Annual Report 2005

Monika Ivantysynova
MAHA Professor Fluid Power Systems

West Lafaeytte, January 2006

Preface

The year 2005 was a really important and very exciting one for the team of the MAHA Fluid Power Research Laboratory. On April 1, 2005 we celebrated the 10th anniversary of my fluid power research group. Since I established my first lab at the University of Duisburg, Germany in 1996 and after five years of working at the Technical University of Hamburg–Harburg, Germany I moved with my entire lab and team in August 2004 to Purdue University. The new MAHA Fluid Power Lab at Purdue was built and set up after three months in November 2004. In 2005 we were able to add a new central hydraulic power supply and a new engine driven power train test rig. I would like to thank Parker Hannifin Corporation for their great support and the donation of the new 400 kW hydraulic power unit. My special thanks go the National Fluid Power Association for their donation of $100,000 to the MAHA Lab. I would like to thank Cummins Inc. for the denotation of an engine for the new power train test rig. While the research team had moved through very dynamic changes the group has continuously grown in numbers. From 10 researchers in fall 2004 the research group has grown to 15 at the end of 2005 with only three senior researchers from the previous team. I am very proud to report that our research results have earned international recognition. We received the PTMC 2005 - Best Paper Award for our paper "Measurements of elastohydrodynamic pressure field in the gap between piston and cylinder" presented at the 2005 Bath workshop. Congratulations to Max Huang and Robert Behr for their excellent work. I am very pleased to report that in honor of our outstanding contribution I have received the JFPS International Symposium Distinguished Service Award from the Japan Fluid Power System Society. I would like to thank all team members for their excellent work in 2005. It is a great pleasure to present a survey of our activities and main achievements in the year 2005 within this annual report.

In spite of the nearly complete renewal of the research team our research activities continued extremely well. In 2005 the work on four larger research projects has been successfully continued and/or completed. In addition we started three new large industrial sponsored projects and completed four smaller industrial sponsored projects. I am especially proud to report that after more than two years of development a new and world wide unique test rig for measurements of dynamic pressure fields in the gap between piston and cylinder has been finally placed into operation. This is the first time that the dynamic pressure in the lubricating gap between piston and cylinder of an axial piston machine can be measured. The test rig is part of our research in modeling and simulation of elastohydrodynamic effects in narrow lubricating gaps to develop computer based optimization methods using micro and nanoscale surface design modification and adaptation. Our multi-domain simulation tool CASPAR, which has been developed over the last ten years by an excellent team work of researchers on this team, plays a central role in this research. In 2005 a new version of the EHD module of CASPAR has been successfully tested. We are very happy that Peter Konarik has made important improvements on our POLYMOD software. This program forms one of our basic tools when simulating energy consumption of hydraulic actuators and drives.

The research work related to development of advanced power split drives has made great progress. Within this research the PSDD tool, previously developed by Dusan Mikeska, plays an important role. Jean Claude Ossyra and Jonathan Liscouet have made significant improvements of this tool. Several new research projects have been started based on the successful work of this team. The research activities related to the development of generic methods for prognostics of mechatronic systems in off-road vehicles have also made great progress. Michael Oppermann has successfully finished a series of field tests using an instrumented wheel loader. He has completed his PhD thesis and will hopefully pass his defense successfully in spring 2006.

In 2005 the MAHA lab could welcome many national and international visitors from academia and industry. On February 9, 2005 Sally Mason, Provost of Purdue University together with Linda Kathi, Dean of College of Engineering and Randy Woodson, Dean of College of Agriculture visited our lab. The Fluid Power Education Foundation held their board of director meeting at Purdue and visited our lab on May 11, 2005. On December 1, 2005 we hosted the ERC team of the proposed ERC for compact and efficient fluid power for the rehearsal of the site visit from National Science Foundation. The proposed research projects were presented on 36 posters placed in the MAHA lab.

I am very proud to report that preliminary program of the 4^{th} PhD symposium has been completed. We have received 66 abstracts from 17 countries. As chairman of the organizing committee I would like to thank Michael for his great job in preparing this event.

I am sure that we can continue our successful research work. I wish all members of the team a lot of success.

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CONTENTS

2 RESEARCH ACTIVITIES

Our research activities focus on two major areas – advanced energy saving hydraulic actuators and drive systems and the investigation of physical processes in displacement pumps and motors especially modelling of flow phenomena in narrow lubricating gaps.

• Advanced energy saving hydraulic actuators

The aim of this research is to develop new valveless hydraulic actuator concepts, including necessary motion control strategies for different applications to avoid energy dissipation by resistance control. Recently, among others, a new valveless linear actuator has been developed and successfully tested on an off-road vehicle. For large mobile robots displacement controlled joint rotary actuator concepts have been developed and successfully tested using a large laboratory test rig. Current research activities include:

- Displacement controlled actuator technology for active roll stabilization
- Active oscillation damping based on displacement control for off-road vehicles

• Computer based pump & motor design

This research focuses on the performance optimization and noise reduction of pumps and motors. These research efforts involve the design of special experimental facilities to develop a fundamental understanding of the complexity of physical effects taking place in displacement machines. One important result of this research on pumps and motors has been the development of the multi-domain simulation program CASPAR. CASPAR represents the first program worldwide, which allows the prediction of flow ripple, instantaneous cylinder pressure, oscillating swash plate forces, gap heights, friction forces and volumetric losses of piston pumps and motors. Current research activities concentrate on investigation of flow phenomena in micro and nano-scale area to improve existing mathematical models and to develop methods for surface optimization allowing a further increase in power density and improvements in efficiency and reliability. Further research focuses on modeling fluid and structure borne noise sources allowing the development of model based optimization methods for the reduction of noise emission from pumps and motors.

• Drive line control of off-road vehicles

Research in this area centers on investigations concerning the feasibility and performance of alternative drive line technologies for off-road vehicles. The aim is to develop system concepts for minimizing exhaust emissions and fuel consumption without limiting the vehicle's driving power. A special software tool called PSDD has been developed to support virtual prototyping of power split drives and complex multi-motor hydrostatic transmissions. The research activities are supported by performance measurements using motor and pump test rigs and a hardware-in-the-loop drive line test rig. Past and current studies include:

- Virtual prototyping of power split drives
- Vehicle drive line control towards optimized primary power consumption
- Advanced system and control strategies for multi-motor hydrostatic transmissions
- Development of generic methods for prognostics of mechatronic systems of off-road vehicles

In 2005 the work on the following research projects has been continued:

- Virtual prototyping of power split drives
- Development of elasto-hydrodynamic simulation model for advanced gap flow simulation
- Active vibration damping for off road vehicles using displacement controlled linear actuators
- Vehicle drive line control towards optimized primary power consumption
- Development of generic methods for prognostics of hydraulic systems in off-road vehicles
- Advanced gap design for displacement machines using tap water
- Noise reduction of axial piston machines based on multi-parameter optimization
- Displacement controlled actuator technology for active roll stabilization and other automotive applications
- Advanced system and control solutions for multi-motor hydrostatic transmissions

The described research activities have been accompanied by extensive experimental work. During the last ten years a comprehensive fluid power research laboratory with pump and motor test rigs, actuator test rigs, drive line control and transmission test rigs including test machines as well as several special test rigs for investigation of tribological systems of displacement machines, has been built. Since October 2004 all the equipment is installed in the MAHA Fluid Power Research Lab @ Purdue University. In 2005 a 450 kW central hydraulic power supply unit has been added to the MAHA lab. The MAHA lab covers an area of 850 m^2 and has an installed electric power supply totaling 700kW.

3 RESEARCH RESULTS & SOFTWARE TOOLS

Research Reports in 2005

Ivantysynova, M. Ossyra, J.-C. and Anderson St. H. 2005. *Investigation of alternative valveless actuator concepts for active roll stabilization.* Research report IV/16-8-1F.

Ivantysynova, M. and Rahmfeld, R. 2005. Displacement Controlled Hydraulic Servo Drives for Wheel Loaders "Valveless Technology". Research report. IV/05/42F

Ivantysynova, M.; Rahmfeld R. and Oppermann, M. 2005*. Advanced multi-functional machinery for outdoor applications. IBIS Final technical report.* Project # 61595.Research report IV/05/43F.

Soares, L.P. 2005. *Study of piston - cylinder assembly of a water hydraulic axial piston pump.* Research report IV/05/44F.

Ivantysynova, M. and Franzoni, G. 2005. *Steady State Measurements of the Parker H1A variable displacement pump*. Research report MAHA01-2005-in.

Ivantysynova, M. and Franzoni, G. 2005. *Steady State Measurements of the Parker H1A variable displacement pump.* Research report MAHA02-2005-ex.

Ivantysynova, M., Ossyra, J.C., Franzoni, G., Liscouet, J. 2005*. Analysis of three alternative transmission concepts using PSDD software*. Research report MAHA03-2005-ex.

Ivantysynova, M. and Stegemann, P. 2005. *Operational Manual of the Tribotestrig*. Research report MAHA04-2005-in.

Ivantysynova, M., Stegemann, P., Franzoni, G., Huang, Ch. 2005. *Modeling, Analysis, Optimization and Steady State Measurements of the Parker H1A 14 cc Axial Piston Pump*. Research report MAHA05-2005-ex.

Ivantysynova, M. and Ossyra, J.C. 2005. *Development of a control concept for powersplit drive for a special truck application*. Research report MAHA06-2005-ex.

Ivantysynova, M., Ossyra, J.C., Konarik, P. 2005. *Maunal for Polymod Rev.05.04*. Research report MAHA07-2005.

Ivantysynova, M., Ossyra, J.C., Liscouet, J. 2005. *Manual for PSDD Rev.05.01*. Research report MAHA08-2005.

Ivantysynova, M., Ossyra, J.C., Liscouet, J. 2005. *Manual for PSDD Rev.05.02*. Research report MAHA09-2005.

Ivantysynova, M., Ossyra, J.C., Liscouet, J. 2005. *Manual for PSDD Rev.05.03*. Research report MAHA10-2005.

Ivantysynova, M., Huang, Ch., Klop, R. 2005. *User Manual CASPAR 2005*. Research report MAHA11-2005.

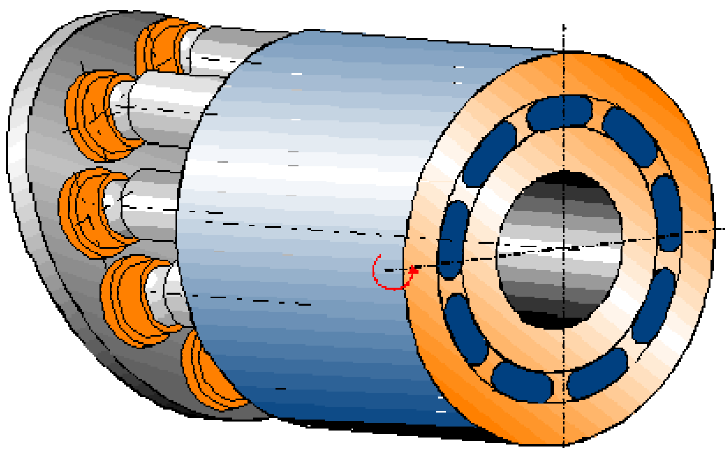
Ivantysynova, M., Christiansen, S., Huang, Ch., Stegemann, P. 2005. *User Manual AVAS Version 1.0*. Research report MAHA12-2005.

Ivantysynova, M., Chen, G. 2005. *Operation Manual of "Olems" Test Rig*. Research report MAHA13-2005.

The following special simulation software tools have been developed and are available for commercial use

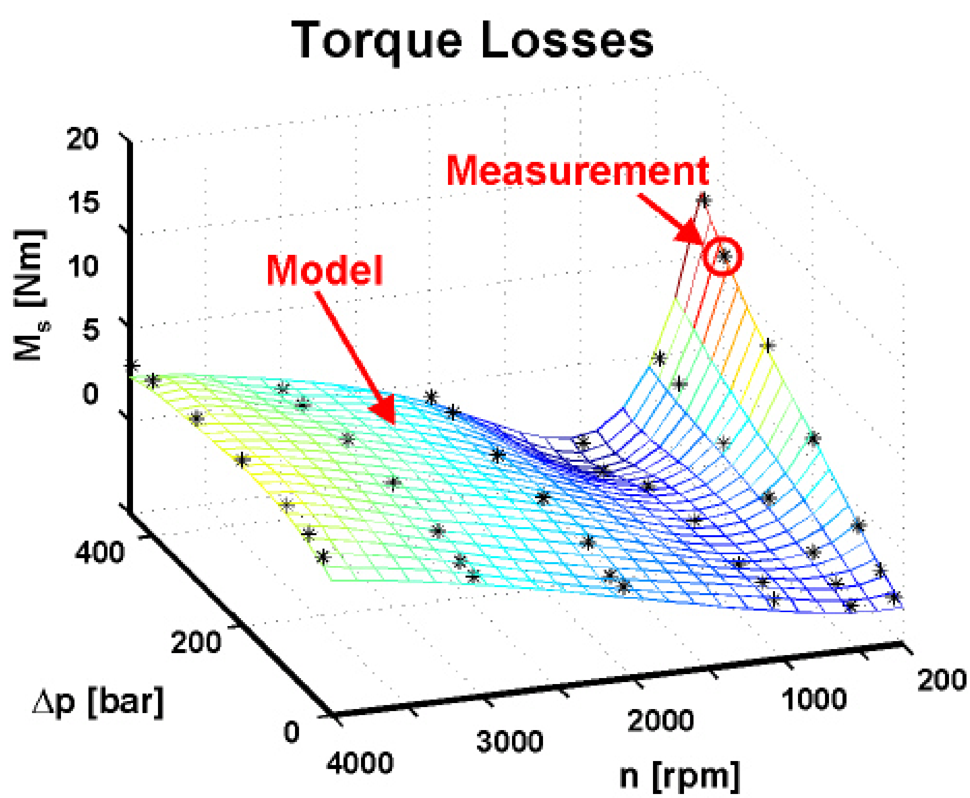
CASPAR

The prediction of pump and motor performance for a given design of a displacement machine requires a simulation model that describes the flow of a compressible and viscous fluid from the ports through the valve plate to the displacement chamber. It must further consider the gap flow through the lubricating gaps that seal the displacement chamber. The change of pressure in the displacement chamber resulting from the basic working process of the displacement machine causes fluctuating forces and moments leading to oscillating micro motion of moveable parts of the rotating group. The simulation program *CASPAR,* which has been developed at the Institute for Aircraft Systems is based on a non-isothermal gap flow model considering the change of gap heights due to micro motion of parts and due to surface deformations for the connected gaps of a swash plate axial piston machines. The program allows the calculation of real flow ripples at both ports, further the calculation of the instantaneous cylinder pressure, the internal and external volumetric losses, viscous friction forces, gap heights, oscillating forces and moments exerted on the swash plate. The program represents a powerful design tool for this kind of displacement machines. *CASPAR* is a stand alone tool developed using the C^{++} programming language. Models implemented and solved in *CASPAR* consider the time dependent change of gap heights due to oscillating forces, the interaction between machine parts, the dependency on design and operating parameters and the energy dissipation within the gaps. The updated relase of *CASPAR* includes the consideration of elasto-hydrodynamic effects due to surface deformation of parts forming the gaps. The mathematical description of the fluid flow from the ports to the displacement chamber and through the sealing and bearing gaps leads to a system of partial and ordinary differential equations. A new numerical method based on iterative coupling of separate solvers for fluid/solid domains has been developed to solve this transient nonlinear system consisting of the Reynolds equation and the energy equation for fluid domain, the equation of elasticity for the solid domain and the determination of gap heights by solving the motion equation of the multi-body system of the rotating group. The initial-boundary conditions such as instantaneous cylinder pressure are obtained by solving the fluid flow from displacement chamber to the ports.



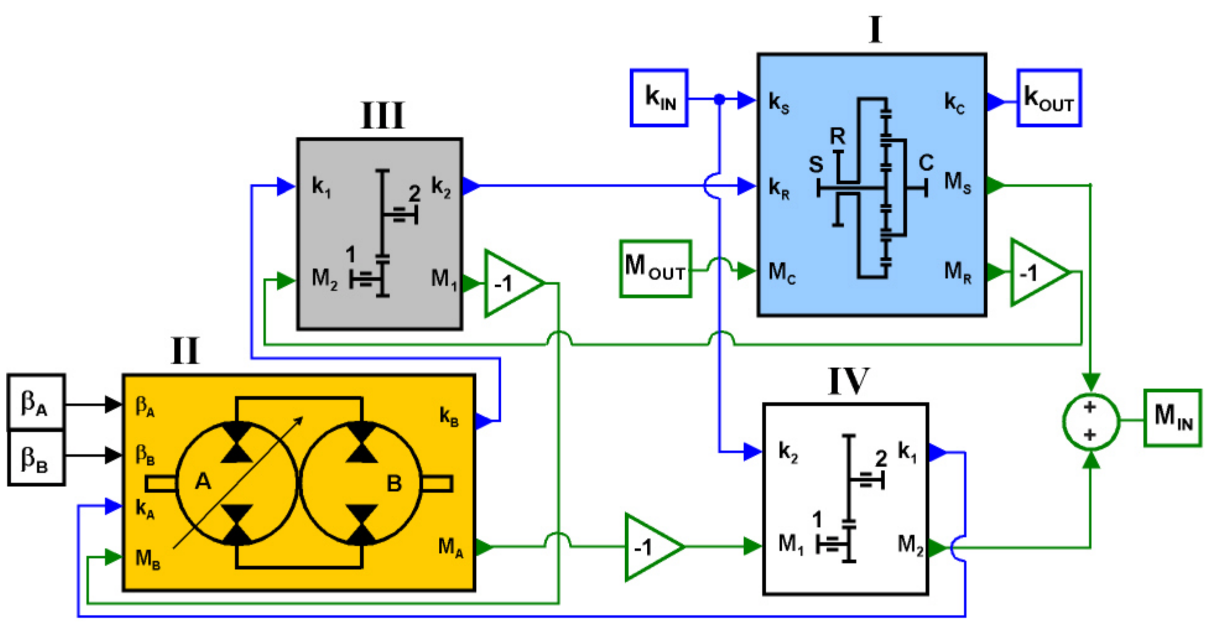
POLYMOD

The prediction of losses of fluid power systems by numerical simulation and the design of energy saving actuators and drive systems require a very high accuracy in steady state models of components, especially displacement machines. In the past a number of different mathematical models for the description of the loss behaviour of displacement machines were developed by many authors. Nearly all available models are based on measurements, but different methods are applied to obtain an analytical description. The limitation of achievable accuracy of most of these models is given by the use of relatively simple analytical expression, whereas a good fit with measured curves is usually obtained only in a limited area of operating parameters. The program *POLYMOD* uses a pure mathematical modelling approach by interpolation of measured steady state characteristics of displacement machines. The use of polynomial fitting of measurement points allows a higher accuracy of the model, especially in the range of boundary operating parameters. *POLYMOD* generates an analytical description of volumetric and torque losses of displacement machines for pump and motoring mode based on measured steady state characteristics. The dependency of all important operating parameters such as pressure difference, speed, displacement volume and temperature can be easily considered. *POLYMOD* can be applied for any kind of displacement machine. The software tool is Matlab-based.



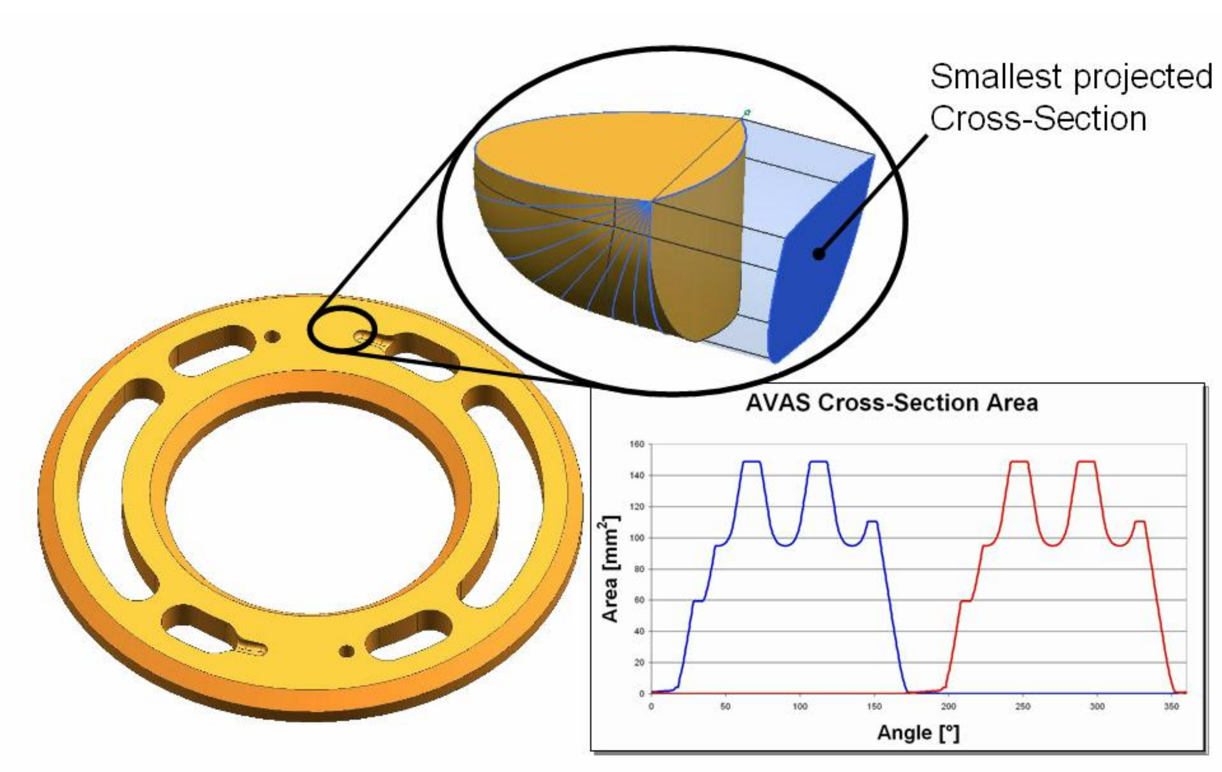
PSDD - POWER SPLIT DRIVE SIMULATION

One of the main reasons for the use of power split drives in many applications is the possibility to have a continuously variable transmission with simultaneously high efficiency in a wide range of operating parameters. This requires the consideration of real loss behaviour of all parts of the transmission. Due to the strong dependence of losses of displacement machines on operating parameters the integration of precise loss models is necessary. The *PSDD* software tool allows the calculation of system parameters including power losses in the whole range of operation for any kind of power split drive structure. This provides the design engineer with very good support during the design process and helps him to find an optimal structure of the power split drive. The tool has libraries for hydrostatic components, gears, clutches and planetary gear sets. These libraries can be extended and completed by the user easily. An open database of most common structures of power split drives is implemented in the CAE tool. The *PSDD* software tool is built in a modular way on Matlab and Simulink platform.



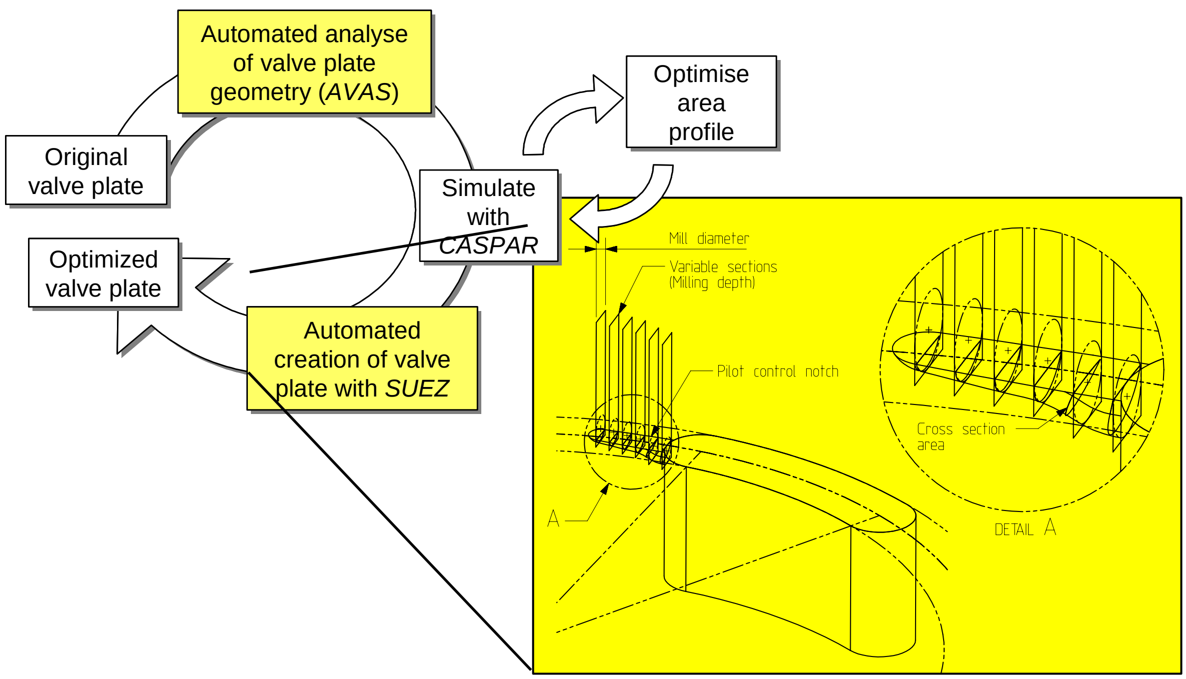
AVAS

The change of pressure in the displacement chamber of a displacement machine is greatly influenced by the smallest cross-section of the fluid flow which is formed by the valve plate and the rotating cylinder block. For simulation calculations, it is important to know the exact size of the flow passage opening to the high and low-pressure side, depending on the angle of rotation. Because of the complex geometric sectioning, an analytical description of the cross-section is not possible. In the past the cross-section was measured and interpolated manually to obtain the area profile. Using a 3D-model of the valve plate AVAS is able to compute the smallest cross-section of the fluid for a complete revolution of the cylinder block automatically. In the single-step mode every calculated passage area can be visualized. AVAS uses *Unigraphics* based routines to determine the smallest cross-section into the estimated flow direction. The program is written in C++ and uses the *UG/Open++* interface to start as an internal application in *Unigraphics*. The 3D-model of the valve plate can be imported from any other CAD-System by the *STEP* interface.



SUEZ

SUEZ allows an automatic design of valve plate openings by reading a corresponding opening area file. SUEZ is based on the 3D CAD System Unigraphics. The pilot control notches of the valve plate are assumed to be manufactured by ball end milling. The cross section area, the length and the angle of the notches can be manipulated to obtain the desired instantaneous cylinder pressure for given operating parameters. The combination of the simulation tools CASPAR, AVAS and SUEZ allows optimizing swash plate axial piston machines in a very cost effective way. This method can also be used for other displacement machines.



4 MAHA FLUID POWER LABORATORY

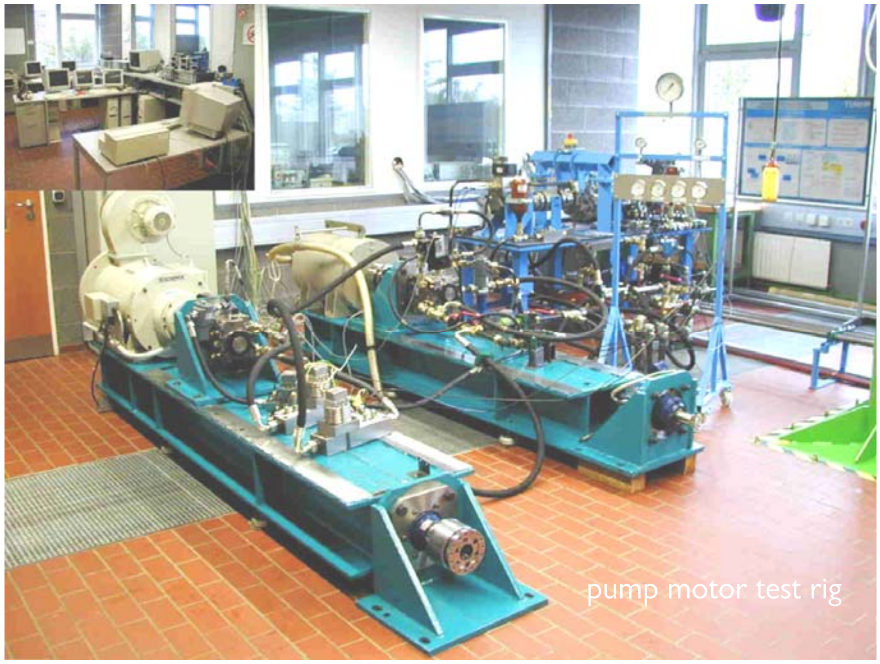
The MAHA fluid power research laboratory @ Purdue University offers a unique and well equipped laboratory for steady state and dynamic measurements on pumps, motors, hydrostatic transmissions and linear and rotary actuators. Different special test rigs are available for experimental investigations of tribological systems of pumps and motors. A 450 kW central hydraulic power supply unit with five individually controlled pressure compensated pumps and a 200 l/min low pressure pump has been installed in 2005. The central pressure net is mainly used to supply hydraulic load units for the individual test rigs, where the load units are based on secondary control. The total installed electric power amounts 700 kW. The lab includes three mobile test machines allowing the test of new actuators and drive technologies as well as prognostic methods during practical field tests. The laboratory area amounts to 850 m^2.

The MAHA lab has been established @ Purdue University in fall 2004. Two new test rigs have been added in 2005.

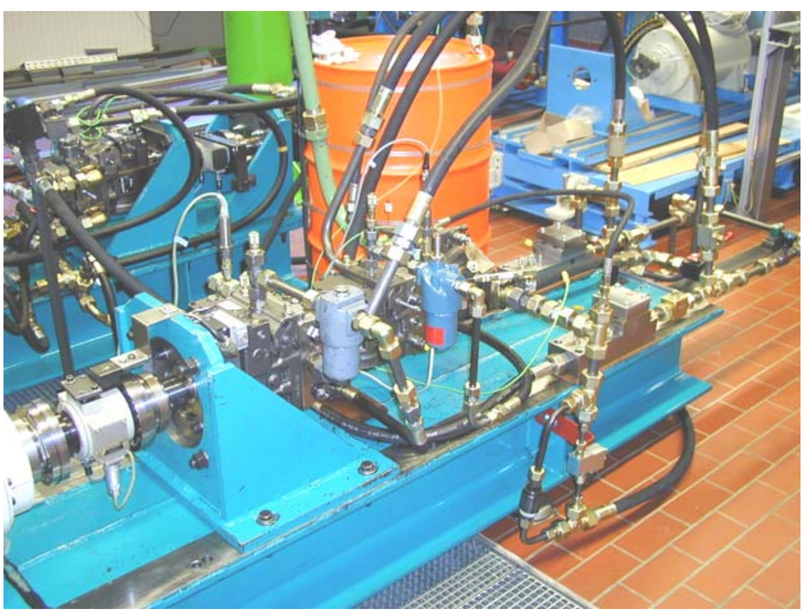
Test Rig Overview

The pump motor test rig allows steady state and dynamic measurements on pump and motors including 1 rpm tests. Using a high speed sensor telemetry in combination with piezoelectric pressure sensors among others the instantaneous cylinder pressure of pumps or motors can be measured.

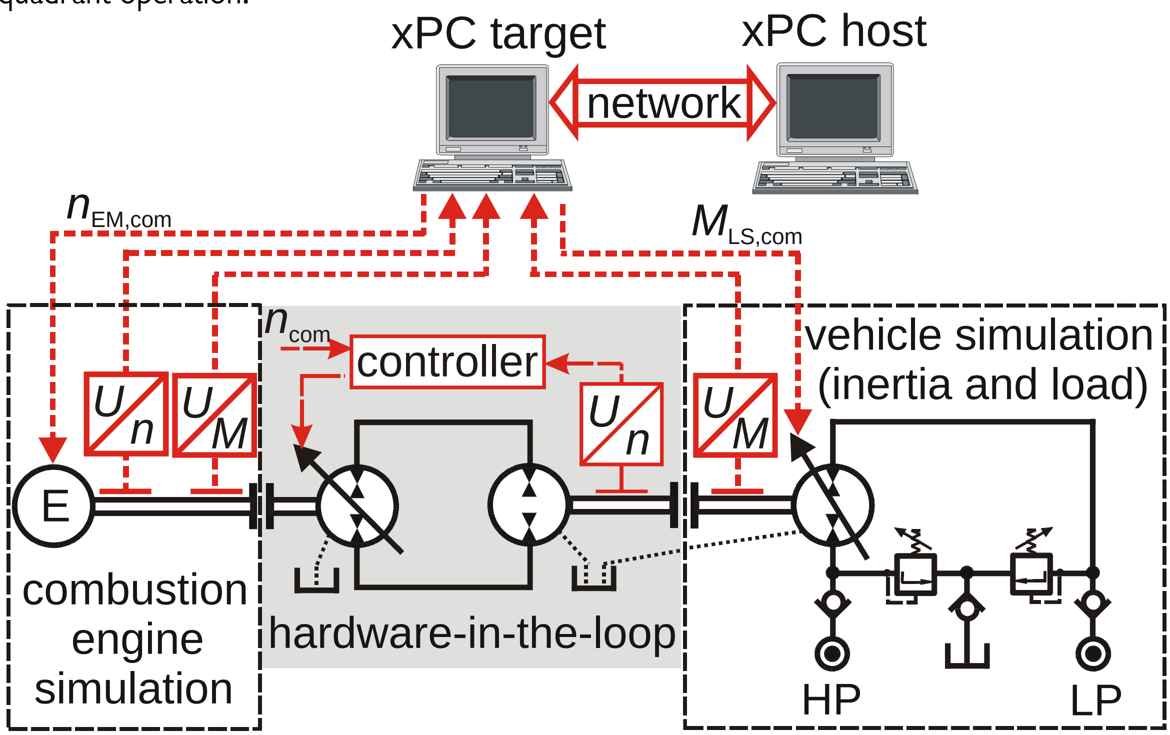
Test rig performance:
Max. installed electric power: 2 x 120 kW
Max. speed:
n_1 = 7000 rpm
n_2 = 3000 rpm
Max. pressure:
450 bar
Max. torque:
M_1 = 300 Nm
M_2 = 500 Nm

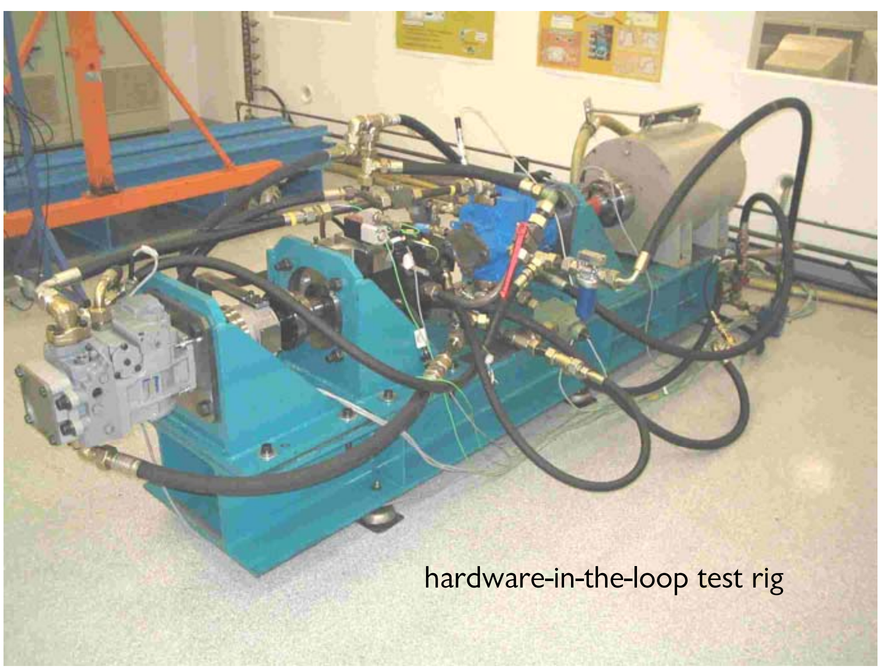

pump motor test rig

The SONO (Structure Borne NOise) test rig allows structure borne noise measurements to investigate and develop methods for the prediction of impending failures on drive lines of off road vehicles. Different methods for failure implementation can be realized.

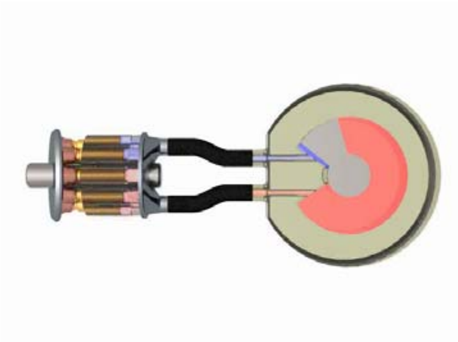


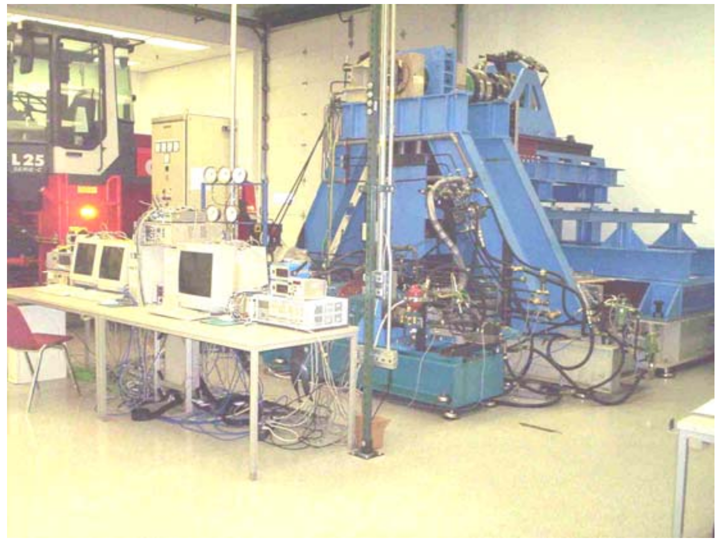
A hardware-in-the-loop test rig serves for testing and developing drive line control concepts for off-road vehicles. The test rig allows the installation of hydrostatic transmissions up to 180 kW. A secondary controlled unit is used for load simulations including the vehicle inertia and allows a four quadrant operation.




hardware-in-the-loop test rig

The joint rotary actuator test rig JIRA has been built for experimental investigations of displacement controlled rotary actuators for use as end effector drives in mobile robots and large manipulators. The developed system and control concepts can also be used for applications, e.g. stabilizers in cars or ships.



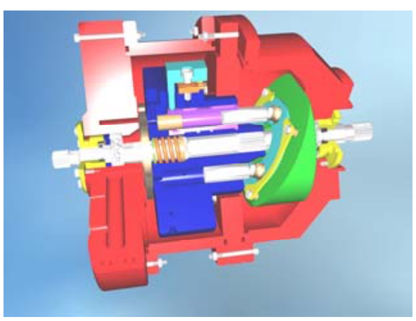


Test rig performance:

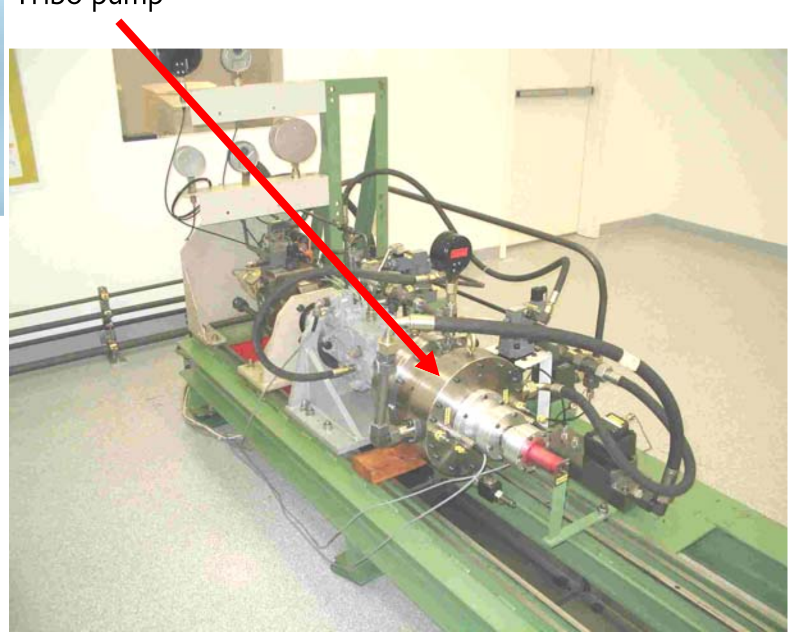
Max. Torque: 30000 Nm
Max. pressure: 350 bar
Max. power: 30 kW

JIRA test rig

The Tribo test rig allows friction force measurements on the piston/cylinder assembly of a special designed test pump. Measurements can be made on the rotating cylinder block using a telemetric and a piezoelectric force sensor installed in the cylinder block.



Tribo pump



Tribo test rig

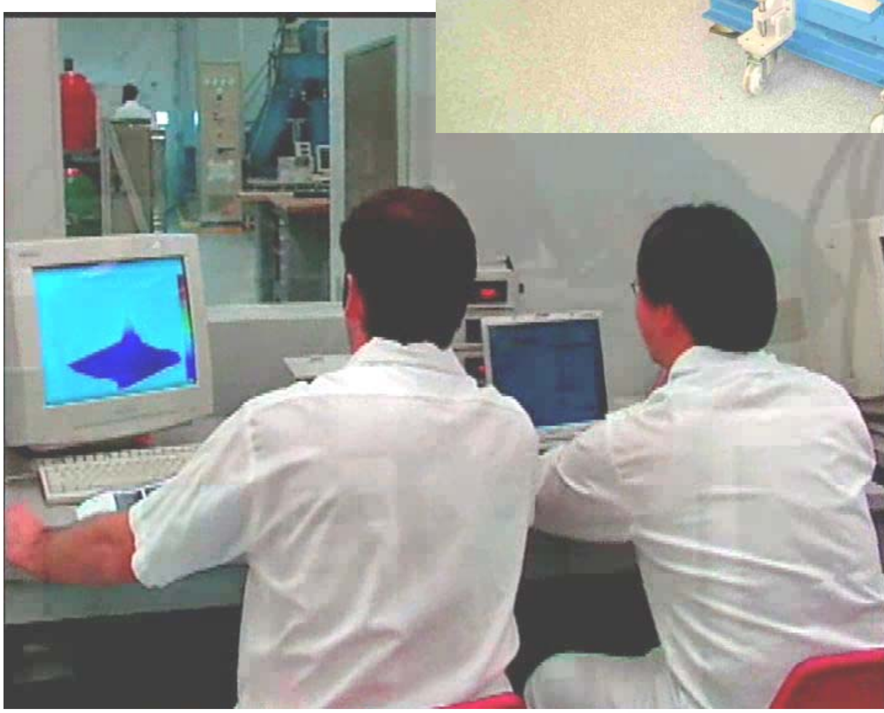
A special test rig allows measurements of the temperature distribution in the gap between the piston and cylinder of a swash plate axial piston pump.

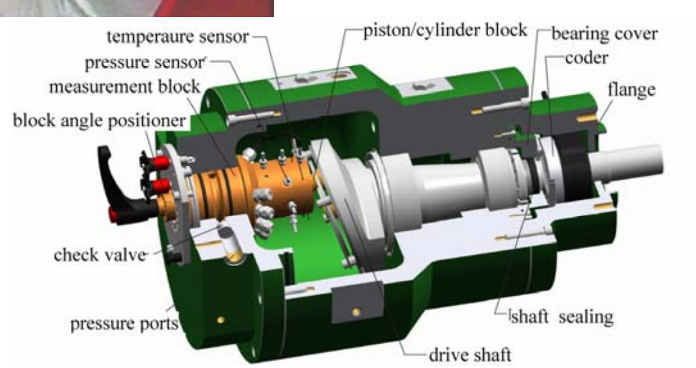

Special temperature distribution test rig

Rich, Blake, Ganesh and Kyle @ transmission test rig

The EHD test rig allows measuring the dynamic pressure field in the gap between piston and cylinder and the surface temperature distribution in the cylinder of a swash plate axial piston pump. A special test pump with a single piston cylinder assembly has been designed for this test rig.

Test rig performance:
Max. power: 60 kW
Pump Speed: 500...3000 rpm
Max. pump pressure: 400 bar
Max. torque: 200 Nm





5 RESEARCH GRANTS IN 2005

Investigation of valveless actuator technology for active roll stabilization of cars, **German National Science Foundation, (2004-2005) 150 000 €**

Model based approach for noise reduction of axial piston machines, **German National Science Foundation, (2004-2006) 160 000 €**

Advanced multi-functional machinery for outdoor applications**, European Union, (2003-2005) 293 000 €**

In 2005 we have applied for the following research grants:

Engineering Research Center for compact and efficient fluid power. **NSF, Five years (2006-2011) Total amount $24,850,000, responsible for** $3,482,929, pending

Integration of Hydraulic Hybrid Drivetrains and Hydraulic Accessories to Optimize Efficiency, Fuel Economy, and Emissions, **EPA, three years, $772,491 – not funded.**

In 2005 we received seven new industrial research awards with a total value of **$ 846,398**.

The total value of public and industrial sponsored research grants in 2005 amounts **$1,134,398**

6 INDUSTRIAL PARTNERS & SPONSORS

Our research and consulting co-operation with industry has been successfully grown in 2005. Finally, we could add some new partners in the list of our industrial partners and sponsors. We like to thank all our partners for their fruitful co-operation and support of our research:

Actia, Toulouse, France
Airbus Deutschland GmbH, Hamburg, Germany
Bosch-Rexroth AG, Elchingen, Germany
Bosch-Rexroth Corporation, Sturtevant, USA
B+V (Blohm+Voss) Industrietechnik, Hamburg, Germany
Case New Holland, Burr Ridge Chicago, USA
Caterpillar Inc., Peoria, USA
Centro Ricerche Fiat, Orbassano, Italy
Claas Industrietechnik GmbH, Paderborn, Germany
Cummins Inc., Columbus, USA
Deltrol Fluid Power, Milwaukee, USA
John Deere Product Engineering Center, Waterloo, USA
K. & H. Eppensteiner GmbH & Co. KG, Ketsch, Germany
Eaton Corporation, Eden Prairie, USA
Gates Corporation, Denver, USA
Hägglunds Drives Inc., Columbus, USA
Hense Systems, Bochum, Germany
Honda R&D Americas Inc., Raymond, USA
HYDAC International GmbH, Sulzbach/Saar, Germany
INNAS, Breda, Netherlands
Jungheinrich AG, Norderstedt, Germany
Linde AG, Aschaffenburg, Germany
Linde Hydraulics Corp, Canfield, USA
Mecalac, Annecy-le-Vieux, France
Moog GmbH, Böblingen, Germany
Moog Inc., East Aurora, USA
Adam Opel AG, Rüsselsheim, Germany
Oilgear Towler GmbH, Hattersheim, Germany
Orenstein & Koppel AG O&K, Berlin, Germany
Parker Hannifin GmbH, Kaarst, Germany
Parker Hannifin Corp., Cleveland, USA
Quality Control Corporation, Chicago, USA
ROSS Controls, Troy, USA
Sauer-Danfoss, Neumünster, Germany

Sun Hydraulics, Sarasota, USA
TRW Automotive, Lafayette, USA
WIKA Instruments Corporation, Lawrencewille, USA
ZF Luftfahrttechnik, Kassel, Germany

7 PUBLICATIONS

Journal Publications

Grabbel, J. and Ivantysynova, M. 2005. Advanced swash plate control for high dynamics of displacement controlled actuators. *International Journal of Fluid Power* Vol. 6 (2005), No.2 August 2005. pp.19- 36.

Anderson,St. H.; Ossyra, J.C. and Ivantysynova, M. 2005. Valveless actuator for active roll stabilization. *International Journal of Fluid Power.* (in review).

Refereed Conference Proceedings

Ossyra, J.C. and Ivantysynova, M. 2004. Application for a Direct Optimization Procedure for Drive Line Control. *Bath Workshop on Power Transmission and Motion Control PTMC 2004, Bath, UK*, pp. 53 – 69.

Ossyra, J.-C. and Ivantysynova, M. 2005. Fuel Savings by Closed Loop Control. *IFPE Technical Conference, Las Vegas, USA. Technical Paper NCFP I05-2.1*

Ivantysynova, M. and Christiansen, S.K. 2005. Automatic Valve Plate Design based on optimized Pressure Profile. *IFPE Technical Conference, Las Vegas, USA. Technical Paper NCFP I05-14.1.*

Ivantysynova, M., Huang, Ch. and Behr, R. 2005. Measurements of elastohydro-dynamic pressure field in the gap between piston and cylinder. *Bath Workshop on Power Transmission and Motion Control PTMC 2005, Bath, UK, pp. 451 – 465* – **Best paper award.**

Eggers, B.; Rahmfeld, R. and Ivantysynova, M. 2005. An energetic comparison be-tween valveless and valve controlled active vibration damping for off-road vehicles. *6th JFPS International Symposium on Fluid Power. Tsukuba, Japan. pp. 275-283.*

Conference Papers

Ivantysynova, M. and Changchun Huang, 2005. Thermal Analysis in Axial Piston Machines using CASPAR. *Proc. of the Sixth International Conference on Fluid Power Transmission and Control, Hangzhou, China. pp. 573-578.*

Oppermann, M. and Ivantysynova, M. 2005. In-Field Tests of a Modular Condi-tion Monitoring System using an Experimental Off-Road Vehicle. *Proc. 9th Scandinavian International Conference on Fluid Power, Linköping, Sweden, 2005, electronic proceedings only.*

Ivantysynova, M., Seeniraj, G., Huang, Ch. 2005. Compariosn of different valve plate designs focusing on oscillating forces and flow pulsation. *Proc. 9th Scandinavian International Conference on Fluid Power, Linköping, Sweden, 2005, electronic proceedings only.*

Invited Lectures

Ivantysynova, M. 2005. Requirements on Fluid Power Systems for Next Generation of Heavy Duty Mobile Machines. *International conference on "Trends in the Development of Heavy Duty Machines", January 17-20, 2005 in Zakopane, Poland.* **Keynote Lecture**

Posters presented

Four posters @ 4th NFPA Educators Summit, October 20-21, 2005. Pittsburgh.

Poster 1: *Prognostics for hydraulic systems in off-road vehicles*
Poster 2: *Valveless actuator for vehicle active roll stabilization*
Poster 3: *CASPAR - EHD – A fundamental research towards computer based innovative pump design*
Poster 4: *Model Based Optimization of Axial Piston Machines Focusing on Noise and Efficiency*

Master Theses completed

Behr, Robert 2005. *Measurement of dynamic pressure field and temperature distribution between piston and cylinder.*

Gang Chen 2005. *Development of a thermal model for the rotating group in a swash plate axial piston machine.*

8 INTERNATIONAL CO-OPERATION

Our successful international co-operations with fluid power research centres world wide could be strengthened by using our membership in the international network "Fluid Power Net International" (FPNI), which is currently joined by members from 26 countries, see http://fluid.power.net

In 2005 the following international students and researchers have worked in our team:

Jonathan Liscouet, Grande Ecole ICAM, France - one year @ Purdue

Germano Franconi, University of Parma, Italy, 9 months @ Purdue

Edat Kaya, Technical University of Hamburg - 5 months @ Purdue

Petr Koňařík, Technical University of Ostrava, Czech republic, 8 months @ Purdue

Jose Antonio Navarro Roig, Universidad Politecnica de Valencia, Spain, 6 months @ Purdue

Robert Behr, Technical University of Hamburg - 6 months @ Purdue

Patrick Stegemann, Technical University of Hamburg - 8 months @ Purdue

9 AWARDS AND HONOURS

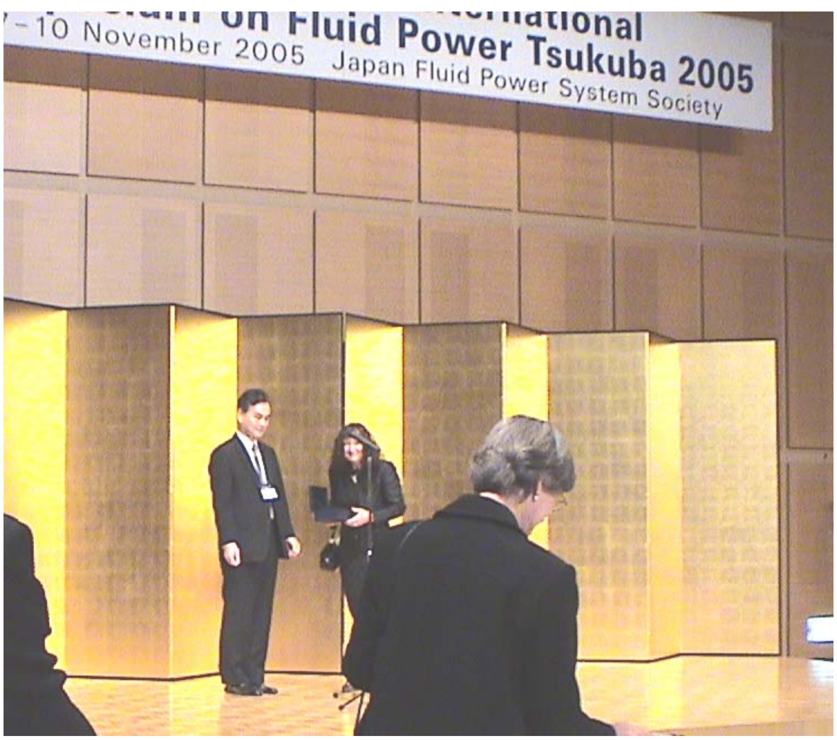
Best Paper Award

Bath Workshop on Power Transmission & Motion Control, PTMC 2005

Ivantysynova, M., Huang, Ch. and Behr, R. 2005. Measurements of elastohydro-dynamic pressure field in the gap between piston and cylinder.
Bath Workshop on Power Transmission and Motion Control PTMC 2005, Bath, UK, pp. 451 – 465

JFPS International Symposium Distinguished Service Award

MAHA Professor Monika Ivantysynova received the JFPS International Symposium Distinguished Service Award in honor of her outstanding contribution to the JFPS International Symposium on Fluid Power on November 10, 2005 from the Japan Fluid Power System Society.



10 OTHER EVENTS

May 11, 2005 the Fluid Power Education Foundation FPEF visited the MAHA lab

ERC site visit rehearsal @ MAHA lab on December 1, 2005

Summer Dinner Party @ Monika's House on September 17, 2005

Jean-Claude's Farewell Party @ MAHA lab on September 20, 2005

11 EDUCATIONAL ACTIVITIES

In 2005 a new dual level fluid power course has been offered. 14 students took this course.

ME 597 /ABE 591 – Design and Modeling of Fluid Power Systems
Fall Semester 2005

Course Desc.: ME 597/ABE 591 Design and Modeling of Fluid Power Systems Sem. 1. Class 3, cr.3. Prerequisite: ABE 435 or ME 309, ME 375 or consent of instructor.

This course provides an introduction into modeling and design of fluid power components and systems. Modeling techniques based on physical laws and measured performance characteristics will be applied to design and analyze component and system performance. Fundamentals: design principles of displacement machines, flow and pressure control, motion control using resistance control, motion control using displacement controlled actuators, variable speed transmissions, modeling of flow in lubricating gaps, transmission line models, secondary controlled systems, load sensing systems.

Textbook: Course Notes

References: J. Ivantysyn and M. Ivantysynova: *Hydrostatic Pumps and Motors Principles, Design, Peformance, Modelling, Analysis, Control and Testing.* Akademia Books International, New Dehli, 2001.
Fitch, E.C. and I.T. Hong: *Hydraulic Component Design and Selection.* BarDyne, Inc. 1998.
H. E. Merritt. *Hydraulic Control Systems.* John Wiley & Sons, Inc.

Coordinator: M. Ivantysynova, MAHA Professor Fluid Power Systems, ME and ABE

Goals: To give seniors and graduates students in engineering the ability to design and analyze fluid power systems applying computational methods. The course is designed to teach students how to apply engineering fundamentals to develop mathematical models of fluid power components and systems, so that advanced systems can be developed.

Prerequisites by Topic:

1. Fluid Mechanics
2. Modeling and analysis of physical systems
3. Differential equations and calculus

Topics:

1. Introduction and overview of components, circuit and system design methods
2. Fluid properties, modeling of transmission lines, impedance model of lines
3. Displacement machines design principles
4. Steady state characteristics, measurement methods and modeling
5. Gap flow models
6. Flow and pressure pulsation
7. Resistance control, modeling of steady state and dynamic performance
8. Pressure and flow control valves
9. Servo- and proportional valves, nonlinear and linear system models
10. Modeling of valve controlled systems, linear and rotary actuators
11. Modeling of displacement controlled actuators, pump control systems
12. Secondary controlled actuator, modeling and application
13. Special system design aspects, load sensing systems

Computer Usage: required in solution of homework problems and final design project. Matlab experience would be helpful but not necessary.

Laboratory Project:

Hardware in the loop test rig of a vehicle drive line

Aim:

To learn to plan, design and operate an experimental test set up for performance testing of a fluid power system. To become familiar with X-PC target software, measurement equipment and data acquisition system used on hardware in-the-loop test rig of a vehicle drive line. The project should also prove the student's ability to perform a measurement, evaluate test data and write a measurement report in an appropriate form.

Method:

Students will have to form teams of three students. One lecture will be used for introduction into the problem and the existing test rig. Students will then have to learn to operate the test rig and to perform measurement. Each team has to write a measurement report.

Formulation of problem:

Students are requested to perform the following work:

1. Study the test rig structure including the X-PC target system and describe it in the report accordingly.
2. Specify a drive cycle of the vehicle you like to test using the hardware- in the loop test environment.
3. Perform the measurement of the drive cycle! Assistance will be given. Each group needs to make arrangements for performing their tests in the lab with Dr. Jean Claude Ossyra.
4. Evaluate the test results and complete a report.

Nature of the Design Content:

The design component of this course will consist of students designing a fluid power system to meet a particular need and required performance. The students will solve several sub problems of an entire system design as part of the regular course homework.

Engineering project to be completed during the course

Aim:

To demonstrate in form of an engineering project the ability to design fluid power systems, to understand the function of components and how to model their steady state and dynamic behavior to predict the system performance. The project should also prove the student's ability to write an engineering report in an appropriate form.

Method:

Students will solve several sub problems of the entire system design work as part of the regular course homework.

Formulation of problem:

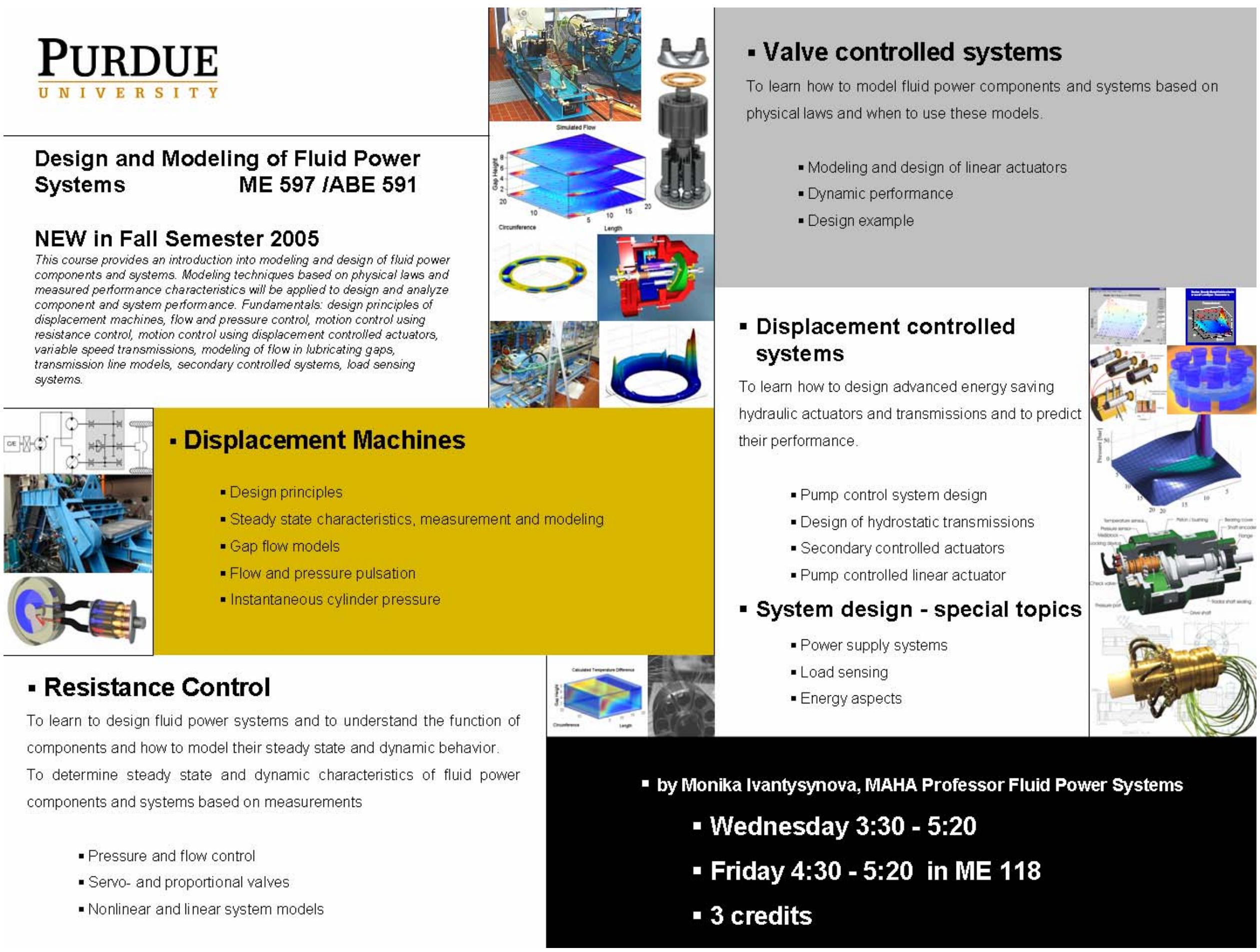
Students are requested to perform the following work:

5. Choose and define your own system design project, i.e. define a hydraulic actuator, drive system or transmission as a part of a machine or vehicle. Describe briefly the machine or vehicle function.
6. Specify the system requirements (work task, operating parameter range, safety issue, energy consumption, type of primary energy source) and conclude the requirements in form of a system specification as first chapter of your project report.
7. Apply individual course topics always to your system
8. During the semester it will be requested that you add a second actuation system to your initial one. This is to ensure that each project has minimum one rotary and one linear drive system.
9. It is also necessary that you investigate and compare minimum one alternative solution for one of your chosen actuator/ drive or transmission solution. The comparison must include energy consumption and a brief statement of other properties. (system complexity, costs etc)
10. Define system structure, draw circuit diagram and a scheme showing the interfaces between your fluid power system and the entire machine/vehicle.
11. Select type and size of components
12. Create models to describe the loss behavior, energy consumption
13. Create models to predict system behavior including dynamics (system parameter as function of time)
14. Define measurement methods and test procedure for a selected component and your whole actuation system
15. Write the system development report

ABET category content as estimated by faculty member who prepared the course description:

Engineering Science: 1.5 credits or 50%
Engineering Design: 1.5 credits or 50 %

Grading: 60% engineering project, 30 % written final exam, 10 % measurement report



12 INTERNATIONAL JOURNAL OF FLUID POWER

The sixth year of successful publication of the *International Journal of Fluid Power* draws to its close. The 17th issue was printed and sent to our readers in November 05. I would like to express my grateful thanks to you all for your continuous support of the *Journal,* especially for reviewing papers and submitting manuscripts. I would like to thank all Associate Editors for their great help and advice. The list of reviewers will be published again in the first issue in 2006.

I am happy to inform you that the Journal's position could be strengthened again in 2005. We have very successfully started a co-operation with the German "Ölhydraulik und Pneumatik O+P", which gives researchers from Germany the possibility to publish their results after publication in the *International Journal of Fluid Power* also in German language in the O+P. Based on this agreement five papers have been submitted to our Journal. Our co-operations at different levels with partners in several other countries, e.g. the Journal of the Japan Fluid Power System Society *"Fluid Power System*", the Italian "*Oleodinamica Pneumatica Lubrificazione*" and "*Go –Fluid"* and the USA "*Fluid Power Journal*" continued very successfully. The ASME Fluid Power Systems and Technology Division has made a second proposal to the American Society of Mechanical Engineers (ASME) for partnering with Fluid Power Net International (IFPN) to referee, print, and disseminate a joint publication called the International Journal of Fluid Power. I would like to thank Richard Burton, Noah Manring and Wayne Book for their initiative. Unfortunately also this second proposal failed the approval by ASME Publications Committee. As Editor-in-Chief I believe that such a joint Journal is the right way to fulfil the Journal's mission in offering a unique platform for high quality information about ongoing research in fluid power technology world-wide. Therefore we will continue this effort in 2006.

We have continued our effort to become indexed by the Scientific Citation index. In February 2005 we have requested a re-evaluation of the Journal. This re-evaluation is not finished yet. I hope that the number of citations has grown enough recently. Our first approach after three years of publication failed because of the low number of citations. Please continue to put references to your and other publications in the *International Journal of Fluid Power.* This will help to overcome this drawback of our Journal.

Currently the Journal is indexed by *Elsevier Compendex Engineering Information*, Cambridge Scientific Abstracts, European Environmental Information Database, CEDEFOP Training Village and Fachinformation Technik.

Let me add some other important facts to inform you about the Journal's progress. In 2005 totally 32 papers were submitted to the *International Journal of Fluid Power,* which means an increase of 6.6%. Currently we have 19 papers in review process. Authors from 29 countries have submitted papers to the *International Journal of Fluid Power* during the last six years. All papers are peer reviewed by at least two experts. Very often three independent reviewers are involved to make sure that the review process is fair and ensures a high level of Journals final publication. The rate of successfully approved papers is 46%.

I am happy to inform you that the Journal will go online with the next issue. Detailed information about online access will be available on the Journal website http://journal.fluid.power.net soon.

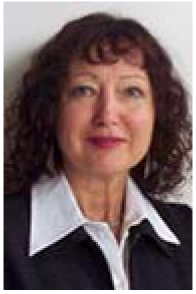
In 2005 we had a 10% increase of subscribers. We hope that the online access will further increase our readership. In 2005 Mrs. Ostrop took over the customer service of the Journal. I would like to thank Mrs. Ostrop for her excellent service and the improvements she made in this important area.

I would like to thank you all for your continuous support of the Journal.

Monika Ivantysynova

Editor-in-Chief

13 MAHA TEAM IN 2005



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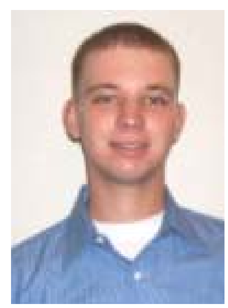

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14 VISITORS & GUESTS

Sally Mason, Provost Purdue University

Linda Katehi, Dean of College of Engineering, Purdue University

Randy Woodson, Dean of College of Agriculture, Purdue University

Frank J. Raab, Jerry A. Wear, Todd M. Frederick, Andrew Krajnik, Caterpillar

John Duncan, Ake Pramstig, Olof Nisson, Hägglunds Drive

Jürgen Weber, CNH

Christoph Kempermann, John L. Kumler, Ng Gorman, Frank A. Cobb, James F. Horack, Linde Hydraulics Corporation

Steve Brooks, Cummins Inc.

Joe Kovach, Lew Casper, Franz Weingarten, Ronnie Werndin, Barun Aacharya, Larey D. Schaffner, Brewce Larkin, Kyle Merill, Verna Hultman, Jonathan Zhu, Nick Kennelly, Andy Holst, Tony Casassa, Art Donaldson, Ed Moore, John Miller Ray Collett, Howard Zhang, Lawrence Schrader, Ken Gorski, Parker Hannifin Corporation

Paul Ukrainetz, University of Saskatchewan, Canada

Tomiji Watabe, Muroran Institute of Technology, Japan

Dan Williams, TRW Commercial Steering Systems

Roy G. Moltar, Kevin Briede, Bobcat

Majid Atimadpanah, Anne Bernadac, Anne Wilhelm, INSA Toulouse, France

Kim Stelson, Perry Li, William K. Durfee, University of Minnesota

Michael Goldfarb, Eric Barth, Vanderbilt University

Andrew Alleyne, University of Illinois

Wayne Book, Georgia Institute of Technology

Thomas Bray, Shajan John, Matey Kaltchev, Vito Gervasi, Milwaukee School of Engineering