Advanced Technologies for a Challenging Future

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Abstract

Minus 15 degrees Celsius, wind speed of 8, and four meter high ocean waves: the external conditions of offshore installations make extreme demands that cannot be reproduced in any lab. The Norwegian research project NODE ART, where offshore outfitters, scientists and hydraulics manufacturers are working together on hydraulics systems and, in particular, on next generation hydraulic cylinders, calls into question all materials, technologies and engineering principles applied so far. This research project, which has already resulted in three phD research projects and numerous other studies, is searching for new ways to considerably increase the service life of large cylinders. The objective is to achieve an, at least, five-year operation period or to cover 20,000 km operation distance for offshore applications, such as production platforms, heave compensation systems on ships or service vessels used in the construction of wind power plants /1/. NODE ART shows that further basic research is essential for the industry to develop new products and solutions based on the results obtained.

KEYWORDS: tribology, fluids, seals, cfd, acoustics

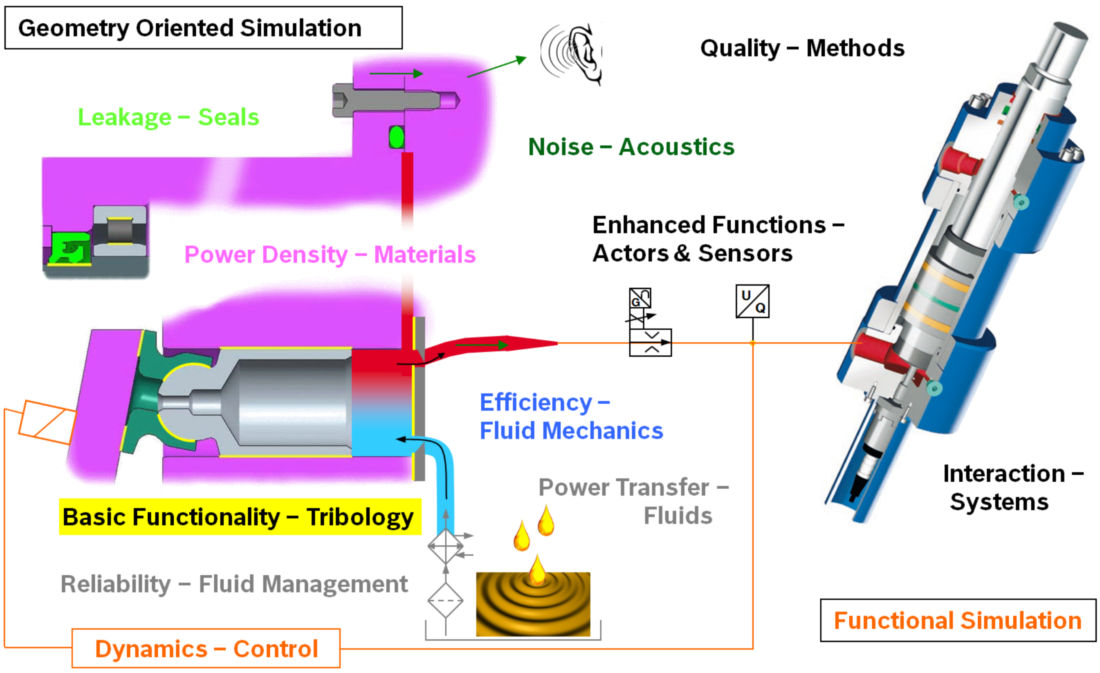
1. Hydraulics in Competition: Maintaining Cost- Benefit

In comparison to electric drive technologies, hydraulics shows both strengths and weaknesses. In many applications the direct generation of linear motion and the high power density are key strengths of fluid technology. This is true, in particular, if the task requires great forces. Especially in rough environmental conditions, whether offshore, in civil engineering, in mobile machines or metallurgy, it has proven to be very reliable and low-maintenance – often for decades.

Electric drives, on the other hand, offer advantages when it comes to noise emissions and efficiency. The continuous improvement in the performance of electric drives has been achieved through intensive research. The resulting cost reduction minor the classic economic benefits of hydraulics. Key evaluation factor of scientific progress in hydraulics is therefore a direct or indirect improvement of the cost-benefit ratio while further improvement of power density in comparison to electric drives may not be neglected.

The State of Research is integrated to a large extend in available products and systems. Manufacturers dominate functionality and are now focusing on optimization of the components and systems. When it comes to controllability, there is no significant difference between the two drive technologies anymore. State-of-the-art electro-hydraulic system solutions can be integrated perfectly within current automation technologies.

The main challenge over the next years will be to further strengthen the strengths of hydraulics while keeping system cost low and to weaken all relative weaknesses. To accomplish this, hydraulics manufacturers need access to new scientific findings – especially in the area of tribology, hydraulic media, materials, acoustics and simulation.



Challenges & Technologies

2. Tribology: Lifetime > 50 Years

Tribology is the technological heart of hydrostatics. Applications are always about two solid bodies like pistons and bushes moving against each other in a piston pump or like linear sealing systems and cylinder rods moving relative to each other in a cylinder. A lubricating film makes sure that no wear is caused and that the movement causes as little friction as possible. The new production methods for the components that are adapted to each other /2/ manage to reduce the tolerances to only a few micrometers.

Studies have already shown the effects that special materials, coatings or surface treatments, incl. contouring /3/, /4/, /5/, /6/, /7/ have on system performance.

Investigation is normally carried out experimentally. Researchers operate a pump on a test stand under nearly realistic operating conditions. To save cost, tests are often carried out in advance on component test stands, tribometers or in the materials lab. Here, the following applies: the further apart the test method from realistic operation, the broader – and the less precise – the conclusion. With the NODE ART project, on the other hand, numerous measuring devices are collecting live data on dynamic loads, wear and corrosion from hydraulic cylinders already installed in offshore facilities. This worldwide unique database is the starting point for the development of future cylinder generations.

This pays off not only for the offshore equipment market, because the results can be transferred also to other hydraulic applications. They are already being used in other projects, such as the modernization of the Panama Canal, where hydraulic system solutions control the locks. Although the new locks will be much bigger, the modern design will still significantly reduce fresh water consumption. In civil engineering projects, such as the Panama Canal or the Welland Canal, operators expect almost maintenance-free operation livetime of 50 years and more.

2.1. Wanted: Mathematical Models

There is still urgent need for a universal tribometer, which supplies reliable data not only on a specific tribological contact, but on various contacts. Equally, there is an urgent need for a mathematical description. First simulation tools (EHD) are in the developing and testing stage /8/. But there is still no software available which could provide, reliable design information. I.e., there is not only a scientific need, but also a significant commercial potential.

A key issue for the future competiveness is the efficiency increase of hydrostatics. Apart from numerous systems based approaches, such as demand-oriented volume-flow generation by variable-speed pump drives, tribology is decisive for improved energy efficiency from a technological point of view.

3. Fluids: Standards Required

Hydraulic fluids can be considered a subset within tribology. They transfer power and lubricate the contacts between the solid bodies. An increased use of non-traditional fluids, such as bio-oils, flame-resistant water-based media as well as energy-efficient fluids or other special media can be observed /9/, /10/, /11/, /12/, which, in part, differ significantly in their properties /13/. On one hand, this allows customized solutions, on the other hand, this variance requires everybody from hydraulics manufacturers to end users to cope with the complexity involved. Competitors in the electric drives segment have only one clearly defined power transmission medium, namely electric current which is defined by volt and ampere.

This is aggravated by the fact that norms and standards are not consistently defined. For manufacturer independent comparison, consistent information is needed regarding properties, such as temperature-dependent viscosity, lubricity or chemical compatibility. For a classification and qualification, valid, economical test procedures need to be developed to compare the specific properties and their respective advantages and disadvantages. Before such norms and standards are defined, the variety of media will weaken the position of hydraulics in competition because it increases the complexity and thus the cost for users.

3.1. Cost-Factor Fluid Management

The entire fluid management, incl. cooling, filtering and oil change, has a significant impact on the total cost of ownership of hydraulic systems. E.g., the oil tank of the newly restored Bolshoi Theater in Moscow holds around 50,000 liters. The theater which was reopened in November 2011 features the most advanced and extensive stage technology in the world with more than 600 hydraulic and electric drives.

Whether it’s 50,000 liters, or 5 liters in small machine aggregates – the operators must comply with sometimes component specific purity levels to prevent damage and corrosion. Possible impurities range from solid body contamination to liquid components, especially water, to gases /14/. The medium’s service life is directly related to the quality of oil conditioning. The challenge is to substantially reduce the complex equipment used so far for filtering, outgassing and cooling /15/ in order to significantly reduce the cost of installation and maintenance over the entire lifecycle. Manufacturers and users need well-founded information on effects produced by particle, liquid and gas molecules regarding chemical properties, size and concentration. This can be used for the development of reliable condition monitoring systems – and can significantly reduce lifecycle cost /16/.

3.2. Fluid-Specific Simulation Models

The corresponding simulation technique is computational fluid dynamics, or CFD. It is available as a commercial tool used by numerous companies. However, CFD does not deal with the chemical compatibilities or effects of particles, but instead computes the flow characteristics of the medium inside a defined area. This software tool serves primarily to examine critical geometries through which a fluid flows, such as valve control edges, narrow channels or commutation in pumps /17/, /18/, /19/, /20/, /21/, /22/, /23/.

By avoiding turbulences, pressure peaks or unnecessary cross-section reductions, design engineers optimize component geometries to increase the efficiency. In addition, developers analyze cavitation problems /24/, /25/ to avoid them through optimized flow guidance. The objective is to avoid local pressure drops that might result in material removal, acoustic stimuli, obstructions or even accelerated media aging. There is still need for suitable parameterization of the medium, due to the inherent variance described above. Valid characteristic data of the various media at very low pressures e.g. is rare to non-existent.

Since fluid simulation as compared to other finite elements methods cannot count on a homogenous material distribution, it needs a significantly higher computing capacity which, in turn, results in increased cost. Alternatively, numerical procedures are required to substantially accelerate the computing times.

4. Seals: Stick-Slip and Leakage

One important characteristics of modern hydraulics is leakage free design. Already today, sealing concepts are available that minimize the leakage of the fluid into the environment reliably. This is, however, true mainly for mineral oil fluids. The esters contained in bio-oils may corrode the sealing materials used with mineral oils and cause leakages. Thus, investigation on the chemical resistance of materials plays an important role /26/. In the end, the focus lies on reliable economic solutions.

While static seals can ensure leakage free components, there is still need to research dynamic linear or rotary seals. Although leakage free dynamic sealing systems can already be achieved, the cost is too high. Complex sealing solutions often include high contact pressures that cause friction, which again reduces efficiency and lifetime due to local overheating /27/. Also, stick-slip effects hinder exact positioning.

5. Materials: Lifetime and Lightweight

In hydraulics, material development activities are focused mainly on tribological aspects, such as friction, wear and corrosion, and on the compatibility with fluids. Progress in materials development can significantly increase lifetime – especially in extreme environments, such as maritime and offshore environments. Manufacturers are investigating coating methods, or they are using corrosion-resistant steel as solid matter for piston rods. Another aspect is lightweight design especially for mobile applications where weight of functional components has to be carried around. The new TIER 4 Final emission standards force the manufacturers of mobile machinery to develop new concepts. The optimization of mobile-hydraulic systems is a key factor when it comes to controllability, power density and power efficiency.

In NODE Art, for example, fiber-reinforced plastics, non-iron metals such as titanium are investigated as well as hybrid constructions with various material combinations. Hydraulic manufacturers must evaluate these approaches in how far they can be realized in economically driven production. Although fiber-reinforced plastics have already proven their feasibility as free-form parts in aeronautics, hydraulics implies completely different demands on compression strength. Titanium, on the other hand, requires completely different production methods than steel. Another more and more important aspect is lifecycle cost and thus in how far materials can be recycled.

6. Acoustics: Facts and Perception

In comparison to electric drives, hydraulics still has major "potential" of improvement regarding noise emission. Noise itself is the result of various factors. Normally, the pump is the source of noise or pulsation. Passive, active or adaptive measures, such as PCV, will minimize the pulsations directly at the source /28/, /29/, /30/. Special pumps of the newest generation and variable-speed pump drives are already available in form of noise-optimized components used in noise-sensitive applications.

However, the volume flow pushed into the high-pressure lines still shows some pulsation, which distributes across the hydraulic system via the pipes and hoses exciting successive components to vibrate. To reduce vibration, system manufacturers incorporate pulsation dampers in various forms or elastic elements to reduce structure-borne noise transmission. In addition, the surfaces that transmit the pulsations to the air are optimized in such a way that noise emission is as low as possible /31/, /32/, /33/.

Mathematical descriptions of single mechanisms are partially available /34/, further research is nevertheless required /35/. Especially regarding noise propagation throughout the system there is still a considerable need for further insights in order to be able to systematically perform acoustic optimizations in the overall system. Little is still known about the effects of the pulsation characteristics of the generator via the transmission mechanisms up to the perception by the human ear.

The generally used characteristic value of noise emission: dB (A) has little to do with the noise perception of the human ear. Close cooperation with other scientific disciplines, such as esthesiophysiology and the psychology of perception may be a suitable way to correlate the subjective sensation to the measured data. Noise emissions of the same order of magnitude can be perceived as irritating, neutral or pleasant, depending on – on what? Take for instance the “noise” produced by a mosquito flying around your bedroom at night.

Cost factors take priority also when it comes to reducing noise emissions. The casings used so far result in high material and application cost which could be reduced significantly using more intelligent solutions.

6.1. Simulation: Virtual Engineering

The functional simulation of hydraulic systems has two main tasks: in high volume production, it serves for a faster and cheaper optimization of the hydraulic systems as compared to the trial-and-error approach. In the project business with number of units = 1 as in plant engineering or stagecraft, simulation is indispensable, as size and functionality must be ensured on the first shot. There are several commercially available tools based on concentrated parameters, which achieve good maturity already on the system level. Matter of research is, for example, to determine individual concentrated parameters, such as the bulk modulus /36/, /37/, /38/, /39/.

In the design of high volume machinery or in individual projects, simulation technology is increasingly being used already in the development phase. Depending on the complexity, a task may require up to several months before a solution is found. Here, the combination of simulation tools of different disciplines may compensate for limited accuracy. At present, however, geometry-oriented simulations are integrated into functional simulations only on rare occasions.

In comparison to traditional engineering, simulation has already reduced development time and cost considerably. Now, it’s about simplifying model generation, improving numerical algorithms, systematic optimization and, at the same time, increasing the accuracy and introducing – or rather developing – a measure of quality.

7. Summary

Hydraulics is only a seemingly mature technology. When it comes to tribology, fluids, materials, acoustics and simulation, there are still large ‘white patches’ which offer significant potential for the further development of hydraulics. If science succeed in filling these blanks with new findings – also through interdisciplinary cooperation and collaboration with hydraulics manufacturers and users –, hydraulics will be able to significantly strengthen its strengths and weaken its weaknesses. Users will benefit the most, as they will be able to employ even more economic, more robust and more energy-efficient hydraulic solutions in the future.

8. Bibliographical Reference

/1/ Bosch Rexroth AG “Die Großzylinder der Zukunft”. Fluid 4/2009, mi-Verlag moderne Industrie, Germany, pp. 14-15.

/2/ U. Bräckelmann, D. Breuer, S. Stoll, U. Piepenstock “Optimized Piston Guidance Design for Swash Plate Pumps” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 3, pp. 249-260.

/3/ L. Leonhard, H. Murrenhoff “Deterministic Surface Texturing for the Tribological Contacts in Hydrostatic Machines” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 49–60.

/4/ A. Hermann, M. Wangenheim, P. Grönefeld “Tribological Impact of Surface Modifications to Frictional Counterparts in Contact with TPU Compounds” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 3, pp. 287-300.

/5/ B. Persson, B. Lorenz “Contact Mechanics for Randomly Rough Surfaces with Applications” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 3, pp. 315-326.

/6/ D. Breuer, “ Reibung am Arbeitskolben von Schrägscheibenmaschinen im Langsamlauf”. Shaker Verlag Aachen, 2007

/7/ M. Ivantysynova, J. Baker, “Power Loss in the Lubricating Gap Between

Cylinder Block and Valve Plate of Swash Plate Type Axial Piston Machines", 2009. International Journal of Fluid Power, Vol. 10, No. 2, pp. 29 – 43.

/8/ S. Gels, H. Murrenhoff "Investigation of Elastic Deformations of Cylinders within the Simulation of Piston-Cylinder-Contacts of Axial Piston Machines" 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 75-88.

/9/ K. Kovanda, M. Greaves, R. Schulze "A New Generation, High Performance, Water Soluble, Polyalkylene Glycols and their Use in Hydraulic Equipment for Environmentally Sensitive Areas" 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 89-102.

/10/ C. Enekes, H. Murrenhoff, W. Dott, J. Bressling "Tribological and Ecotoxicological Behaviour of a Synthetic Ester and its Effect on Friction and Wear in Axial Piston Pumps" 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 127-140.

/11/ A. Fatemi, A. Wohlers, S. Drumm, H. Murrenhoff " Tribological Properties of Tailor Made Fuels from Biomass" 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 141-154.

/12/ S. Herzog, P. Michael "Hydraulic Fluid Viscosity Selection for Improved Fuel Economy" 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 167-178.

/13/ Bosch Rexroth AG, „RD 90220: Hydraulikflüssigkeiten auf Basis von Mineralölen und artverwandten Kohlenwasserstoffen", Bosch Rexroth AG, Lohr

/14/ W. Bock, J. Braun, N. Puhl, H. Heinemann "Air Release Properties of Hydraulic Fluids, Dynamic Air Release Behaviour" 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 3, pp. 327-340.

/15/ H. Karl, T. Fisher "Biogenous Hydraulic Fluids – Influences of Operations on the Filtrability" 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 117-126.

/16/ T. Torikka, "Bewertung von Analyseverfahren zur Zustandsüberwachung einer Axialkolbenpumpe". Shaker Verlag Aachen, 2011

/17/ D. Bottazzi, F. Franzoni, M. Milani, L. Monorsi “Analysis of a Hydraulic Valve by Means of a Transient Multidimensional CFD Approach” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 1, pp. 409-422.

/18/ V. Tic, D. Lovrec “Design of Modern Hydraulic Tank Using Fluid Flow Simulation” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 1, pp. 469-482.

/19/ G. Kabisch, A. Arnold, J. Wiedemann “Use of CFD Simulation for Optimizing the Functionality of Mass Flow Controllers” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 4, pp. 565-578.

/20/ K. Wartlick, R. Dombrowski, A. Schindelin “Filter and Participle Simulation for Hydraulic Systems” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 4, pp. 579-592.

/21/ M. Heinz, R. Fidler, W. Dittrich, M. Krätschmer “Axial Piston Pump and – Motor Optimization by Means of CFD” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 4, pp. 605-616.

/22/ N. Bügener, S. Helduser “Analysis of the Suction Performance of Axial Piston Pumps by Means of Computational Fluid Dynamics (CFD)” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 4, pp. 641-654.

/23/ W. Wustmann, „Experimentelle und numerische Untersuchung der Strömungsvorgänge in hydrostatischen Verdrängereinheiten am Beispiel von Außenzahnrad- und Axialkolbenpumpe“, Dresden 2009.

/24/ L. Liang, J. Zou, X. Fu, X. Shao “Unstable Cavitation Behaviors in Spool Valves with U-Notches” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 1, pp. 423-434.

/25/ D. Gerlach, K. Habr, M. Robohm, “Kavitation”. Hydraulik Trainer, Bosch Rexroth AG, Lohr

/26/ G. Clark, A. Clark, D. Showalter “Rubber Compatibility with Biodiesel Fuel: The Effects of Blend and Fluid Temperature” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 27-36.

/27/ O. Heipl, A. Wohlers, H. Murrenhoff “Numerical Simulation of Friction at Hydraulic Rod Seals” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 3, pp. 379-392.

/28/ W. Fiebig, K. Helle “The new Way for the Noise Reduction of External Gear Pumps” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 253-266.

/29/ T. Nafz, H. Murrenhoff, R. Ruslan “Noise Reduction of Axial Piston Pumps Using Variable Reversing Valves” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 267-280

/30/ G. K. Seeniraj, M. Zhao, M. Ivantysynova, “Effect of Combining Precompression Grooves, PCFV and DCFV on Pump Noise Generation”, 2011. International Journal of Fluid Power, Vol. 12, No. 3, pp. 53 – 64.

/31/ A. Breuer-Stercken, „Systematische Untersuchung von Strukturschwingungen im Hinblick auf die Entwicklung geräuscharmer Kolbenpumpen“. RWTH Aachen, 1999

/32/ U. Bittner „Anwendbarkeit von Topologieoptimierung in der Strukturakustik“ 2009, 27th ANSYS & CADFEM Users’ Meeting, Leipzig

/33/ J. Dantlgraber, A. Feuser, A. Herr, V. Seifert, „Geräuscharme Hydraulik durch »Flüsteraggregate«“, Ölhydraulik und Pneumatik 46(2002) 5, Seite 300-302.

/34/ J.M. Mondot, B. Petersson, „Characterization of Structure-Borne Sound Sources: The Source Descriptor and the Coupling Function”, Journal of Sound and Vibration, London 1987

/35/ U. Heisel, V. Slavov “Investigation of the Structure-Borne Noise Transmission Behaviour of Hydraulic Hoses” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 243-252.

/36/ C. Riedel, H. Murrenhoff, C. Stammen “Physically Correct Hydraulic System Simulation with Mass Conservative Approach” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 1, pp. 523-534.

/37/ H. Gholizadeh, D. Bitner, R. Burton, D. Sumner, G. Schoenau “Investigation of Experimental Techniques for the Measurement of the Effective Bulk Modulus of Oil-Filled Pipes and Hoses” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 179-192.

/38/ I. Lee “Evaluation of Effective Bulk Modulus of Oil in Hydraulic Dampers – Effects of Cylinder Shell Elastic Deformation” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 193-206.

/39/ B. Feng, G. Gong, H. Yang “Study on Measuring and Increasing Effective Fluid Bulk Modulus” 2010. 7th International Fluid Power Conference, Aachen, Germany, Vol. 2, pp. 207-216.