sea water, the pilot valves also all have to be suitable for this medium. There are valves on the market that can be used with fresh water, but these are unsuitable for application in saline environments. Because there are practically no standard components available for seawater-hydraulics, these components have to be separately developed and manufactured. Single units and small series are already expensive enough, but the costs quickly mount up when the job requires exotic materials, as in this case. For comparison: a standard valve costs about 70 Euro.

Stainless steel variants are around 2500 Euro, and valves built from Inconel (the material we ultimately chose) are in the neighbourhood of 10,000 Euro per unit. Inconel is the trademark for a family of nickel alloys that is resistant to high temperatures and offers strong corrosion resistance.

3. Cartridge design

To keep costs manageable, we have opted for a hybrid approach, employing both pure water-hydraulics and pure oil-hydraulics. Under this approach, valve control is accomplished using conventional oil-hydraulics, while the main pressure flow consists of seawater. The principle is illustrated in figure 4. For this solution we have chosen an active cartridge that incorporates physically separated areas for the pilot pressures (pilot areas) and main pressure medium (seawater). Below-left in figure 4 we see the incoming hydraulic oil that supplies the standard valves before returning to the power pack via the line below-right. The pilot pressure port Z1 as shown is connected to a separated drain line. This enables any leakages of oil/water to be detected, so that further damage to the system can be minimized. However, this feature has only been incorporated during the test phase.

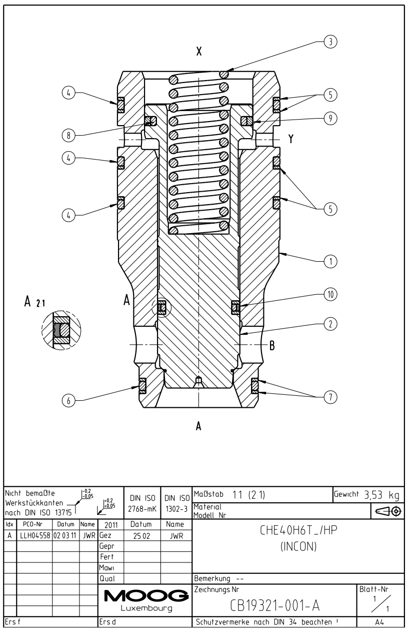

Figure 5. Cross-section of an Inconel cartridge with reduced rubbing surfaces to minimize friction

3.1. Standard versus exotic valves

The use of a cartridge with separated pilot areas (see figure 5) makes it possible to use standard pilot valves. In the solution for the hydro-hammer, this means a saving on

16 Inconel valves, so that instead of 26, just 10 valves in this exotic material need to be procured. A saving of some 150,000 Euro. The quantity of oil required for this solution is minimal, and this in turn requires only a small pump with a capacity of 3 to 4 litres/min and an oil tank with a volume of 10 to 15 litres. A quantity that, in the event of leakage, would not normally cause any serious problems for human health or the environment. The two problems alluded to earlier, increased wear due to the low compressibility of water and the lack of lubricating properties, are solved by the application of the material Inconel, and by minimizing the rubbing surfaces.

3.2. Control functions

Inconel cartridges with standard valves can be supplied as check valve, control valve, pilot valve, 2/2 directional (open/close), pressure relief valve and reducing valve. All functions can also be accomplished with proportional control (servo) valves. Compared to standard variants, Inconel valves have the disadvantages of higher price, plus a reduced dependability due to the risk of seawater seeping under pressure through micro-fissures orsother microscopic irregularities. Moreover, standard pilot valves have a shorter lead time, plus they can be supplied with a wide range of control functions, and (if necessary) in explosion-safe variants.

4. Testing

Some ten months ago, IHC started initial testing with this Duplex manifold and the use of the new and specially-developed Inconel cartridges. The tests are performed using brackish water, pre-filtered at 10 µm. Until now, no symptoms of wear have been observed. The disadvantage of this test set-up is that the hydrohammer is constantly running, so that the valves in the manifold to control the passage of seawater are practically always open. This results in a more or less static set-up, in which the cyclic performance (dynamic behaviour) of the special valves remains untested. The standard oil valves cycle around 40 times per minute.
We are now awaiting a larger project, in which the solution can prove its feasibility under more realistic circumstances. However, we do not anticipate any problems.

5. Manifold production costs

The high costs of the definitive solution are related to both the materials used in the cartridges and the manifold, and the required production methods.

5.1. Material

In respect to the materials used, there are several possibilities for bringing down the cost. For example, by following the approach described earlier. Moreover, in the cartridge the evidence of erosion due to the volume flow is present at just a few points, namely the

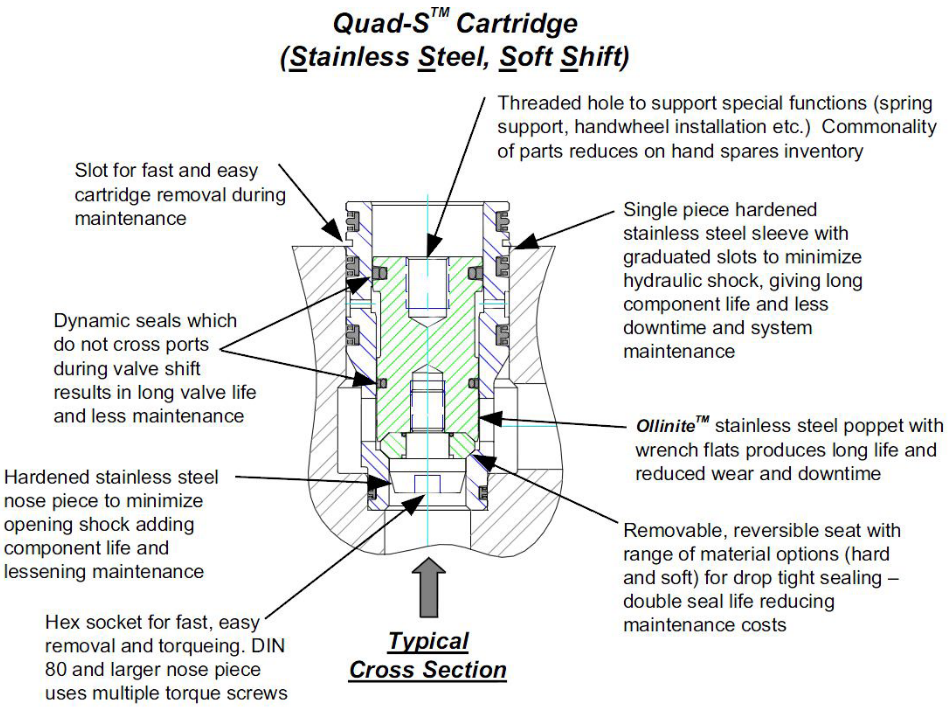

Figure 6. American-made cartridge with exchangeable nose

cartridge nose valve seat and possibly the outflow opening. In this light, it is not really necessary to fabricate the entire cartridge from Inconel. For example, one can choose to manufacture the vulnerable parts as inserts, and produce the remaining parts (body and piston) using more conventional materials, as shown in figure 6. New technologies such as nanotechnology in the form of a coating also deserve further investigation.
To extend the service life of the cartridges, it is advisable to look into a more suitable design for the valve and seat, aimed at limiting harmful high flow speeds. One possibility might be the valve design used in a typical internal combustion engine.

5.2. Production methods

The manufacture of a manifold, especially in exotic materials, is a labour-intensive and costly production process. Production in Duplex steel can easily take as much as 14 times as long as working with steel. So it is essential to look into new techniques for achieving this.
One possible solution may lie in working with ‘multilayer’ technology. This technology brings to mind some of the rapid prototyping / rapid manufacturing techniques in which products are rapidly built-up as layerssin processes such as laser sintering. A similar principle can be applied to the production of cartridge valves. Thin layers of the desired

Figure 7.
By applying multi-layer technology, it may be possible to reduce the cost of a manifold made of exotic materials

material are cut from sheets (e.g. using laser cutters) and subsequently stacked and joined. This is a more inexpensive way to fabricate products from Inconel.
Voith is a company with experience in this field (figure 7), in cooperation with Trumpf, a manufacturer of laser cutting machines. The major limitation at this time is in achieving a good bond between the many layers, but as soon as developments are sufficiently advanced, this will create considerable freedom to design practically any product, and especially solve the problem of undercuts. See also figure 8 on the next page, which shows a valve manifold in negative.

6. Future

In respect to the future of water-hydraulics, or more specifically, water-hydraulics using seawater, future developments will be focused on the use of untreated (or minimally-treated) seawater. This calls for a high degree of cooperation between business and knowledge institutes. Among others, in the area of research: which materials can withstand use in seawater; what is the influence of seawater on systems that work with high pressures; what needs to happen in the area of filtration; and so on. Apparently, at 32 °C and pressures at or above 410 bar (the operating pressure of the hydrohammer), seawater is a more aggressive corrosive than hydrochloric acid.
To arrive at practical solutions, Hydroplus anticipates that developers will literally have

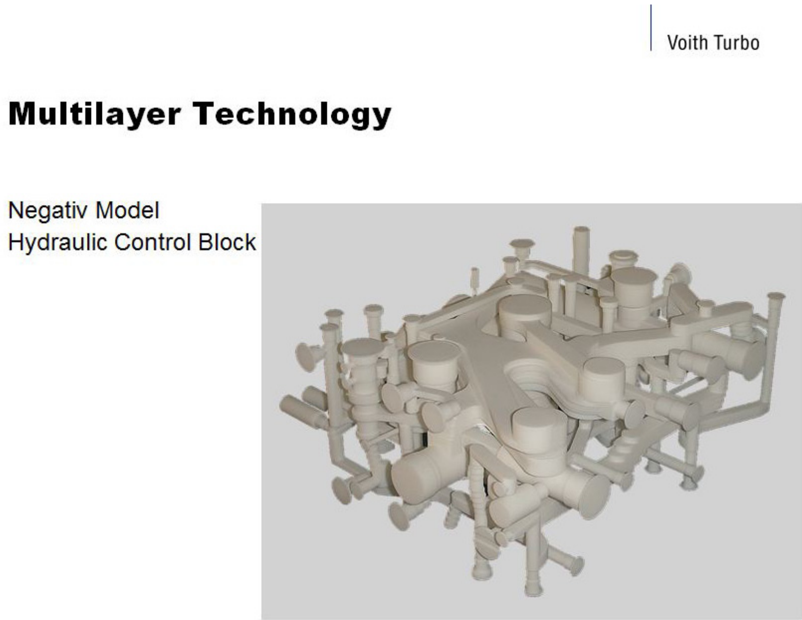

*Figure 8.
Multi-layer technologies offer unheard-of flexibility in the design of manifolds and other complex shapes*

to get off the beaten track, set aside the standard solutions for a while, and explore the unknown. For the initial phase, it is also recommended to keep the range of valves to a minimum in order to save costs, and to produce the valves that are needed in greater volumes.

About Hydroplus

Hydroplus b.v. specialises in the design, assembly and testing of hydraulic manifold systems within the fluid power industry. The company was started in 1995, working alongside its sister company Mabotec b.v. Hydroplus's expertise lies in the company's knowledge of cartridge valve manifold systems. Mabotec specialises in the manufacture of hydraulic manifold blocks up to nine tonnes in weight.

References

[1]] 'Duplex staal; Kort verleden doch een grote toekomst' (Dutch: 'Duplex steel; Short past but a big future'). Article by Karel Bekkers, metallurgist and welding technique consultant, and Robert van Voorst, managing director, Titan Projects bv, from 'Roestvaststaal' no. 8 / 2009.