Group 5: Abstracts

5-0 Achievements and Potentials of Hydraulic Drive Technology demonstrated on plastic injection moulding machinery

G. P. Holzinger, R. Schiffers

This general lecture will give an introduction to the Group 5 on Industrial Hydraulics at the 8th International Fluid Power Conference in Dresden in Germany. Introductory market-relevant existing injection moulding machines concepts will be presented with respect to the different areas of application. In addition to standard injection moulding machines more complex systems with high level of integrated functions as can be found in automotive applications will be shown. This is followed by a summary of the demands for the different drive axles of injection moulding machines. The focus here is force, speed, reproducibility and energy consumption. For the purpose of comparison electro-mechanical drives are also listed with. Furthermore, the competitive situation of electro-hydraulic and electro-mechanical drive technologies in injection moulding machines is illustrated and a prognosis for future development will be presented. Finally, trends and requirements for the hydraulic drives are formulated from the perspective of an injection moulding machine manufacturer.

5-1 Analysis of the Energy Efficiency of Hydraulic Deep Drawing Presses

H. Lohse, J. Weber, D. Klug, T. Klusmeier, K.-H. Petzold

Hydraulic deep drawing presses are widely used for industrial sheet metal forming today. Small manufacturers of drawn parts and suppliers of the automotive industry especially appreciate these machines because of their flexibility in process design.
Despite their high energy consumption, the energy efficiency of modern hydraulic presses is nearly unknown due to a lack of experimental investigations as well as suited simulation models.
The authors' objective is to reduce this gap by analyzing the energy efficiency using measurement and simulation. This is the prerequisite for systematic technical improvement.

5-2 Variable-Speed Pump Drive System for a 5000 kN Ring Expander

E. Siemer

In cooperation with Bosch Rexroth and MAE Maschinen- und Apparatebau Götzen, a new hydraulic drive system has been designed using the example of a ring expander. Ring expanders are part of a process chain for the manufacture of high-precision rolled rings in particular for high-alloy steels. In this application a large differential cylinder acts on an expanding cone. This in turn acts via 9 or 12 segments, so-called expanding shoes, on a rolled ring to calibrate the inside diameter. Here, similar to a bending process, the ring is expanded beyond its yield point and brought to the required dimension.
The concept is based on a frequency-controlled servo-asynchronous motor with a drive power of 65 kW. An axial piston pump rotating clockwise and a second axial piston pump rotating anti-clockwise are mounted on a common drive shaft. Both pumps are designed as variable pumps with a mechanical torque controller. The swash plates are designed for two-quadrant operation. The reliable reduced set-up speed is attained without additional valve control by means of the reliable limitation of the servo-motor speed according to Cat. 3 via a module in the frequency converter.
"With the variable-speed pump drives, Rexroth now offers pump control in a highly dynamic intelligent electrical drive which only generates the volume flow actually required. Reduced speed during breaks in the cycle or when not running at full power mean a significant drop in the energy required, in noise emissions and in hydraulic power losses. The pump drive increases the speed of the highly dynamic motors as required as soon as the hydraulic system needs more power. All components come from the standard Rexroth product portfolio." /1/

Group 5: Abstracts

5-3 Energy Efficiency of Various Hydraulic Drives used in Injection Moulding Machines

R. Schiffers, G. P. Holzinger

The presentation starts with an introduction of the injection moulding process. The basic process steps of the injection moulding cycle as well as the relevant machine functions are illustrated.
Besides the performance and productivity of injection moulding machines in recent years the subject of "energy efficiency" has moved more and more into focus and can be demonstrated by an increased marked demand in the plastics processing industry. Driven by the need of an improved systems efficiency several new developments have been introduced in the hydraulic drives technology of injection moulding machines. One approach for example is the use of frequency converter controlled variable speed servomotors in the power pack of injection moulding machines. Compared to the current standard drive, the mains-powered asynchronous motor with variable displacement pump, they have very low power losses at low flow rates or in idling phases. Depending on the mould that is installed and the corresponding process settings, the savings in terms of energy can be as high as 50% of the total energy required by the machine. The presentation will offer an overview on the different drives that are used in injection moulding machines and will give a classification by means of energy efficiency in different fields of application.
Since the hydraulically driven injection moulding machines have to compete with electromechanically driven ones at the market, these are also taken into account.

5-4 Dynamic improvement of hydraulic drive trains by trajectory planning and learning algorithms

T. Radermacher, J. Weber, D. Dorner, B. Wagner

The improvement of servo-controlled applications and the disturbance-compensation with good dynamics, little overshooting and minimization of steady state errors is a focus of investigation in electrohydraulic drives. The need for energy-saving solutions with good efficiency leads to the question how the productivity of drive trains can be maximized. The approach proposed in this paper shows a way to maximize the utilization of repetitive processes taking the drive limitations into account. Combining the planning of trajectories according to the systems limitations and an iterative learning controller (ILC) this paper shows a way to achieve good accuracy despite varying drive system parameters and limitations. The iterative approach uses an inversion-based mathematical model of a highly nonlinear plant to minimize the position error on basis of a quadratic next-iteration cost criterion. To show the potential of the ILC it is applied to the displacement-controlled clamping unit of a 1600 kN injection moulding machine. Furthermore the methodology shows a way to recall the maximum dynamic potential of the displacement-controlled hydraulic drive system without reaching stability limits.

5-5 Pump Actuator Based Control of a Clutch System

C. Junge, F. Budschun

Typically a clutch brake combination (CBC) is actuated by a hydraulic unit consisting of a pump and a valve system. By operating the valves different pressure levels can be generated, which determine the transmittable torque. The rated power of the pump is considerably high, consuming a lot of energy even when no work is done. If a system requires additionally the availability of multiple possible pressure levels, the system gets very complex. Furthermore at the attachment of the system the valveadjustment takes a big manual expenditure of human labor.
A flexible adaptation and the elimination of disturbances would be excellent for modulating the torque. Additionally the reduction of the energy consumption becomes more important today.
Therefore the standard hydraulic pump is replaced by the pump actuator, which essentially consists of a variable speed driven hydraulic pump. This generates superior control possibilities over a standard hydraulic system and allows a great reduction of the energy consumption, better control possibilities for the complete system, as well as new methods of fault diagnostics.

Group 5: Abstracts

5-6 CLDP - Hybrid Drive using Servo Pump in Closed Loop

B. Brahmer

This paper presents an approach for energy efficient hydraulic drives. A differential pump is directly connected to a differential cylinder. By principle, energy losses and heating of the fluid are very low. Control loop design is surprisingly simple, because given technology and software from electromechanical drives may be applied. Finally, the approach is attractive because of the degree of freedom in mechanical layout and also because from the outside, the drive appears to be “non-hydraulic”. Ease of use and wide technology basis of electromechanical drives is combined with the ruggedness and overload proof of hydraulics.

5-7 Better Braking – Energy Saving Concept for Cylinder Drives with Large Masses

R. Bublitz

Energy saving is currently one of the major trends for drive technology. This applies to the automotive industry as well as to mobile and industrial applications. Intensive research on alternative drive concepts is done not only in the automotive industry but in mobile and stationary hydraulic systems, too.
For hydraulic drive systems enhanced solutions such as variable speed controlled pump drives were developed. These systems provide only the required volume flow and pressure level and avoid throttle losses.
Another approach is only to rethink about the dimensions of the cylinder drives. If a single rod cylinder has to move large masses dynamically the required cylinder diameter is sized by the resulted acceleration and deceleration force.
Within this paper a new drive concept is presented that uses an additional circuit to realise significantly higher deceleration without overloading the cylinder. It allows at the same cycle time the use of cylinders with smaller piston diameters. This reduces the needed pressure level at the same volume flow and the needed hydraulic energy input.

5-8 New Options for a Cost-Saving Wear Monitoring in Fluid Power Systems

C. Krähling, T. Meindorf

In recent years oil condition sensors have been proven as a reliable way to reduce the total cost of ownership. A major application hereby is the cleanliness or wear monitoring. During the operation of hydraulics and gearboxes contamination and wear will cause high costs for the machine owner. The damage by particle contamination results in unexpected downtime, long lead time of spare parts and loss of production. Contamination and wear in gearboxes and hydraulic systems are nowadays monitored with optically operated automatic particle counters and monitors. Alternatively, inductively operating metal particle counter are used to detect metallic particles. However, in certain applications these types of meters are impractical due to the high costs and technical limitations, such as inadequate measurement accuracy or sensitivity to air bubbles. An old fashioned and cost-effective way to detect ferromagnetic wear particles are magnetic plugs, which are still widely used in many applications. Although the sensors are relatively cheap in the production, a costly service is needed to manually inspect and clean the sensor during operation, such as the high-wear situation at the run in of a machine. As part of the contribution a novel sensor concept based on a magnetic debris sensor is presented, which overcomes the shortcomings of known magnetic plugs. The sensor uses a permanent magnet to attract ferromagnetic particles on the sensor surface and accumulate them. The measurement of the accumulated amount of particles is done inductively, which makes a visual inspection unnecessary. Through the sensitivity of the measurement principle even small amounts of wear particles can be measured. The accumulation of wear can be further assessed as sum over time and not as separately occurring events. To enable a repetitive measurement the sensor cleans
itself automatically, using an electromagnet, which produces an opposing field to compensate the permanent magnet. By evaluating the time between two cleaning cycles of the sensor the contamination of the system or the wear of a component can be detected. Long cycle times between indicate small ferromagnetic wear, short times indicate increased wear. The sensor principle is initially designed for wear monitoring of tribological systems with ferromagnetic materials, e.g. roller bearings. However, it is also possible to detect the wear of non-ferromagnetic materials, through secondary induced abrasion.

Group 5: Abstracts

5-9 Recirculation of Hydro-Mechanical Power at Stands for Testing Endurance of Hydraulic Cylinders

T. C. Popescu, D. D. I. Guta, R. Radoi

Endurance testing on volumetric machines and hydraulic equipment involves high energy consumption, as it takes a long time to carry them out and they are conducted at rated power. Energy consumption of the test stand can be reduced by a special construction of the pumping group. This includes two hydraulic volumetric machines, a pump and a motor, connected in a closed hydraulic circuit and mechanically coupled to an electric motor. Hydropower produced by the pump is reused in order to drive the pump through the engine. Thus, the power delivered in the system must cover the difference between the power consumed by the pump and the one supplied by the motor, and energy-saving process is called "hydro-mechanical power recirculation".
The material shows the influence of hydro-mechanical power recirculation on energy consumption at stands for testing endurance of hydraulic cylinders, by: comparative analysis of energy consumption for two modes of operation of a mini-stand for testing endurance of hydraulic cylinders, coupled and uncoupled to hydro-mechanical power recirculation; demonstration of energy saving at these stands for testing endurance that operate on the principle of hydro-mechanical power recirculation.

5-10 Experimental Study of Motion Synchronization of Hydraulic Servo Cylinders for Moulds of Continuous Casting Machines Oscillation

T. S. Eldin, S. Kassem

This paper reports the details of a test rig as well as results of experiments conducted to investigate the effect of using a cross coupling controller (CCC) on motion synchronization of two hydraulic servo cylinders. The drive and control system of the two cylinders in the rig is similar to that used frequently nowadays to oscillate the heavy moulds of continuous casting machines. In these systems each of the two cylinders is driven independently in an accurate closed loop control system. The accuracy of position synchronization of the two cylinders is affected in practice by disturbances that have detrimental effects on motion synchronization and may eventually lead to unpredictable production interruptions. A CCC with either a fuzzy logic controller (FLC) or a Proportional (P) controller had been proposed. It showed theoretically to reduce synchronization errors (SE) due to disturbances to practically acceptable values. During experiments each of the two servo cylinders had been loaded with almost constant load by means of two other hydraulic servo cylinders to simulate the mould weight. The experimental results showed that the FLC yields better motion synchronization compared with the P controller .

5-11 Multi Domain Mechatronic Optimization of an Intelligent Electro-Hydraulic Actuator

F. Poltschak, O. Koch, B. Farrokhzad, W. Amrhein, J. Weber

Electro-hydraulic systems combine the advantages of both, the electromagnetic and hydraulic domain and bring together e.g. the good controllability and precision of electrical drives as well as the unbeatable power density and higher robustness of hydraulics. An interesting application in this area is an electro-hydraulic actuator specifically designed for high-speed, high-force, high-precision punching applications. To further optimize the actuator design for the next machine generation the traditional layout process can be enhanced by an optimization step. This starts at the stage of conceptual design, needs a fundamental understanding of the underlying processes and a multi-domain mechatronic model. Therefore the simulation software designed for optimizing electrical machines is enhanced to cover electro-hydraulic and thermal issues too. The advantages of the integrated approach and the principle functionality of the simulation tool are demonstrated in context of the optimization of a newly developed electro-hydraulic actuator which was originally developed for punching machines.

Group 6: Abstracts

6-0 Pneumatics- Future through mechatronic Integration and Efficiency

F. Schnur, M. Fiedler

This paper shows a survey of market requirements, research and development activities of pneumatic components and systems, independently from suppliers.
The market stream, driven by legal and society requirements for saving resources, moves to overall energetic consideration of fluidic and electric drives or handling systems.
Besides savings in electric power supplies of components as well as savings of compressed air by lowering the pressure level, reduction of compressed air leakages, recuperation of exhaust air and compression losses, this paper summarises the benefits of higher integration designs by minimising the amount of parts, size, weight, and costs.
Densification of functionalities in subsystems allows online condition monitoring and remote control.
Using well improved software tools for system calculations, pneumatic drives and components can be used with tremendous saving potential of compressed air. Over engineered layouts will be replaced by miniaturisation and design according to required function. Miniaturisation, light weight design and smart combination of modern production technologies enable further reduction of moving masses and electric power supply e.g. of industrial robots.
A rich variety of benefits and improved functionality will justify the future of pneumatics.

6-1 Development of a New 5 mm Solenoid Valve with a Rocker Type Armature

P. Tappe, J. Weiß

For solenoid valves with an overall width less than 10 mm also rotationally acting functional principles become more significant as a supplement to translatory armature movements. Already at the beginning of the 90s Magnet-Schultz has developed a 5 mm solenoid valve on the basis of a rocker armature (rotationally acting). The present patented design represents a consequently continued development with the following targets: Performance-oriented magnetic circuit with double coil, reduction of the swelling behavior of the sealing nipples, sealed overmoulding of the magnetic coil, integration of manual override and media separation.

6-2 Highly Integrated Rotational Drives for Servopneumatic Applications

O. Reinertz, H. Murrenhoff

This paper summarises the development of pneumatic rotational drives under aspects of miniaturisation and sensor integration. At this, an ample miniaturisation can only be achieved by significantly minimising leakage and friction while these often are contradictory optimisation goals, requiring a methodical development of novel actuator principles. Furthermore the integration of customised sensor and gear modules is necessary to meet the miniaturisation requirements. After a simulative optimisation of several novel drive concepts, the best suited concept and a test rig for its characterisation are built up. The paper closes with a discussion of the obtained measurement results and an outlook on ongoing research activities on the described subject.

6-3 Adaptive Gripper Jaws for High-Value Crops Harvesting

W. Gauchel, S. Saller

Grippers for agricultural application must be able to adapt to different sizes and different geometries of the fruit. The following paper describes two possibilities to realize adaptive gripper jaws. One of the grippers is used for apple harvesting, the other for sweet pepper handling. Further on the paper explains options to detect if such an adaptive gripper has gripped a fruit or not. Especially the integration of a force sensor into a FinRay finger produced with rapid prototyping technologies is presented.

Group 6: Abstracts

6-4 Alternative Operating Concepts for Decentralised Automation of Pneumatically-Controlled Hygienic Process Valves

R. Bachmann, U. Brinkmann, K. Große

This paper presents two concepts for local operation and display that can be used for pneumatically-controlled hygienic process valves. The first concept is based on coded magnetic fields applicable for a simple manual override or for a wireless magnetic keyboard. Using this purely mechanical keyboard, a control device can be operated in the field in a convenient, cost-effective and safe way without needing to be opened. The other concept for application-specific integration of indicators and displays into housings makes use of an innovative internal selective metallic coating technology for plastics in combination with laser technology. The most stringent hygiene and environmental requirements are fulfilled at reasonable costs.
Both concepts have been successfully implemented in a new control head and have proven to be very effective for this kind of application.

6-5 Exergy Flow Diagrams as Novel Approach to Discuss the Efficiency of Compressed Air Systems

S. V. Krichel, O. Sawodny, S. Hülsmann, S. Hirzel, R. Elsland

Compressed air systems are among the major consumers of electrical energy in industry. As the importance of energy-efficiency grows in general, so does the need for valid and reliable metrics for discussing efficiency. Today, energy flow diagrams are a common tool to illustrate energy efficiency in compressed air systems. They are however subject to various shortcomings which are mainly related to their lack of transparency and reproducibility. Therefore, a novel approach for the assessment of efficiency is presented which is based on the exergy concept. This approach allows for a transparent calculation of flow diagrams for compressed air systems, including the possibility to illustrate the effects of a heat recovery system. The concept is illustrated at the example of an industrial set-up starting at the compressor inlet and ending at the application. The resulting diagram allows a more transparent and objective view on efficiency evaluations and thus contributes to a better understanding of energy-efficiency in compressed air systems and related applications.

6-6 Improving Energy Efficiency of Pneumatic Handling Systems

J. Hepke, J. Weber

This paper proposes an approach for the investigation and further development of the energy efficiency of pneumatic handling systems. A new aspect in this paper is that the analysis is not only based on the compressed air consumption of pneumatic systems but rather on the balancing of energies. This strategy enables the continuous balancing of all fractions of energy and energy losses. Thereby the foundations to detect and address energy saving potentials can be laid.
In this article the energy distribution within a typical standard pneumatic handling system is analysed based on an experimental and simulation-based method. The results are used for the identification of energy saving potentials. With regards to these potentials adequate energy saving measures can be selected. In the first instance these measures are tested via simulation. Then they are validated by implementing them at selected pneumatic drives of the handling system. The experimental results of the energy consumption comparison of the handling system before and after the modification, show energy savings of more than 20 %.

Group 6: Abstracts

6-7 Energy Efficient Adaptive Control of Pneumatic Drives with Switching Valves

M. Doll, O. Sawodny, R. Neumann

With an increasing interest in energy efficiency in automation processes, pneumatic drive applications are often compared to their complementary technology of electrical drives. Motion tasks performed by pneumatic cylinders are said to be energy inefficient due to the operational mode of throttling the exhaust air at the outlet of the cylinder. A novel, model-based operational strategy is presented in order to improve the energy efficiency of the overall pneumatic drive application. The advantage of huge air savings for the optimized system is accompanied by a reduction of the system's stiffness and robustness. A thorough system analysis shows high sensitivities towards parameter uncertainties and the operational strategy itself. To overcome these drawbacks, an adaptive open-loop control strategy is proposed, which adjusts the dynamic model to the real system dynamics. Thus, maximum robustness of the system is satisfied. The result is a stable pneumatic drive system with air savings from 50% to 80% in comparison to the standard pneumatic systems.

6-8 Air Bearings for Heavy-Duty Industrial Applications - Effect of Bearing Type and Operating Conditions on Energy Efficienc

O. Calonius, P. Kiviluoma, P. Kuosmanen

In the process industry, air bearing technology could provide a competitive alternative to the oil lubricated sliding bearing technology which has high power consumption due to the high viscosity of oil. Typically, air bearings are used in applications where frictionless and precise motion is needed. There are also air-cushion bearings for moving heavy loads in along the fairly rough factory floor in the production of, e.g., trains and large diesel engines. The purpose of this study is to explore the possibility for using air-cushion bearings in industrial machinery in cases with moderate counter-surface quality, fairly large tolerances and dynamic loading. The operating characteristics of an air-cushion type of bearing are put in contrast with those of an air bearing of the porous material type. It was found that the latter type is a good choice for machinery where adequate sliding surface quality can be achieved. High stiffness and fairly low air consumption was found. The air-cushion bearing lacks stiffness but it could function in machinery as additional load carrying unit. Good energy efficiency appears to be possible in the low-leakage mode of operation that was found. However, further testing is needed to determine if the low leakage is associated with contact between the air-cushion membrane and the counter surface.

6-9 Improvement in Dynamic Properties of a Pilot-Operated Gas Pressure Control Valve

V. Sverbilov, G. Makaryants, M. Makaryants, et al.

In this paper, dynamics of a pilot-operated gas pressure control valve are studied through measurement and mathematical modeling for the purpose of obtaining high accuracy and stability over a wide range of flow rate. The pilot stage helps to increase accuracy. However, fluid-born noise and vibration often occur in such type of valves and pressure controllers running at supersonic pressure drop and high flow rate value. These phenomena are caused by instability of balance of the valve in a flow, instability of damping and friction forces. In the paper, the analytical and experimental research is carried out to reveal the most essential factors influencing stability and dynamic properties of the valve. The nonlinear and simplified linear models based on the perturbation technique are developed to predict the stability domain in the space of structural and operational parameters. The stability criterion for the system is deduced using D-decomposing method. CFD software is employed to study the effect of the poppet geometry on aerodynamic lifting force. Simulation is carried out with MatLab/Simulink, considering factors that influence on the dynamic properties of the valve such as lifting force, nonlinear friction and pilot dynamics. The analysis and simulations show general agreement with experimental data. Effective means for obtaining stable operation of the system are proposed.

Group 6: Abstracts

6-10 Reducing the Limit Cycle Oscillation of a Full-Digital Pneumatic Motor Speed Control System

J.-C. Renn

In this paper, an improved full-digital closed-loop pneumatic motor speed control system with reduced limit cycle oscillation is developed and realized. A significant feature of the proposed structure is the combination of the proportional technology as well as the full-digital control scheme. The utilized proportional full-digital control valve (FDCV) consists of four parallel-connected 2/2 pneumatic on-off valves with multiple flow-rate outputs. Compared to the PWM flow control scheme using four fast-switching 2/2 on-off valves, the proposed FDCV possesses several advantages like medium operating noise, long life, ease of control and low cost. The simple but effective binary coding system is chosen for this study. The major fault of the conventional FDCV, however, is its nonlinear saw-toothed flow-rate characteristic which generally results in the undesirable limit-cycle oscillation in the steady-state response. Therefore, a novel technique to reduce the amplitude of limit-cycle oscillation is developed in this paper. The basic idea is to reduce the opening areas of four on-off valves in the FDCV simultaneously by applying lower current inputs to the valve coils in the steady-state. Consequently, the limit cycle oscillation of the pneumatic motor speed control can be successfully reduced without any hardware modification. Finally, experiment results prove that the amplitude of the steady-state limit cycle oscillation is significantly reduced by using the proposed two-step current switching controller. Therefore, the FDCV together with the proposed novel current switching control strategy is a potential alternative of precise closed-loop pneumatic motor speed control.

Group 7: Abstracts

7-0 The Piston Cylinder Assembly in Piston Machines – a long Journey of Discovery

M. Ivantysynova

This paper summarizes the main contributions of researchers and engineers to the discovery of physical phenomena defining the fluid film properties and the operational conditions of the piston cylinder interface in hydrostatic piston machines. The main focus of this paper is the piston cylinder assembly of designs, where the design principal is based on torque generation requiring a large side load of the piston. Since 1965 more than 20 dissertations have been completed on theoretical and/or experimental studies of the piston cylinder interface. Listing all of the papers published worldwide on analysis of piston kinematics and dynamics, modelling and simulation of piston/cylinder interface and experimental studies would exceed the allowable length of this paper. Therefore only major milestones in discovery will be discussed.

7-1 Design of Hydrostatically Balanced Bearings of Radial Piston Pumps by the Use of FE Computation with Interaction of Multibody and EHD Simulation

T. Kentschke

In the actual MOOG R&D projects a new computation software tool was used for the verification of bearing capacity of pre-designed geometries of hydrostatically balanced bearings of radial piston pumps RKP in prototype phase. This software tool combines multibody computation and elasto-hydrodynamic theory (EHD) with a sequenced solution of Newton's Equation of motion and Reynolds Equation of flow. The computation considers both geometrical boundary conditions such as bearing clearance and surface roughness of the contact partners and operational conditions such as relative velocity, forces resulting from pressures, friction coefficients and fluid viscosity. Local deformations of surfaces resulting from multibody computation are directly used as boundary conditions for the solution of the Reynolds Equation of flow. The results of the computation for the bearing geometry are for example the distribution of bearing gap width, the local bearing pressures and, if mixed friction occurs, the local contact pressures. For verification of the software the model of a proven bearing with accordingly substantial knowledge regarding operational and wear behaviour was set up and calculated.

7-2 A Fluid – Structure Interaction model to analyze Axial Balance in External Gear Machines

S. Dhar, A. Vacca, A. Lettini

This paper presents a novel approach for studying the lubricating gap between lateral bushes and spur gears in external gear machines. Pressure compensated lateral bushes are important elements for efficient operation of an external gear pump or motor, being responsible for functions such as sealing the displacement chambers, and limit the local pressure peaks and cavitation associated with the teeth meshing process. Due to the complexity of creating a dynamic model of fluid film lubrication for this kind of machine, efforts thus far have stopped short of analysing the axial balance of the lateral plates and the hydrodynamic squeeze effect of fluid film lubrication has not been considered. The current study describes an original method of modelling the axial balance of the lateral bushes considering full hydrodynamic and elasto-hydrodynamic effects coupled to the motion equation of the bushes. The pressure field in the gap is solved using a finite volume solver of the Reynolds Equation. The fluid flow in the lateral gap is fully coupled with the deformation caused in the lateral bushing, which is solved using a finite volume stress solver. Details of the developed solution for solving this complex Fluid – Structure Interaction problem are reported in the paper, and results are presented for a representative gear machine design.

7-3 An innovative external gear pump for low noise applications

M. Lätzel, D. Schwuchow

The reduction of noise in stationary and mobile applications is becoming more and more important. In this paper a new type of an external gear pump is presented. In order to understand the design features of the pump, first an overview of the relevant sources of noise in an external gear pump is given. Subsequent to that different ways to reduce the noise are shown and finally combined to achieve the new SILENCE PLUS pump. Afterwards results of the new pump are presented, before the paper concludes with an outline which applications will benefit from the new type of pump.

Group 7: Abstracts

7-4 Noise reduction of hydraulic systems by axial piston pumps with variable reversing valves

T. Nafz, H. Murrenhoff, R. Rudik

Noise reduction is one of the main targets in the development of hydraulic systems. Hereby, hydraulic pumps are often considered to be the leading noise source. The main criteria for noise generation of hydraulic piston pumps are the flow ripple, the pulsating piston force and the pulsating swash plate torque.
Common methods to reduce noise of axial piston pumps are grooves or boreholes to smoothen the reversing process. More recently, pre-compression volumes are used which mainly focus on flow ripple reduction. However, these methods only have the ability to reduce noise and flow ripple significantly in a designed operating range.
Using special reversing valves, a variable approach to reduce noise is investigated in this paper. Hereby, the valve openings can be adapted to the actual operating point of the pump, which is defined by the rotational speed, the pump displacement and the system pressure. Furthermore, this variability allows different control strategies, so that the focus can be shifted between the different noise criteria and optimized for a specific hydraulic system. The required valve openings for different control strategies and operating points were determined by simulation runs and verified by measurements.
Depending on the applied control strategy and the investigated operating point, flow ripple reductions of up to 50% and swash plate torque ripple reductions of up to 70% were measured. Furthermore, different cylinder pressurization slopes are presented along with the resulting pump noise. Depending on the operating point, sound power level of the pump itself can be reduced by up to 2dBA compared to a highly optimized standard pump.

7-5 Analysis of the Flow Conditions in a Dosing Pump with Regard to New Fuels

M. Petzold, J. Weber, E. Dautry, O. Ohligschläger, A. Müller

Conveying new fuels with a high proportion of ethanol leads to an increased cavitation tendency inside a pump. This paper presents investigations of the flow conditions in a dosing pump using Computational Fluid Dynamics (CFD). For accurate spatial resolution of fluid mechanical details, a three-dimensional computational analysis of fluid-structure interaction in the outlet valve is surveyed. Comparisons are made by experimental testing. Noteworthy is a technique based on a laser Doppler vibrometer for examining the dynamics of the piston inside the fluid. The applied CFD cavitation model is parameterized and validated by experimental (optical imaging) and numerical investigations of the cavitating flow in an orifice flow. The objective of the developed method is to identify and reduce the potential locations for cavitation in order to ameliorate the high level of delivery accuracy.

7-6 Radial Piston Engine with Cone Valve Plates

J. Berbuer, D. Schulze Schencking

The Radial Piston Unit with Axial Cone Valve Plate (RAC) is a new type of hydraulic displacement unit, generated by the recombination of established and well controllable functioning principles. It uses a tilted piston design that enables direct torque generation in the cylinder star without inducing transverse forces on the piston. Moreover, the entire rotational group is hydrostatically supported and as a result no hydraulic forces act on the shaft and the shaft bearings.

7-7 A hydraulic transformer with a swash block control around three axis of rotation

P. Achten, T. van den Brink

A new design of a hydraulic transformer is presented. The design combines the floating cup principle and the three-port hydraulic transformer concept of Innas. The design resembles the design of the variable displacement, floating cup pump. An important difference is the bearing of the swash block. In the variable displacement pump, the swash block has a cylindrical bearing, and has only one degree of freedom. In the new transformer design, the swash block is supported by a spherical bearing, which results in three rotational degrees of freedom.
This paper describes the fundamental design principle of the new ‘Oiler’ transformer, its design constraints and the most important design solutions. The new design allows an unlimited control range of the hydraulic transformer, combined with large, unrestricted oil passages for all operating conditions.

Group 7: Abstracts

7-8 Dosing pumps - revisited

V. Peters, O. Ohligschläger, A. Müller

Initially used for auxiliary parking heaters for mobile automotive systems, the range of applications for electromagnetically driven dosing pumps has been widely enlarged during the past few years. Whereas originally only diesel fuel had to be delivered, nowadays all kinds of liquid media have to be pumped. These, diesel and petrol fuels and a lot of additives, require verification and improvement of the design for optimal usage and low energy consumption. Thus, the dosing pump has been improved to efficiently deliver and admeasure more or less any kind of liquid media. One of the most innovative operational areas of such compact metering units is the fuel cell reformer technology, wherein a constant flow of a certain amount of fluid is required.

This contribution is concerned with the principal design of such pumps, functioning, potential of accuracy and lastly with some specific features (valve function, dry run behaviour and self-priming potential) as well as the potential for optimization (installation space, part reduction).

Group 8: Abstracts

8-0 Actual trends in the design and development of valves and actuator control

C. Boes

The development of motion control technology during the last years has been driven by different requirements from the application markets as increased dynamic performance, low energy consumption, higher power density or easy to use features. The publication shows how the leading companies react on these technical market requirements. This article responds also to the trend towards electric and hybrid motion control systems due to their low energy consumption.

8-1 Design of an Internally Pilot Operated Proportional Valve by Use of the Floating Spool Principle

P. Mejsnar, E. Englberth, G. Schuster

Nowadays, hydraulic systems are an integral part of various machines and equipment, both in stationary and mobile applications. Earth-moving machines like excavators of various sizes and designs use the benefit of hydraulic drives to a great extent.
One possibility to extend operation capabilities of excavators and loaders significantly is the use of a special adapter-head enabling the rotational and swinging movement of the working tool (roto-tilt). The adapter is installed between the excavator arm and the bucket and can be seen as a controllable joint.
Based on this context, the development of a CETOP03 proportional valve with an internal pilot stage is described in this paper. Therefore the boundary conditions have been given due to the application of an excavator rotational-tilting adapter.
During the development phase a Matlab/Simulink model has been built up to enable a better understanding of the valve behaviour. By an example, which occured during the development phase, it will be shown how well measurement and simulation technique complement each other and help to find the solution of side effects in a shorter period of time.

8-2 Compact, Lightweight Valve Actuators with Polymer Gears Using the Harmonic Principle

F. Pöhlau

Traditional electromechanical actuators for fluidic systems (hydraulics, pneumatics, processing technology) use (metallic) spur and planetary gears. The multitude of components of those gears have a negative impact on space, accuracy and cost. Harmonic Drive steel gears have long been known for their precision and power density, also in valve acutators. By employing a flexible gear element, the Flexspline, high precision and high reduction ratios can be achieved in a small envelope with few components and low weight.
Transferring the gear principle into moulded plastics makes it possible to use its advantages also for large series, integrating additional functions in cost-efficient, lightweight components with tight tolerances. Fluidic applications include thermostatic valveheads, but also pumps for very small liquid volumes as in medical devices.
This paper presents the principle, application examples and some research results on improving gear efficiency and durability by varying materials and design.

8-3 Novel piezoelectrical drive mechanism for small valves

R. Tautenhahn, T. Dreher, J. Weber, M. Fuchs

Piezo actuators show several advantageous properties which make them interesting as drives for fluid power components. However, using these actuators poses a technological challenge. In order to use commercially available piezoelectric stack actuators as drives in small valves, a new piezoelectrical drive mechanism was developed. This paper presents a concept to ensure proper valve operation, independent of manufacturing variations and temperature influences. The tolerance to manufacturing variations is realised by an adjustable design. For the temperature stability a compensation mechanism is shown, which helps suppress the thermally induced deflections. The required miniaturization is achieved by a load-specific design.

Group 8: Abstracts

8-4 Performance Optimization of a Two-Stage Piezohydraulic Servovalve

D. Sangiah, A. Plummer, C. Bowen

This paper describes the performance optimization of a two stage piezohydraulic servovalve developed for use in aerospace. The valve uses a piezoelectric multilayer actuator in the pilot stage and a conventional main stage spool. The actuator moves a deflector which directs a jet to to create a differential pressure at the pilot control ports which drives the main stage spool. A mechanical feedback wire provides position feedback of the main stage spool to the deflector. The valve has been developed in an attempt to reduce servovalve manufacturing cost.
From a simplified model it can be shown that the maximum spool displacement and the frequency response of the valve are directly influenced by the relative stiffness of the piezoelectric actuator and the feedback wire. In this paper, the model is used to predict this design trade-off and hence optimise the performance of the valve. Two versions of the valve are tested to validate the prediction method.

8-5 Fault Detection and Diagnosis Method for a Process Control Valve

T. Manninen

In this paper is presented a simple fault detection and diagnosis (FDD) method. This model based method is especially suitable for embedded systems because need for computing power is minimal. The static model scheme is utilized to model inherent system nonlinearities in the method. Model is obtained during system normal operation after the explanatory variables are specified. Separate fault learning is not need. The introduced method is applicable for all the systems where feedback control is utilized and some of system's internal variables are measurable.
In this method the faults can be detected through detecting internal variables operation point changes. These operation point changes are consequences of the faults since feedback control tries to compensate them.
Eight typical faults (leakages, friction changes and backlash) for a process control valve were simulated in the process control valve fault simulator and proposed method tested. The results indicate that all the faults can be detected and diagnosed before severe impact to control performance of the system. Some of the faults were tested also in the real process control valve test bench in the laboratory. The results in the real environment are consistent with the simulator results.

8-6 Sensor-Less Position Detection at Electromagnetic Actuators

J. Heinzmann, P. Tappe

In this presentation a new patented procedure is described which allows to detect the armature position of an actuator by means of the variance of a turn-off pulse depending on the stroke point.
In order to generate the turn-off pulse the current flow is interrupted by the coil for a short time as a result of which the magnetic coil generates a voltage pulse in dependence of the coil inductance. The voltage pulse depends on the position of the solenoid armature, so there is a clear connection between the armature position and the time sequence of the turn-off pulse. This temporal change of the voltage reduction can be detected by means of an electronic device. A big advantage of sensor-less position detection is that no electronic device or additional mechanism has to be applied directly at the actuator resp. no loss of installation space will occur. Furthermore this procedure allows the use of the actuator coil as pure sensor coil, the position detection hence may be realized also at a “force-less” armature by the use of short measurement pulses.

Group 8: Abstracts

8-7 Identification of Critical Operating Conditions for Robust Evolutionary Optimization of Hydraulic Valve Controllers

J. H. Braun, J. Krettek, F. Hoffmann, T. Bertram

The design and optimization of complex technical systems is an important task in engineering and development. Evolutionary hardware-in-the-loop (HIL) optimization constitutes a powerful method as it performs robust search in complex and high dimensional search spaces. The operating conditions severly influence the quality and performance that a solution subject to an HIL evaluation is able to achieve. Thus it is essential to properly control and select these operating conditions in the context of HIL optimization in order to accomplish robust valve performance across a large range of processes and applications. The identification of crucial operating conditions in terms of stimuli, disturbances and external parameters such as hydraulic load and pressure constitutes an optimization task by itself. The approach presented in this paper employs evolutionary optimization to identify test scenarios at the boundaries of the operating envelope under which regulation of the valve position is particular difficult. The parametrization and optimization of these conditions are illustrated and experimental results under realistic valve operation conditions are provided.

8-8 Improving the Performance of an Electro-Hydraulic Load-Sensing Proportional Control Valve

R. Babbone, M. Milani, F. Paltrinieri, L. Montorsi, M. Bartoli

The paper deals with the simulation and the experimental verification of the hydraulic behavior of an electro-hydraulic load-sensing proportional control valve. An innovative CAE methodology, developed combining CFD simulations with lumped and distributed numerical modeling, is firstly introduced and tailored by comparing the numerical results with measurements coming from an experimental campaign performed for a wide range of pressure loads and metered flow rates. Then, both the reliability and the limits of the numerical approach are highlighted through a detailed numerical vs. experimental comparison, involving the pressure of the main hydraulic lines, the flow rate through the first section and the local compensator displacement. Finally, the CAE methodology has been applied for assessing the internal ducts hydraulic permeability and the local compensator spring pre-load influence on the control valve metering curves. At the end of this analysis, an optimized design configuration, featuring a maximum controlled volumetric flow rate increased of more than 25%, has been proposed.