MINERAL OIL-BASED HYDROSTATIC DRIVES AS THE BASIC DRIVE SYSTEMS IN THE CONSTRUCTION OF OFFSHORE EQUIPMENT PROJECTS

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Abstract

The aim of this article is to present the components used in the production of mineral oil-based hydrostatic drives as the basic drive systems for the offshore industry. The article contains descriptions of the components of the said systems, with the description of their suitability for mineral oil operation and offshore applications.

Keywords: hydrostatic drives, offshore industry, offshore equipment projects.

1. Introduction

Projects based on the construction of offshore equipment need to follow strict technical requirements. A drilling platform in an open sea needs to provide adequate safety for the drilling operation and the crew. This is achieved not only through special equipment (sensors, blowout prevention equipment, drift compensators, etc.) but also by following technical procedures in the construction of all the platform's hardware in the mechanical, hydraulic, and electrical areas.

Making the proper design choices is usually an art of making compromises, but with the safety and efficiency of operations as the primary concerns, certain parameters can be reliably set.

The aim of this article is to present mineral oil-based hydrostatic drives as the basic drive systems to be considered when planning and carrying out offshore equipment projects in open-sea oil deposit exploration and extraction.

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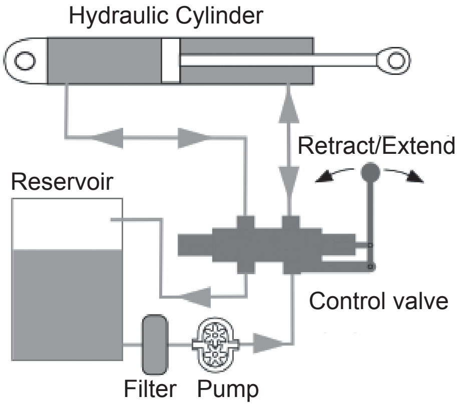

Fig. 1. basic hydrostatic drive system. Author: Duk, source: Wikimedia Commons, license: CC-BY-SA-3.0

2. Power sources

Hydraulic pumps, which are used in hydrostatic drive systems, convert mechanical energy – supplied as torque or speed – into hydraulic energy in the form of flow and pressure. This is the basic requirement, summarised in one sentence, but specific requirements for individual applications are much more complex and involve medium compatibility, required pressure ranges, temperature limitations, noise levels, costs, etc. The HY30-3300/UK Parker Hannifin pump catalogue, even though it encompasses only the basic fixed-displacement gear pumps (see below for clarification) is almost 100 pages long, and catalogues offering information on Parker's other hydraulic pump types are usually at least that long. Even though most pumps share a common characteristic in which they work according to a displacement principle, where the fluid enters into sealed chambers inside the pump from the inlet port and is displaced through the outlet port, the specifics are varied. A good overview of the displacement pumps can be found in the first volume of The Hydraulic Trainer, and the individual unit types will be described following that publication.

The most commonly used displacement pumps are gear pumps, where the volume is created between the gears and housing in an external gear pump (having two gears), between the gears of a single gear wheel, housing and spacing/sealing elements in an internal gear pump or – as is the case with a ring gear pump – between a gear wheel that has one tooth less than the internally geared stator (the rotor moves in a planetary motion).

Another used type of pumps is a screw pump, where the displacement chamber is found between the threads of a screw and the housing of the pump.

There are two major variations of yet another pump type: the vane pump. The volume in such units is generally created between the circular rotor, stator and vanes in a single chamber pump. The twin cam forms of the stator in a double chamber vane pump make two displacement processes possible in one revolution.

The last of the most popular pump types relies on the use of pistons. Radial piston pumps can make use of an eccentric cylinder block or an eccentric shaft. In the former case, the pistons rotate within a rigid external ring. In the latter, the eccentrically-rotating shaft causes oscillating movements of the pistons.

Piston pumps are also available in an axial setup. The bent axis design allows the piston stroke to be limited by the angle at which the body of the pump is in relation to the port plate, while with a swashplate design the stroke of the pistons is limited by the angle at which the said swashplate is set.

Available subject literature mentions other types of hydraulic pumps, apart from displacement ones. Galal Rabie adds rotodynamic and special effect pumps to the above list. The former type is more suited for hydrodynamic applications, because – as the name of the pump type suggests – the rotodynamic pumps work by exchanging the momentum between the liquid and the rotor, and will not be discussed further [Rabie, 2009, p. 89].

The special effect pumps work according to different principles, and this category encompasses e.g. jet pumps or airlift pumps; this category will also be omitted.

The pumps can work with fixed displacement (typical for gear pumps which offer only this work mode) or variable displacement, which is available with all the other pump types – as Galal Rabie states, the second variety is used for two rationale: economy and control considerations. Also, with different pump designs, a variety of factors must be considered [Rabie, 2009, p. 122]. Displacement pumps, which are the focus of this section, differ in their volumetric efficiency, or losses in delivery caused by leakage [Rabie, 2009, p. 95]. This characteristic ranges from 0.8 for vane and gear pumps to 0.99 for piston pumps. Pressure in pumps is also lost due to friction, where part of the driving torque is consumed to overcome viscous friction in oil and mechanical friction of the pump's elements, depending on oil viscosity, delivery pressure and pump speed.

Even though product literature (e.g. catalogues) specifies design parameters for components, including pumps, these values are rather theoretical and are treated as average or mean [Rabie, 2009, p. 98]. Each chamber in a pump delivers a flow rate that equals the change in its volume, minus the volume that results from the pump's volumetric efficiency. It starts at a value of zero at the start of the stroke, reaches the maximum value midway through the stroke and after this point starts decreasing back to zero. The net pump flow, therefore, is of pulsating type, resulting in non-uniform flow and non-linear action of the working parts (pistons, etc.). Pressure oscillations decrease with the effect of oil compressibility and with an increased volume at the exit line. In axial piston pumps they are also smaller for odd numbers of pistons and flatten as the number of pistons is increased.

Galal Rabie summarises the displacement pump types in a table and provides basic characteristics of each: volume per each stroke, rotation speeds and maximum available pressures [Rabie, 2009, p. 130]. According to this summary, single-stroke vane pumps and georotor pumps provide the lowest pressures of ca. 100 bar, while radial piston pumps can reach pressures as high as 1200 bar, even though their rotation speeds are amongst the lowest (500–2000 rpm).

3. Hydraulic actuators

The loads designed for the hydrostatic machines can be moved with the use of three types of actuators: hydraulic cylinders, performing linear motion, hydraulic motors performing continuous rotary motion, and hydraulic rotary actuators, performing limited angular motions [Rabie, 2009, p. 251].

Typically, a cylinder consists of a piston, a piston rod, cylinder barrel, cylinder head and cylinder cap with the piston rod extruded through the head. The piston and cylinder head are equipped with seals, to ensure internal and external tightness, respectively. The activity of a cylinder is regulated by means of providing different directions and volumes of flow, which translates to the direction and speed of movement. When a cylinder reaches its end position, the movement is suddenly stopped and therefore, in order to minimise impact forces, may need to be cushioned.

Cylinders may be single-acting, where the piston is driven hydraulically in one direction, while return movement is possible by external force or a built-in spring, or double-acting, with both movement directions driven by pressure from the power supply. The latter can be equipped with a single or double rod. Cylinders with mechanical locking elements and telescopic units (single- and double-acting, similarly to the basic design) can also be found.

Amongst rotary actuators, one can find setups where the linear movement of a cylinder is converted to rotary by means of rack and pinion, allowing for bidirectional rotary movement in a predefined scope of distances. Depending on the piston stroke and gear ratio swivels of up to a full revolution may be designed. Piston-type rotary actuators, where two parallel cylinders are pressurised alternately, offer an operating angle of up to 100 degrees. Vane-type rotary actuators, depending on their setup, offer operating angles from 150 degrees (double-vane) to 320 degrees (single-vane).

Hydraulic motors operate on a principle which is the opposite of the principle at which hydraulic pumps operate and offer the user continuous rotary motion. As with pumps, different motor setups are possible, including bent axis piston, swashplate axial piston, vane and gear units. Galal Rabie stresses the design similarity of hydraulic motors to that of hydraulic pumps with each type of motor to be described as a reverse of a pump [Rabie, 2009, p. 268].

4. Energy control elements

A flow of hydraulic energy needs to be controlled if it is to do a useful job; constant load from the hydraulic pumps would mean constant movement of the hydraulic actuators (regardless of the type chosen) which is naturally undesirable, especially with actuators of limited movement range (all other than hydraulic motors).

The basic element that controls the flow of fluid is a valve which may control the pressure, flow rate or the direction of the flow [Rabie, 2009, p. 139]. Control valves are categorised as follows:

1. Ordinary switching valves, further classified as:
   - 1.1. Pressure control valves:
     - a) relief valves, either operated directly or through a pilot,
     - b) pressure reducing valves, either operated directly or through a pilot,
     - c) sequence valves, either operated directly or through a pilot,
     - d) accumulator charging valves.
   - 1.2. Directional control valves, either operated directly or through a pilot.
   - 1.3. Flow control valves:
     - a) throttle valves,
     - b) series pressure-compensated flow control valves,
     - c) parallel pressure-compensated flow control valves,
     - d) flow dividers.
   - 1.4. Check valves:
     - a) direct operated,
     - b) pilot operated – with a hydraulic or mechanical pilot.
2. Proportional valves.
3. Servo valves.
4. Digital valves.

Relief valves serve to limit the operating pressure in high-pressure lines by returning excess fluid to the fluid tank once the predefined pressure is exceeded. The excess pressure causes the valve's spool or poppet to travel into the open position and opens the flow to the return tank. The activation of relief valves may be direct, where the poppet / spool is moved by the excess pressure, or such valves may be pilot-operated, or in other words activated by a second relief valve with very small port diameters. Such setups allow for larger flow rates at lower override pressures when compared to directly-activated relief valves.

Pressure-reducing valves serve to reduce the pressure in a branch of the system where lower pressure ranges are recommended for safe operation. This is done by modifying the size of the throttle areas in spring-loaded valves, where the spring compression adjusts the outlet (reduced) pressure. Pilot-operated pressure reducers are installed in machines where greater flow rates are expected.

Sequence valves serve to initiate a certain sequence of events based on the level of system pressure. Typically, they allow for a separate section of the hydraulic circuit to be powered after certain pressure threshold has been reached [Stryczek, 1995, p. 351], when braking, unloading or load counter-balancing [Rabie, 2009, p. 154]. This type of valves, too, can be pilot-operated, which is a solution for higher flow volumes.

The last type of pressure control valves mentioned by Galal Rabie are accumulator charging valves. Accumulators are described in section 4, for now it will be sufficient to say that they are meant to store hydraulic energy and release it when necessary, thus they need to be charged prior to releasing the energy.

The second type of valves described by Galal Rabie are directional control valves (DCVs). They are used to start, hold or change the flow of the fluid. Their specification quotes the number of controlled ports and the number of control positions. Galal Rabie provides descriptions of two types of DCVs, being constructed with a poppet design and providing support for two lines and three to four control ways and spool type DCVs which are used more frequently, since their construction allows for six or even more ways [Rabie, 2009, p. 157]. Any of the two valve types can be operated in a number of methods, including mechanical operation (hand lever, cam and roller, rotary knob), hydraulic control, pneumatic control, and solenoids.

European product literature, especially that of the producers of hydraulic control elements, relies more on the ball construction of a DCV[3], offering between 2 and 4 ports to be controlled in up to three positions. Butterfly valves can also be found [Doddannavar, 2005, p. 117].

Throttle valves are used to limit the flow in a hydraulic system. Simple flow control mechanisms in the form of throttle valves [Rabie, 2009, p. 179]. do not offer the benefit of precise control of the flow of the hydraulic medium, since this parameter depends on the current pressure inside the hydraulic system pipelines (and on the shape of the throttling opening [Lang, 1991, p. 244], but this issue can be addressed by proper design of the valve), so there exist pressure-compensated throttle valves addressing this issue.

Simple throttle valves can restrict flow in both directions or, when equipped with a check mechanism (see below for information on check valves) can work to adjust the flow in one direction only. Product literature[4] offers needle valves as the fundamental throttling mechanism, but subject literature points also at sleeve mechanisms and an orifice throttled with a helical lip core as allowing to control the amount of fluid running through a valve [Rabie, 2009, p. 180]. Pressure-compensated throttle valves can either be set up as serial models (a flow control valve and a

[3] MHA Zentgraf 2012/2013 product catalogue.

[4] MHA Zentgraf 2012/2013 product catalogue.

pressure compensator are connected in series, with the pressure compensator located downstream) which allow the flow to be controlled in one direction only, or as parallel units, or three-way flow control valves. Such devices allow for practically constant flow rate within their control zone of the system when the pressure exceeds a predefined value.

A separate category of flow control valves is the group of flow dividers, which divide the flow into a preset number of parts, either equal or with a defined division ratio. These are divided between displacement and spool types [Rabie, 2009, p. 185]. The former type of flow dividers is constructed of two or more hydraulic motors (depending on the number of output flows) mounted on a common shaft and may also be used as a pressure intensifier. The latter type of flow dividers, spool dividers, consists of two (or more) spring-loaded spools which move forward and retract according to the load on the valve's inlet and outlet ports, eliminating the imbalance of outward flows.

Check valves [Rabie, 2009, p. 175]. serve to direct the flow in one direction, similarly to how a diode operates in an electrical system, blocking the return flow. For this reason, another term which is used to refer to this type of valves is "non-return valves"[5]. As with other valve types, they can be operated via a pilot or can work directly (there is no external control element associated with check valves). A spring in a check valve or its operating pilot valve is set at a certain pressure difference, called cracking pressure. If the pressure between the inlet port and the outlet port of the check valve exceeds the set minimum, the valve opens allowing the fluid to pass through. Cracking pressure for check valves usually does not exceed 10 bar and can be even below 0.2 bar for sensitive applications, where there is no spring inside the valve [Rabie, 2009, p. 175].

Proportional valves[6] are electronically-controlled valves whose outlet pressure changes according to the changes in the inlet pressure, at the same ratio. They are not a different valve type, because their difference from the above valve types relies mainly on the method of actuation. Hydac in its proportional valve catalogue offers pressure relief, pressure reducing, needle, flow control and directional control valves, where the actuator for the valve is a solenoid. The same can be said for electrohydraulic servo valves, where the valve is controlled by a servomechanism – practically, a fluid installation in itself. Yet another method of controlling the functions of a valve is through a digital controller.

5 Parker Hannifin product catalogue 4100-9/UK, Industrial Tube Fittings Europe, 2011, p. O2.

6 http://www.hydac.com/de-en/products/valves/proportional-valves.html, accessed January 6, 2017.

5. Additional elements

Subject literature, product literature, and industry practices dictate that apart from the elements that control the mechanical energy into hydraulic energy (pumps), power transmission elements (pipelines, described below), components controlling the power (valves) and actuators (cylinders and motors) a hydrostatic drive system needs an array of accessories. The first volume of the Hydraulic Trainer warns against underestimating this category of components and stresses that they are just as important in the smooth and problem-free operation of a hydrostatic drive as all the "core" components. Galal Rabie mentions the following elements in this category [Rabie, 2009, p. 208]:

1. Hydraulic tanks, needed to store excess fluid and also facilitate its cooling.
2. Coolers and heaters, actively adjusting the temperature of the working medium to the desired parameters.
3. Hydraulic filters, required to maintain the cleanliness level of the working medium, further limiting the overheating and failures.
4. Measurement and monitoring elements, such as gauges, thermometers, flow meters, either allowing to control the parameters of the operating drive or even – when equipped with automatic functions – reacting in emergency situations to e.g. shut down the overloaded system.
5. Energy storage elements, such as accumulators.

The Navedtra course adds quick-disconnect couplings to the above list, together with sealing materials of different type. The first tome of the Hydraulic Trainer also adds noise reduction components and vibration dampers.

Hydraulic tanks [Doddannavar, 2005, p. 132] are installed to mainly provide an uninterrupted supply of hydraulic fluid to the system (air can be detrimental to the components, causing e.g. cavitation) but they also serve as methods of dissipating heat, settling the contaminants and helping air escape from the fluid. Because of their size they are also frequently used as mounting support for pumps and other components of the system. They ought to be equipped with a baffle plate, so as to prevent incoming fluid from entering the pump inlet directly and lengthen the way the fluid takes between these two points, losing heat along its course, an inspection cover, a level indicator, filter breather and appropriate connections. Usually, taking into account fluid expansion and cylinder requirements, the tank ought to be able to contain 3–4 times the minute consumption of the system with free space above the fluid line.

Heat dissipation via the reservoir may not be sufficient to cool down the oil, and in some applications (such as flushing of the hydraulic system or when operating on low-temperature conditions) the oil needs to be warmed up. Coolers and heaters are therefore used to actively affect the temperature of the working medium. Heat is generated in the system because no component can work at 100% efficiency and the lost energy is converted to heat and in situations when fluid flows from a high- to a low-pressure area without doing any mechanical work. Excessive heat may cause the fluid to lose its predictable viscosity, hasten its oxidation and thus deteriorate the system sealing components. Heat exchangers may either be air-cooled or water cooled, where the former type offers the use of cheap cooling medium and low installed cost at the expense of the size of the cooling unit and high noise levels. The latter size offers compact cooling unit sizes and low noise levels, combined with the possibility of installing water heat exchangers on dirty environments, at the cost of water prices and the need of regular maintenance.

Even though assembly of hydrostatic systems for the offshore segment is conducted in clean environments[7] and a system's pipelines are flushed prior to commissioning, contamination may arise in the liquid in the form of gasses (entrapped In oil in e.g. the hydraulic tank), water (as condensed moisture) or solids of varying origin (rust scales, worn-out sealing material pieces, oil oxidation products). In order to maintain the cleanliness of hydraulic medium at a proper level (and thus prevent overheating, decreased performance or faults of the individual components) hydrostatic drives make use of filters and strainers. Filters help remove non-soluble contamination from the working medium by passing the fluid through a filtering insert (cartridge) where it must go through nylon, paper, wire mesh or cloth protected by coarse wire and leave the contaminants on the entry side of the filtering material. Filter inserts are replaced when they have been saturated, usually with an indicator present on the filter body. Filters may be installed on the pressure side, in a return line or as an off-line kidney loop, where each setup has own advantages and disadvantages (pressure side filters protect the installed system components, except the pump, and need to be more robust since they are subject to typical supply pressure, much higher than in the return lines).

Fluid cleanliness can be represented by a few standards, including ISO 4406 and NAS 1638, which are the most popular. The first standard assigns a cleanliness code based on the number of solid particles in 100ml of fluid, giving three values. The first one corresponds to the number of 4 μm particles, the second one – 6 μm and the third one 14 μm in the sample. According to the table, ISO 4406 code 18/16/13, which is a general machine requirement and a World-Wide Fuel Charter requirement for The lower the codes, the fewer contamination particles are allowed. NAS 1638 makes use of one code. Even though the cleanliness class table notes the difference of a few contaminant particle sizes, namely 5–15 μm, 15–25 μm, 25–50 μm, 50-100 μm and >100 μm, the worst-case scenario is reflected in this fluid cleanliness level code.

[7] Inspection rules for companies wanting to provide assembly services for the offshore segment mention e.g. the separation of assembly space from grinding / machining space, dust-free walls and protected (for example painted) floors of the assembly rooms, as well as adequate ventilation.

It is possible to determine the cleanliness level of the fluid either by collecting a fluid sample from a working machine (via specifically installed sample ports) and analysing it in a specialist laboratory, counting the actual particles under a microscope, or by using specialised equipment[8] capable of performing the measurements on-site and printing or electronically storing the results. Such devices are not a regular part of the machines, due to their cost and rare use.

There are a few parameters of hydraulic fluid in a system that can, and should be quite often, checked in order to guarantee that the system is working correctly. These are temperature, flow and pressure. Temperature can be measured with thermometers and indicated directly on the thermometer or converted to electronic signals and transmitted to a measurement/control unit. Flow is measured with special turbines and also either displayed directly or transmitted to a special unit. In order to measure system pressure, gauges (normally filled with glycerine) of varying pressure ranges are used.

Hydraulic energy can be stored, which is one of the advantages hydrostatic drives offer compared to other drive systems, and used in leakage compensation, as backup energy source or as a shock absorbing method. This is accomplished by accumulators, which store potential energy of an incompressible fluid, held under pressure by external sources, against dynamic force. The dynamic force can either be gravity, mechanical springs or compressed gas and this division determines the construction of an accumulator [Doddannavar, 2005, p. 146]. The oldest type of accumulator, of weight-loaded type, relies on a weight set up on top of a cylinder and piston setup, where the load maintains the potential energy of the unit. This type of accumulator is, however, characterised with large size and weight.

The weight can be exchanged with a spring (an element which is commonly used in e.g. check valves). This results in variable pressure exerted by the spring on the chamber and makes such accumulators most suitable for delivering low quantities of oil at low pressures; otherwise, they are large in size and heavy. Also, the usefulness of such accumulator types does not penetrate into high cycle rate applications, since under frequent operation the spring may lose its elasticity.

Gas-loaded accumulators, referred to as hydro-pneumatic, rely on Boyle's law (also: Mariotte's law in France), stating that the pressure (p) of gas under constant temperature (t) varies inversely with its volume (v); $pv = const$. The storage of potential energy in the accumulator is made possible by the compression of gas, forcing the fluid out when it expands.

Dry-break quick disconnect couplings might be mentioned in the section on connecting elements, but, as stated above, they have been designated as auxiliary

[8] An example is a Parker LCM 2022 laser particle counter, capable of working with pressures of up to 420 bar and detecting particles from 2 μm upwards, which satisfies both the ISO and NAS norms. See http://www.parkerhfde.com/pdf/conmon/LCM20.2025-USER-MANUAL-%28ACFTD%29.pdf, accessed January 7, 2017.

components in the Navedtra course. They are installed at locations where frequent uncoupling of the lines – especially hoses – is required or expected without losing the liquid in the system or introducing foreign matter into the pipelines, due to inspection, maintenance or as spill prevention when hose ripping can be expected. They are composed of two parts – male and female – each equipped with shutoff mechanisms. Quick-disconnect couplings can either be of screw type, where the two parts are held together by a nut, or push-to-lock, which can in some designs even be disconnected with one hand[9].

An ideal hydraulic system needs to be sealed in order to minimise leakages out of the system and to prevent external contaminants from entering the pipelines, which can be detrimental to the operation of the individual components. Leakage is usually permitted only internally, in order to lubricate the system. In developing of the sealing components, a variety of materials have been used, and currently used materials are selected taking into consideration fluid compatibility, resistance to heat, pressure, wear, hardness and type of motion expected when sealing moving parts.

The Navedtra course enumerates the following sealing materials: cork (limited use, undesirable in high fluid velocities and pressures due to tendency to crumble), leather (flexible and resistant to abrasion at the cost of mainly extrusion under mechanical pressure), metal (copper rings or direct metal-to-metal sealing), natural and synthetic rubbers and PTFE (previously produced under the brand name Teflon by DuPont). Combinations of the above are also possible, such as cork and leather, and especially rubber and metal.

Seals can be of different types, including T-seals, V-rings, O-rings, U-cups and quad-rings (named all after the shape of the sealing profile).

6. Transmission lines

All the components enumerated above need to be connected in a way that allows the fluid to flow in an uninterrupted manner, without losing much, if any, of its pressure. There are two types of hydraulic lines that can be used, namely rigid and flexible lines.

Rigid lines, or hydraulic tubes and pipes[10], are used when connecting components that neither vibrate nor move relative to each other. They are characterised by a number of features, each of which has specific bearing on the applications a given tube / pipe can be used in.

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[9] GS-Hydro 2012 product catalogue, p. 412.

[10] The difference between pipes and tubes is that the former's most important property is its inside diameter, while the latter's – the nominal outside diameter. Tubes are more expensive to produce than pipes since their tolerances are tighter. See http://www.engineeringtoolbox.com/pipes-tubes-d_347.html, accessed January 7, 2017.

Usually hydraulic tubes are made of carbon steel – grades St 37.4 and St 52.4, corresponding to E235N and E355N, respectively, with the latter being able to work with higher pressures. In the basic delivery standard, tubes are provided as "black" – phosphated and oiled with both ends plugged with plastic caps. The treatments make tubes somewhat corrosion resistant, without exposing customers to high prices. Both tube types can also be zinc-plated, further increasing their corrosion resistance, again without raising the overall costs of the installation too much. Zinc is more reactive than iron (the basic chemical element found in steel) and thus attracts almost all local oxidation until it corrodes entirely (inhibiting the further process of corrosion along the way) and allows steel to take further oxidation over, prolonging its service life. At first, the most widely used method of coating of carbon steel components, not limited to piping, was the so-called "yellow zinc" coating, which involved the use of hexavalent chromium (Cr-6) in the production process. Since hexavalent chromium exhibits strong toxic properties and its use is regulated[11], attempts have been made to introduce non-toxic zinc coatings[12]. Currently, the details of the prevalent method of zinc-coating of steel components, and again, not restricted to piping, is dependent on the producer[13]. Offshore applications, however, require certain anti-corrosion resistance from every component that works either in seawater itself or below its splash line. Outdoor equipment, regardless of the heights at which it operates, is usually also required to withstand corrosion for extensive time spans, so carbon steel components are normally installed only inside structures (such as crane machinery houses) and even then are frequently required to be wrapped in anti-corrosive tape, such as Densotape.

Since outdoor offshore structures need to provide resistance from corrosion, tubes for such constructions need to be provided in stainless steel. The most popular tube grades for the offshore segment are ASTM A269/A213/A312 (TP 316L) / EN 1.4404 or TP 316Ti / EN 1.4571. Other materials, such as Duplex / Super Duplex, with increased amounts of chromium and molybdenum and still better anti-corrosion properties, can also be found on offshore equipment, but are rather uncommon because of economic considerations.

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[11] See EU Directive 67/548/EWG. Hexavalent chromium was classified as Category 2, which means it may be carcinogenic under specific circumstances, and skin contact may evoke allergic reactions.

[12] See for example Tube-Mac's declaration of switching to non-toxic coatings, available at http://www.tube-mac.com/headline19.asp, accessed January 7, 2017. Producers of e.g. hydraulic fittings may still deliver "gold-plated" components containing hexavalent chromium upon request.

[13] E.g. Eaton, yet another major supplier of hydraulic fittings, advertises its "Guardian Seal" technology at http://www.eaton.com/ecm/groups/public/@pub/@eaton/@hyd/documents/content/pct_490633.pdf, accessed January 7, 2017. Parker Hannifin (Catalogue 4400/UK, p. 14 declares that as of 2006 all hose couplings are produced with trivalent chromate.

Tubes can be delivered in a variety of sizes. The two most popular ones are metric sizes and schedule sizes and both specify the size of the tube as a combination of its diameter and wall thickness, although each system treats this data differently.

Metric sizes use the SI-derived units of millimetres to denote the outer diameter of the tube and its wall thickness, so e.g. 38x4.0 tubes measure 38 mm in their outside diameter and have a wall thickness of 4 mm, which leaves 30 mm inner diameter (outside diameter minus twice the wall thickness). Schedule sizes specify the tube's nominal diameter in inches and add a letter-number designating the wall thickness[14]. These refer to different wall thicknesses for different nominal sizes, so that the standard 40S schedule for a 1-inch tube means the wall thickness of 0.133 inches, or 3.38 mm, while for a two-inch tube the same schedule denotes the wall thickness of 0.154 inch, or 3.91 mm. 24-inch tubing of schedule 40S has walls of 0.375 inch or 9.53 mm in thickness. Given the flow volumes that the system is supposed to carry and the design pressure of the hydrostatic drive, a design engineer may follow the calculations for the Reynolds number[15] (since during normal operation laminar flow is expected) and wall thickness (according to hydraulic system component suppliers or classification society norms) to specify the diameter and wall thickness of a tube to be used.

Tubes are delivered in lengths of 6 meters in outside diameters of up to 60 mm and in random lengths of between 5 and 7 meters in larger sizes. This, on one hand, makes it necessary to connect and clamp the piping on longer stretches (see the section on additional components for information about clamps; tube couplings will be discussed further) and on the other it presents certain problems as far as transport (especially on roads) and storage is concerned.

The tubes for offshore applications are normally seamless (as opposed to seamed tubes which are produced usually by welding metal sheets) and cold-drawn. Cold-drawing a tube is a multi-pass process ensuring high precision of the resultant tube and is frequently performed on floating mandrel drawing mills. Each production batch ("heat") is numbered and certified in a range of conditions. The 3.1 certificate that is delivered with each heat specifies eddy current tests, ultrasound tests, mechanical tests (flaring, bending, hardness, crushing), chemical tests, composition, microstructur and dimensioning tolerances.

As noted before, rigid lines (tubes) may not be installed in places where the designer expects vibration or in instances where movement of parts relative to each other is expected and hydraulic hoses are used instead. These are produced of rubber

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[14] http://www.engineersedge.com/pipe_schedules.htm, retrieved January 7, 2017., also GS-Hydro product catalogue 2012, pages 195-197.

[15] Reynolds number is the ratio of inertia forces to viscous forces in a liquid and helps determine the existence of laminar or turbulent flow in a pipeline. Each type has its own uses; laminar flow is normally desired in regular operations, but turbulent flow is desired when cleaning the hydrostatic drive components of impurities prior to commissioning.

interior tubing (usually NBR nitrile rubber), with reinforcement which helps raise the working pressure of the hose (stainless steel wire braid or spiral steel wire braid, with one to six braid layers; textile braids are also available for lower pressure ranges) and top cover, protecting the hose from external mechanical and chemical factors. Since hydraulic hoses are produced of soft materials (other than steel which shows stability in connection with varying media and external conditions), the question of compatibility with hydraulic fluids must be considered (hence the information on the material the inner tube is made of is crucial) together with information on working conditions when selecting the external protective layer, which apart from protecting the hose externally from substances that might react with it also serves as abrasion inhibitor. Hoses are also characterised by their bend radius, useful when dimensioning the movement of the application parts and working temperature ranges, which are not as wide as for steel tubes because of the material type used. Connecting the hose nipple to the rest of the installation is similar to tube connection technologies, because the threads and most connection technologies are the same[16], however, the issue of producing a hose out of a length of flexible line and couplings needs to be addressed. There are a few ways of combining hoses and couplings, including push-in couplings for lower pressure ranges of up to 2.4 MPa / 24 bar and crimped couplings which form the basic method of producing hydraulic hoses and offer working pressures of up to 50 MPa / 500 bar[17]. Crimped couplings may either come as 1-piece or 2-piece elements (with the ferrule integrated with the coupling or not); 2-piece couplings may or may not require the hose to be skived internally, externally or both (skiving is removing of the layer of internal tubing or external cover to place the coupling and assure a tighter grip on the hose). Final assembly is made using specialised machines and detailed crimping charts which detail the dimensions that need to be achieved on swaging the coupling on the hose. Normally, the swaging charts specify couplings and hoses from one producer, since these combinations result in completed hydraulic lines that may be certified according to different classification society rules and secondly, hoses and couplings from different producers may vary in sizes slightly, thus making universal charts impossible to produce, and experiments prone to failure.

7. Conclusion

When selecting the drive system for offshore equipment, mechanical setups with their large masses and inertia do not work well with precise manipulation of heavy and expensive objects such as pipeline segments, drill bits, etc. Pneumatics

[16] The two most popular connection types are a swivel nut connector (because it is recommended not to twist a hose the swivel nut is the only rotating element of a hose connection) or a nipple which is connected to an installation block by means of flanges or semi-flanges.

[17] Parker catalogue 4400/UK, p. Ab-3.

must also be discarded because of low pressures that translate to the equipment capable of manipulating only limited weight. Hydrodynamics, with the possibility of producing only rotary motion without complicated devices, needs to be disregarded as well. Electrical power systems are used increasingly frequently, but with – again – being able to produce mainly rotary motion, the choice of offshore equipment manufacturers as to the drive system technology is hydrostatic drive systems.

The second choice is the medium for the hydrostatic drive system, where the choice is rather wide, but practice dictates three groups of popular media: water-based liquids, synthetic liquids and petroleum-based liquids. The first category has limitations on operating temperatures, biological considerations also play a role. The second category of fluids raises cost concerns. Petroleum-based fluids are not a perfect solution, but when their parameters are monitored and conditioned with additives and filters, they serve the purpose very well.

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NAPĘDY HYDROSTATYCZNE NA BAZIE OLEJÓW MINERALNYCH JAKO PODSTAWOWY SYSTEM NAPĘDOWY W PROJEKTACH KONSTRUOWANIA URZĄDZEŃ OFFSHORE

Streszczenie

Celem pracy jest przedstawienie zakresu komponentów wykorzystywanych przy budowie systemów napędu hydrostatycznego urządzeń klasy *offshore*. Zawiera opisy kompo-

nentów takich systemów napędowych, wraz z opisem ich zastosowania właśnie w napędach bazujących na oleju mineralnym jako medium przekazu energii i dostosowania do sprzętu klasy *offshore*.

Słowa kluczowe: napędy hydrostatyczne, przemysł offshore, projekty urządzeń offshore.