Maha Fluid Power RESEARCH CENTER

PURDUE UNIVERSITY

2010 Annual Report

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Preface

After four years of development, 2010 saw CCEFP researchers with a functional prototype for testing displacement controlled actuation. Testbed 1 is a 5 ton compact excavator that has been retrofitted with variable displacement pumps to control the digging arm. Independent testing of the prototype displacement controlled excavator and a standard Bobcat 435 excavator was conducted by Caterpillar, Inc. and the displacement controlled machine was found to consume 40% less fuel than the standard machine while moving the same amount of dirt in a truck loading cycle. This confirms previous year's predictions using computer models. The prototype machine moved 17% more dirt per hour than the standard machine which results in a 70% machine efficiency improvement defined as dirt moved per fuel consumed.

A key highlight for Maha Fluid Power Research Center was hosting the 6th FPNI – PhD Symposium in Fluid Power in collaboration with Fluid Power Net International (FPNI) at Purdue University. This symposium was the largest yet with 222 participants and 96 PhD students from 23 universities and 11 countries presenting their work. FPNI would like to specially thank Najoua Jouini and Erica Wilson for all of their work in planning and organizing all the events during the symposium making it a huge success.

The International Journal of Fluid Power (IJFP) has journeyed into the 11th year of existence during 2010. Of the three annual issues, the November 2010 issue was published as a Special Issue on Digital Hydraulics highlighting the several aspects including latest research and future challenges.

2010 has been a busy year of travel for attending conferences and receiving honors. In addition to organizing and attending the 6th FPNI PhD symposium, I along with three of my PhD students, travelled to Aachen, Germany for the 7th International Fluid Power Conference. Then shortly after the FPNI symposium I attended the Bath ASME Symposium on Fluid Power and Motion Control with 2 different PhD students. It was at this conference that I had the great honor of receiving the Joseph Bramah Medal 2009, as well as the best paper award from the conference for the previous year. To conclude my travels for the year returning to my Alma matter, the Slovak Technical University in Bratislava to receive an Honorary Doctorate.

This was also a special year as 3 of my students, Chris Williamson, Rajneesh Kumar, and Richard Klop successfully completed and defended their PhD thesis. I am very proud to say that each plans to remain in the field of fluid power, continuing their excellent research which they began at Purdue. Shinok Lee also completed his Master's work and returned home to South Korea to fulfill his military duty working in the Korean Institute of Industrial Technology. Although I re-gret to see such fine researchers leave Purdue I wish them all the best in their future endeavors.

Despite the departures, the Maha team continues to grow. In the fall, we welcomed three new PhD students as well as two new Master's students. Marco Zecchi, Rohit Hippalgaonkar and Dat Lee started their PhD work. Marco enjoyed his time as a visiting researcher from Italy during 2009 so much that he was excited to join the team as a PhD student. Rohit joined the lab after undergraduate work at the Indian Institute of Technology and Master's work at Cornell, while Dat is starting a direct PhD program after his studies in Vietnam. The two Master's students are Minming Zhao from China, and Mike Sprengel from Missouri S&T. We also continue to enjoy visiting researchers from around the world who come and contribute to fluid power research. Zhao Hui from Wuhan University in China, Phillip Koppold from Karlsruhe Institute of Technology in Germany, and Toyohito Uchizono from Japan were the researchers we welcomed this year.

I would like to thank all team members for their excellent work in 2010. It is a great pleasure to present the following survey of our activities and main achievements during this past year.

I am confident that we will continue our exciting research. I wish all the members of our team much success during 2011.

Monika Ivantysynova

Maha Professor of Fluid Power Systems

CONTENTS

1 Research Activities

The Center for Compact and Efficient Fluid Power

The year 2010 marked a major milestone for the National Science Foundation (NSF) Funded Engineering Research Center know as the Center for Compact and Efficient Fluid Power (CCEFP), renewal. Renewal by the NSF provides funding and resources for the next five years towards the advancement of research in fluid power science, technology, and education. Purdue is one of seven universities represented in the CCEFP. The other participating universities are the Georgia Institute of Technology, the University of Illinois at Urbana-Champaign, the University of Minnesota, Milwaukee School of Engineering, North Carolina A&T State University and Vanderbilt University. Dr. Monika Ivantysynova of the Maha Fluid Power Research Center at Purdue University sits on the executive committee of the CCEFP and is the leader of Thrust Area 1: Efficiency. Together with the other two thrusts of compactness and effectiveness the CCEFP aims to overcome the current technological barriers facing fluid power.

Currently there are five Purdue faculty members as well as their graduate student teams participating in the CCEFP: Monika Ivantysynova, Andrea Vacca, Steven Frankel, John Lumkes and Ashlie Martini. 2010 also saw the graduation of two Purdue ERC students Chris Williamson and Mark Batdorff. Both Chris and Mark graduated with PhDs after their many successful years within the CCEFP. Chris currently works in the R&D group within Bucyrus International and Mark works at Caterpillar.

2010 Annual Meeting

The CCEFP annual meeting this year was held June 14-15th in conjunction with the 6th FPNI PhD symposium held at Purdue University. Presentations at the meeting included presentations concerning the 4 CCEFP test beds while individual research projects were presented at the symposium through papers and posters. Purdue was well represented in the proceedings as the following list of presentations and posters attests.

Presentations

- 1A.2: Stability and Motion Control of Inertial Loads with Displacement Controlled Hydraulic Actuators, *Christopher Williamson (PhD Student)*
- 1B.1: A Simulation Study on the Impact of Material Properties on Piston/Cylinder Lubricating Gap, *Matteo Pelosi (PhD Student)*
- 1B.2: Experimental Measurements of Static Friction for Line Contacts at High Speed Step Inputs, *Jose Garcia (PhD Student)*

- 1E.2: Design and Dynamic Analysis of High Speed On/Off Poppet Valves for Digital Pumps/Motors, *Gabe Wilfong (MS Student)*
- 1E.3: Operating Strategies and Valve Requirements for Digital Pump/Motors, *Kyle Merrill (PhD Student)*
- 1E.3: Test Stand Development for Investigating Digital Pump/Motor Operating Strategies, *Michael Holland (PhD Student)*
- Test Bed 1: Reduction of Engine and Cooling Power by Displacement Control, *Josh Zimmerman (PhD Student)*
- Test Bed 1: Heavy Mobile Equipment, *Josh Zimmerman (PhD Student)*

Posters

- 1A.2: Optimal Power Management with Displacement Controlled Actuators, *Christopher Williamson (PhD Student)*
- 1B.1: Advanced Surface Design for a New Generation of Pumps and Motors, *Matteo Pelosi (PhD Student), Marco Zecchi (PhD student) and Andrew Schenk (PhD Student)*
- 1B.2: Surface Effects on Start-up Friction and their Application to Compact Gerotor Motor Design, *Jose Garcia (PhD Student)*
- 1E.2: High Speed On/Off Valves to Enable Efficient and Effective Fluid Power Systems, *Gabe Wilfong (MS Student)*
- 1E.3: High Efficiency, High Bandwidth Actively Controlled Variable Displacement Pump/Motor, *Michael Holland (PhD Student) and Kyle Merrill (PhD Student)*
- Test Bed 1: Heavy Mobile Equipment - Excavator, *Josh Zimmerman (PhD Student) and Jess Rose (MS Student)*

Industrial Support

Although academic research is the primary focus of the CCEFP, there is considerable support from industrial sponsors. After the 2007 annual meeting in Atlanta, a cadre of industrial representatives was selected to work directly with CCEFP students and faculty to support their research and promote the future transfer of ideas from academia to commercial production. CCEFP Industrial sponsors of Maha research and their representatives included:

- Bobcat: Thomas Sagaser, Daniel Krieger, Gunter Matt
- Caterpillar: Chris Beaudin, Bryan Nelson, Jim Aardema, Viral Mehta, Jordan Liu
- Eaton:Richard Lyman, Srinivas Patri, Dennis Szulczewski, Jamie LeClair
- Enfield Technologies: Dan Cook, Edwin Howe
- Evonik-Rhomax: William Cleveland
- Gates: Dan Hergert
- HUSCO Intl: Dwight Stephenson, Joe Pfaf
- John Deere: Jeff Dobchuk, Mike Brammer
- Netshape Technologies, Inc: David Moorman, Wiley Abner
- Moog, Aircraft Group: Thomas A. Greetham
- Parker Hannifin: Joe Kovach, Bruce Larkin, Rollin Christiansen, Blake Carl, Rajneesh Kumar

- Poclain Hydraulics: Ludovic Loiseau, Simon Rempfer, Guillaume Charrier
- Sauer Danfoss: Jeff Hansell, Robert Rahmfeld, Jeff Herrin, Mike Betz, Olver Meincke, Mike Gandrud
- Toro: John Heckel
- Trelleborg: Mark Sitko

Education and Outreach

Another mission of the CCEFP is educational outreach through programs that promote the teaching of science and technology concepts related to fluid power. This outreach occurs at both the secondary and graduate levels and encourages participation from underrepresented minorities. The Research Experience for Undergraduates (REU) program places undergraduate engineering students in ERC laboratories for 10 weeks of the summer, where they work with graduate students doing original research. In 2010, the Maha Fluid Power Research Center hosted three REU students:

- Enrique Busquets, University of Texas at El Paso
- Ben Walke, Embry-Riddle Aeronautical University
- Jim Hancock, Purdue University

Enrique Busquets worked with PhD student Josh Zimmerman, using modeled energy and power results to create a thermal excavator model capable of predicting temperatures of the hydraulic oil in an excavator system. He also set up and took temperature measurements during machine operation for model validation. Ben Walke worked with MS student Michael Cross, investigating ways for improving the laboratory's current efficiency models for hydraulic pumps and motors over a range of operating conditions. These loss models are required for high fidelity system level models of hydraulic hybrids and other mobile machines. Last of all, Jim Hancock worked with PhD student Matteo Pelosi investigating the fluid film conditions and energy dissipation in the piston/cylinder lubricating gap. Specifically, Jim ran simulations investigating the impact of pressure and thermal deformation on the lubricating gap performance. Matteo, as part of his mentorship of Jim, was a finalist for the REU Mentor of the Year award. This is a great honor given the more than 100 mentors participating in this program at Purdue, and is indicative of the work being done at the Maha Fluid Power Research Center.

Another form of outreach that began in 2010 and will continue for years to come is in conjunction with the Principles of Engineering classes at Lafayette Jefferson High School. For a day the students of this class had the opportunity to tour the facilities and experience the breadth of engineering impact possible through fluid power. Brian Bettag the Engineering/Technology Education Instructor commented later, “the students saw many aspects of how engineering impacts various applications that I don't think they ever realized before.” This looks to be the first of many tours through Maha for future engineers in the Lafayette community.

The Maha Lab also proud to announce its first high school student, Francis Grover, has completed the Science Research Course in affiliation with Jefferson High School. Francis's contribution at Maha was in the project, Investigation of Pump and Transmission Noise Sources. Francis performed several sound power measurements of a test pump and studied the relationship between audible noise and predicted noise sources. Francis presented his work at the Lafayette Regional Science & Engineering Fair at Purdue and was awarded the ASM Materials Education Foundation Special Award, Silver Medal in Energy and Transportation, College of Science Dean's 2nd place Award, and the US Air Force Special Award.

Research Areas at Maha

Our research activities are focused in five main areas:

1) Advanced energy saving hydraulic actuators, new system architecture and controls
2) Fluid Structure Interaction in critical piston pump/motor interfaces
3) New computational design methods for piston pumps and motors
4) Investigation of pump and transmission noise sources
5) Advanced hydraulic hybrid power trains and control

Research related to the first three listed areas is supported by the NSF through participation in the CCEFP and by several industrial partners. The other topics are funded by separate industry sponsors.

Advanced energy saving hydraulic actuators

The aim of this research is to develop new valve-less hydraulic actuator concepts including necessary motion control strategies for different applications that avoid energy dissipation by resistance control. The focus of this work has been on a concept known as "displacement control" (DC) in which the motion of a linear cylinder is controlled directly by controlling the oil volume displaced by a variable displacement axial piston pump. In years past, the first displacement control concepts were tested using the joint integrated rotary actuator (JIRA) test rig. These concepts have since been demonstrated by our research group on wheel loaders, a skid-steer loader, and excavator systems. In the year 2010 numerous milestones were reached with respect to DC systems. A project studying active vibration damping in DC skid steer loaders was completed and showed a reduction of up to 33% in cab vibration when driving over rough terrain. Also fuel consumption and the productivity measurements of the CCEFP prototype DC excavator were conducted in cooperation with Caterpillar Inc. Through this study measurements were taken on both a standard system and the prototype system performing a truck loading cycle. In conclusion it was found that the DC machine used about 40% less fuel and about 13% less time than the standard system while performing the same task. These are landmark results showing that the DC system performs nearly 70% more work per fuel consumed. 2011 is set to be another great

Displacement controlled excavator uses 40% less fuel!

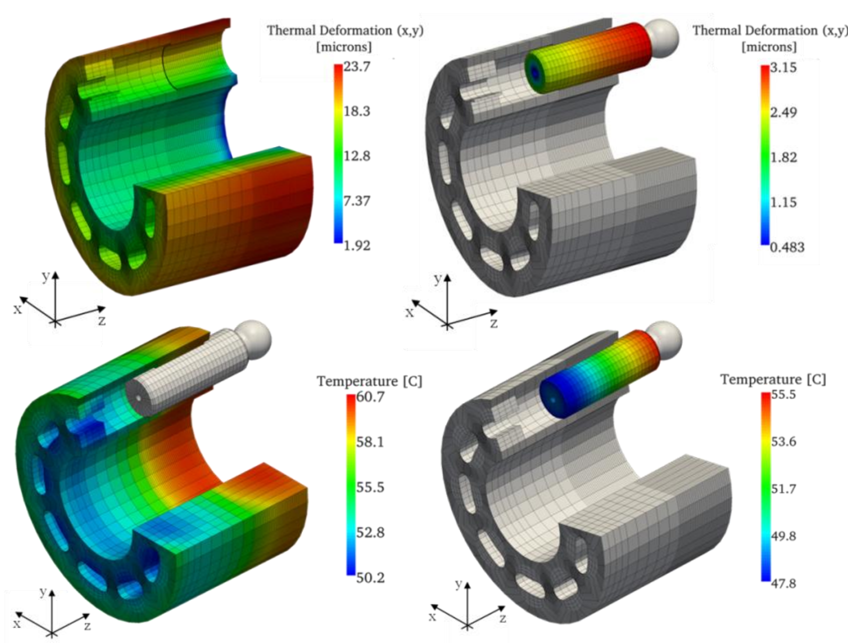
year in this research as the focus moves from basic displacement control circuits to hybrid systems where the improvements are expected to be even greater.

Fluid Structure Interaction in Pump Gaps and Computer based pump & motor design

This research focuses on the performance optimization and noise reduction of pumps and motors. These research efforts have involved the design of special experimental test rigs 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 (Calculation of Swash Plate Type Axial Piston Pump/Motor). CASPAR represents the first program worldwide that predicts flow ripple, instantaneous cylinder pressure, oscillating swash plate forces, gap heights, friction forces and volumetric losses of swash plate type piston pumps and motors.

Currently, CASPAR is undergoing some significant updates. The aim of the project is to develop a detailed, fully coupled fluid-structure-multi-body model for benchmarking the complex physics of the primary lubricating gap interfaces in axial piston machines. The interaction between the fluid and structure in these types of gaps is very important. Unlike other interfaces, which primarily only fulfill either a bearing or sealing function, these interfaces must simultaneously fulfill both a sealing and bearing function under highly dynamic load conditions. The current kernel of CASPAR includes a fluid-structure interaction model and non-isothermal gap flow model for the piston/cylinder and cylinder block/valve plate lubricating gaps.

Another objective of the current work with CASPAR is to implement the Thermal-Elasto-Hydrodynamic (TEHD) lubrication theory which couples the Reynolds Equation, universally used to model film thickness behavior, with the heat transfer to the solid parts (T), and the surface elastic deformation of the solid parts (EHD) due to pressure and thermal induced strains. This TEHD model will be implemented in the piston and valve plate interfaces, but not the slipper/swashplate interface. Being able to predict the heat transferred from the lubricating gaps to the solid parts will allow an accurate determination of the boundary temperatures, for a better prediction of the fluid viscosity. The fluid viscosity in fact is strongly influenced by the temperature distribution and is very important for the gap behavior. Also, the surface elastic deformation of the solids parts is determined both by the dynamic pressure fields gener-



ated inside the gap and the thermal loading condition which leads to thermal expansion. These effects strongly influence the film thickness and therefore the oil load carrying capabilities. The thermal deformation is especially important in the piston-cylinder interface to predict and avoid a piston stick condition. The piston model is beginning to be used in comparison with special test-rigs (the EHD and OLEMS test-rig) measurement results that will allow for confirmation of the numerical results. See the above plots for an example of initial results from both the cylinder block and piston.

Using the current kernel of CASPAR, research activities concentrate on developing methods for surface optimization that increase power density and decrease losses in the lubricating gaps. Two patents have been filed for novel micro-structured surfaces applied to the cylinder block and piston respectively. Additionally, new research is underway that uses advanced optimization techniques with the CASPAR slipper model to optimize slipper geometry design.

Investigation of pump and transmission noise sources

This research focuses on one of the main problems of every hydraulic system – high noise levels. The airborne noise emitted from the hydraulic system can be attributed to two main sources, namely, Fluid Borne Noise Sources (FBNS) and Structure Borne Noise Sources (SBNS). The hydraulic displacement units (pumps and motors) are usually the main source of noise generation in a hydraulic system. And, the demand for the displacement units to be quieter is increasing as the units are widely being employed in systems with varying operating conditions. In this research, the problem of noise in the hydraulic systems is being approached from two directions.

The first approach aims to reduce noise generation at the source (FBNS and SBNS) level i.e. directly at the pumps and motors. A multi-parameter multi-objective optimization procedure has been developed to reduce sources of noises from pumps and motors which operate in a wide range of operating conditions. The optimization procedure has been implemented as a software (*VpOptim*) which assists a pump designer in a search towards an optimal rotating group design which will have the minimum possible noise sources in a wide range of operating conditions.

The second approach aims to reduce the noise generation at the system level. The system chosen here is a hydrostatic transmission which employs pumps and motors usually running at varying displacements, speeds and pressure levels. A simulation tool (*TransModel*) has been developed which includes a time-domain model of the transmission coupling the pump and the motor using a line. *TransModel* has the capabilities to investigate different factors such as rotating group design and hose dimensions which have an effect on the overall noise of the system.

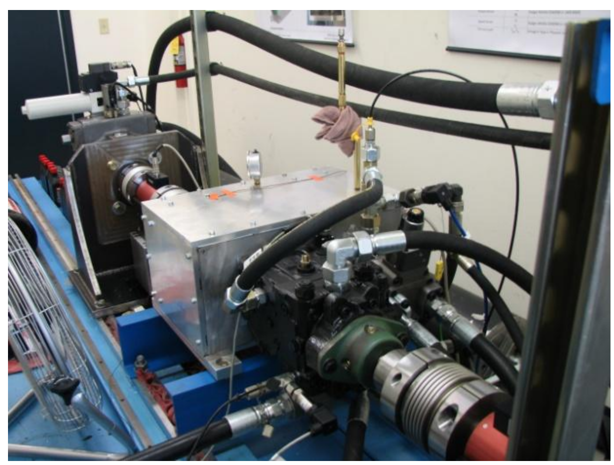
A semi-anechoic hydraulic transmission test facility is available in Maha Fluid Power Research Center to measure the sound power radiated from the sources. The facility has two electrical units which are used as electric motor/generator combination. These two electrical units are coupled with hydraulic displacement units to recreate the entire hydrostatic transmission. The facility also enables to investigate noise levels of different design of displacement units and transmissions. A major milestone of 2010 was a detailed case study of noise source generation of a series hybrid transmission. This case study looked at various system configurations and used the simulation model to predict the system configuration with minimal noise sources. Measurements were found to validate the results of the model.

Advanced energy saving hybrid power trains

Research in this area focuses on investigating the feasibility and performance of alternative drive line technologies for different types of 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 (Power Split Drive Design) has been developed to support virtual prototyping of power split drives, multi-motor hydrostatic transmissions and hydraulic hybrid power train configurations. The research activities are supported by performance measurements using pump and motor test rigs and a hardware-in-the-loop power train test rigs based on hydrostatic dynameters. Some past studies include:

- Working on power split hydraulic transmission for heavy on/off road hydraulic vehicles
- Virtual prototyping of power split drives and hydraulic hybrid power trains
- Advanced system and control strategies for multi-motor hydrostatic transmissions
- Development of generic methods for prognostics of mechatronic systems of off-road vehicles
- Power management for hydraulic hybrid power trains using optimal control techniques

Over the past year there have been significant strides made in the hydraulic hybrid transmission group. Two powertrain test rigs were designed, built, and tested. The first was a series hybrid test stand for a class 1 delivery vehicle. The second test stand was a hydraulic hybrid Prius. In this test stand, the same planetary gear box from a Prius was used (Fig. right). Hardware-in-the-loop tests were conducted on both test rigs to validate mathematical models and test new advanced control concepts.



Also this year saw the graduation of, Rajneesh Kumar. Rajneesh worked on the optimal control of hydraulic hybrids. His thesis *A Power Management Strategy for Hybrid Output Coupled Power-Split Transmission to Minimize Fuel Consumption* showed significant improvements in fuel efficiency through the use of stochastic dynamic programming.

Maha Research Projects in 2010

In 2010 work has been done on the following research projects:

- Active vibration damping for off-road vehicles using displacement controlled linear actuators
- Development of a general thermal model in displacement controlled systems

- Optimal power management strategies using displacement controlled actuators
- Development of a elasto-hydrodynamic (EHD) model of the slipper/swash plate for advanced gap flow simulation
- Investigation of the effect of piston surface shaping on losses in the lubricating gaps of axial piston pumps and motors using CASPAR
- Investigation of micro-waved surface designs for piston pump interfaces
- Development of a coupled line-pump-motor model to investigate transmission noise sources
- Virtual prototyping of power split drives and hydraulic hybrids
- Vehicle drive-line control towards optimized primary power consumption

The described research activities are accompanied by extensive experimental work. During the last ten years a comprehensive fluid power research laboratory has been built and equipped with pump and motor test rigs, actuator test rigs, drive-line control and transmission test rigs including test machines as well as several specialized test rigs for investigation of tribological systems of displacement machines.

2 Research Results & Software Tools

Research Reports in 2010

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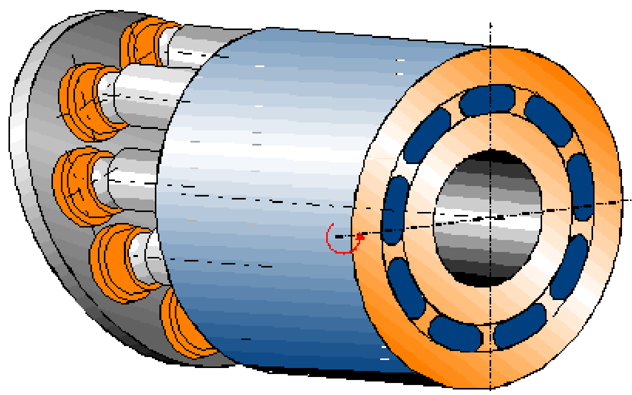
Software Tools

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

CASPAR

The simulation model, *CASPAR* (Calculation of Swash Plate Type Axial Piston Pump/Motor), is a model for predicting the performance and losses of swash plate type axial piston pumps and motors considering specific machine geometry and operating conditions. The program 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 deformation for the connected gaps of a swash plate axial piston machines. The program calculates the flow ripple at both ports, 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 model has been developed to meet the need of the next generation of pump and motor researchers and designers and represents a powerful design tool for this kind of displacement machine.



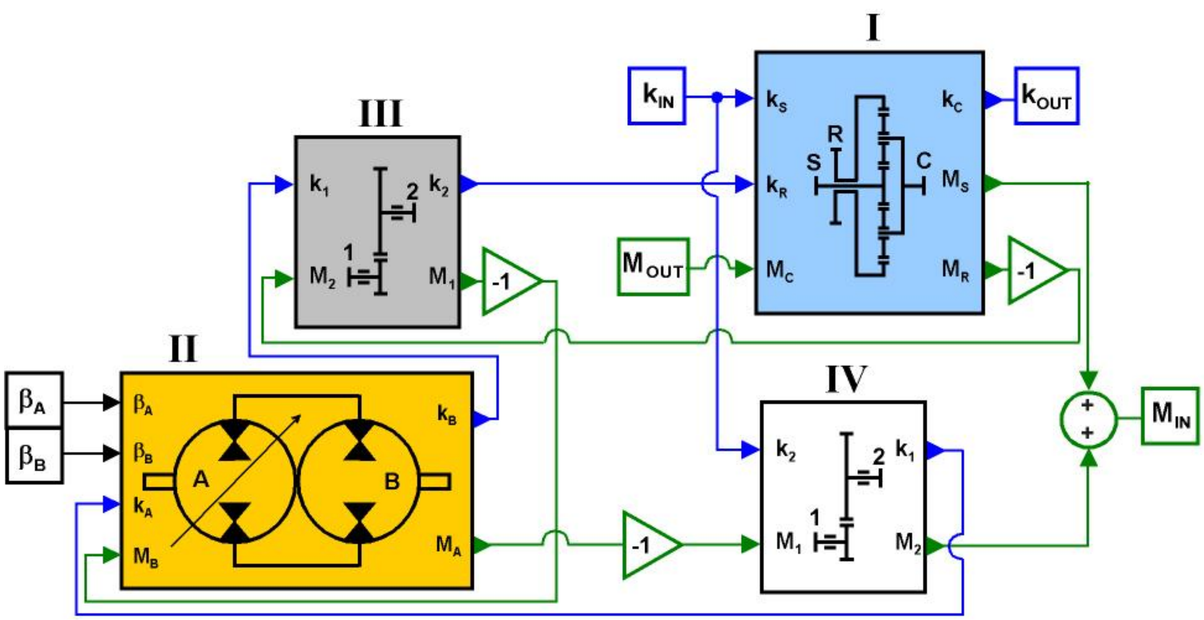
CASPAR describes the flow of a compressible and viscous fluid from the ports through the valve plate to the displacement chamber. It further considers non-isothermal gap flow through each of the three lubricating gaps that seal the displacement chamber. The change of pressure in the displacement chamber 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 which are considered by the model. For the gap flow calculation, *CASPAR* considers a balance between external and fluid forces, i.e. full film lubrication. No mixed friction model is present. Additionally, the model neglects any surface roughness of the solid parts, assuming ideally smooth sliding surfaces. 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.

CASPAR also considers the influence that surface deformation of parts forming the gaps has on machine performance and behavior. 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 the 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 the displacement chamber to the ports.

The model is continuously under development with the aim of achieving a fully coupled, multi-domain model that accurately predicts the gap height. Since 2005, the ability to predict the performance of a spherical port plate and a more comprehensive fluid property model has been added. Further updates of the software have included a more accurate description of a pump with a variable piston gap length. This past year, a Thermal-Elasto-Hydrodynamic model has been implemented for the piston cylinder interface and is currently under development in the valve plate interface. The updated program promises to be more efficient and will incorporate the EHD and non-isothermal gap flow models for the three considered lubricating gaps. Additionally, by using external meshing software, the models are now able to capture complex geometries easily for use with EHD calculations. *CASPAR* is a stand-alone tool developed using the C++ programming language.

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 behavior 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 for 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, planetary gear sets, engines and accumulator models. These libraries can be extended and completed by the user easily. An open database of the most common structures of power split drives is implemented

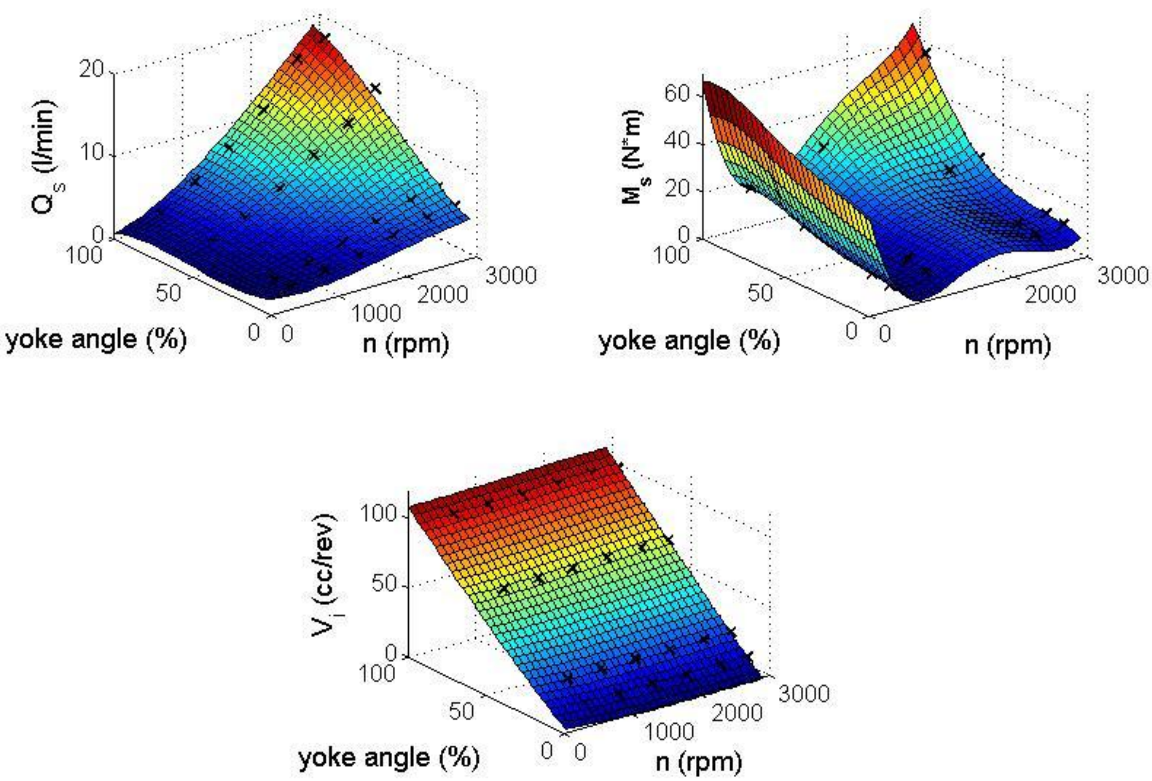


in the CAE tool. The *PSDD* software tool is built in a modular way on the Matlab and Simulink platforms. To increase the fidelity of simulation models highly accurate empirically based loss models should be used.

I: Planetary Gear Simulink model
II: Hydrostatic Transmission Simulink model
III: Gear Simulink model
IV: Gear Simulink model

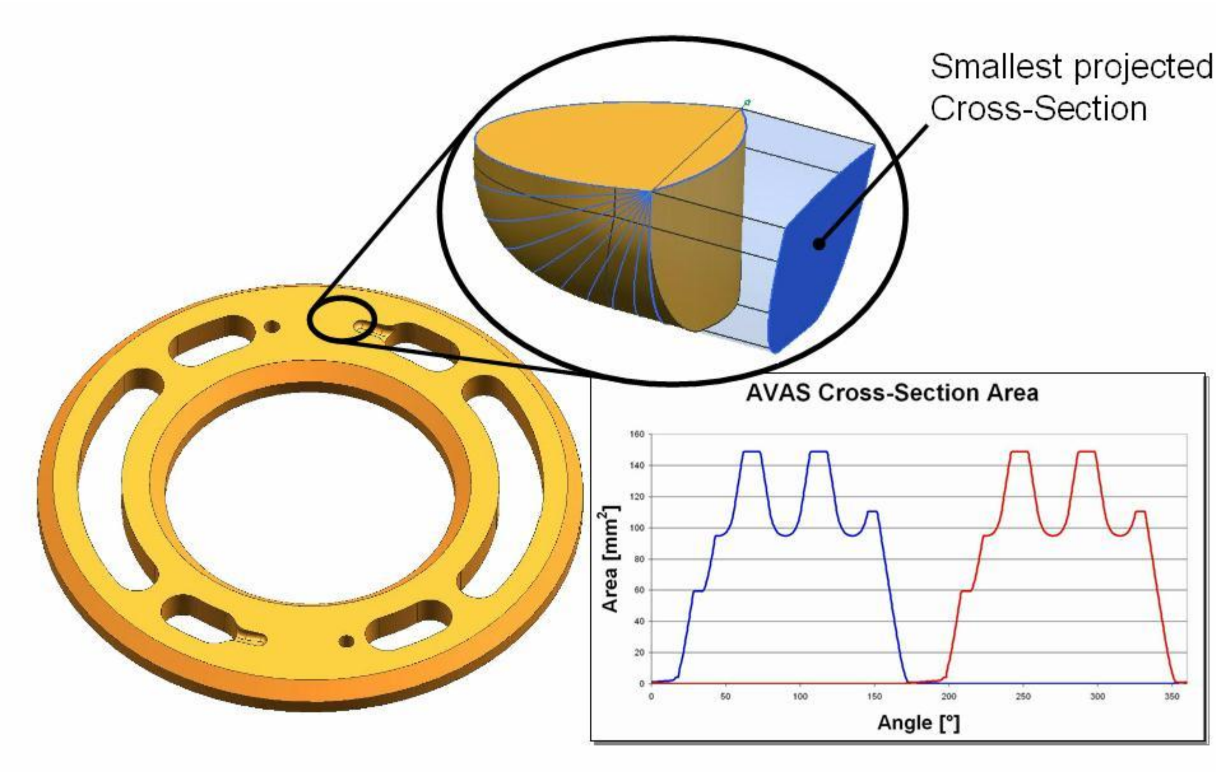
Polyfitn, N-d Polynomial Linear Regression Model

Polyfitn is a Matlab based polynomial regression tool designed to handle any order of polynomial. At the Maha Fluid Power Research Center, polynomial regression is used to map discrete steady state pump measurements to a continuous polynomial map. These polynomials model the torque and volumetric losses, as well as the derived displacements for any pump displacement, differential pressure, and rotational speed. Combined, these three polynomials make up the pump/motor loss model. Because these models are continuous they can be used in a simulation environment like PSDD. The figure below is a snapshot of one of these loss models at a fixed differential pressure. Using empirical loss models like these, significantly improves the fidelity the mathematical models created in the Matlab/Simulink environment.



AVAS

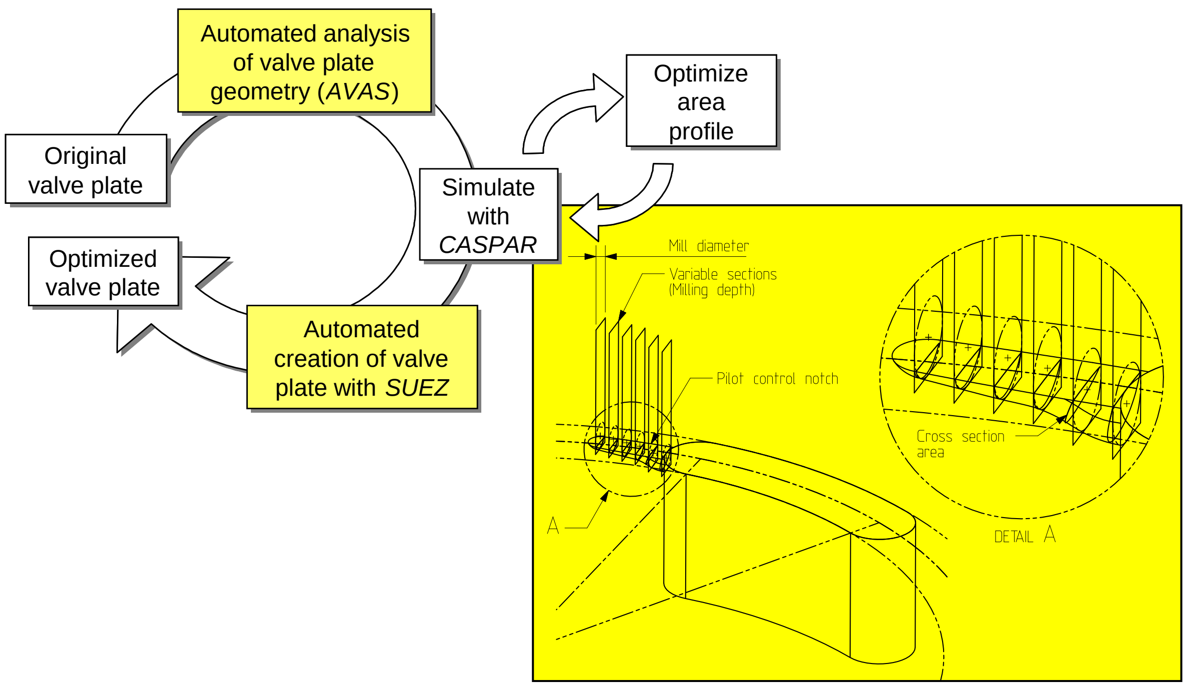
The change of pressure in the displacement chamber of a displacement machine is greatly influenced by the small cross-section of the fluid flow which is formed by the valve plate and the rotating cylinder block. For simulation calculations, it is important to know the exact size of the flow passage opening 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.

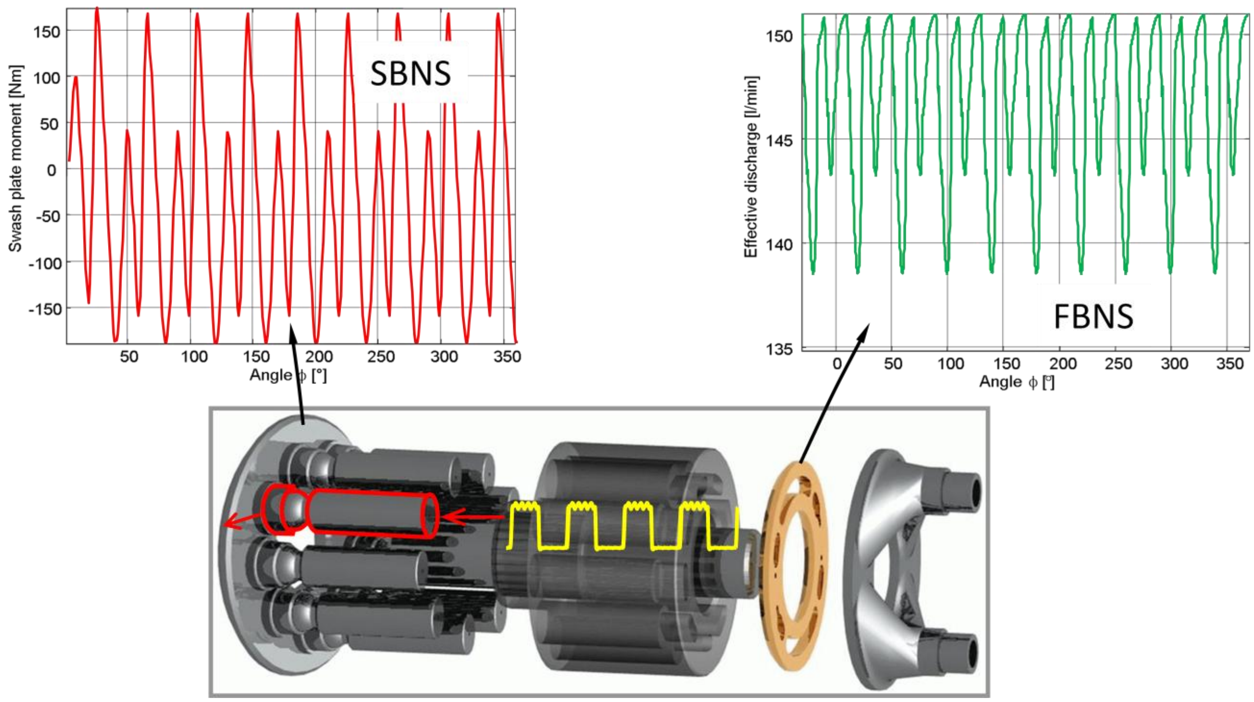
SUEZ

SUEZ automatically creates a 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 for an optimization of swash plate axial piston machines in a very cost effective way. This method can also be used for other displacement machines.

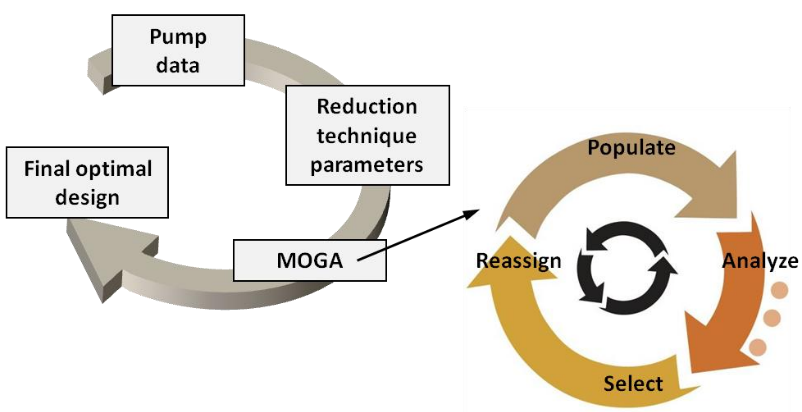


VpOptim

VpOptim stands for Valve plate Optimization. *VpOptim* is a software implementation of a multi-parameter multi-objective design optimization procedure. VpOptim assists a pump designer in a search towards an optimal rotating group design which will have the minimum possible noise sources in a wide range of operating conditions. VpOptim allows using two different reduction techniques to be optimized namely relief grooves and precompression filter volume with relief grooves. These two reduction techniques have several parameters which affect the area available for flow transfer between the displacement chamber and the pump ports. The parameters of the reduction techniques are subjected to a Multi Objective Genetic Algorithm (MOGA) to select an optimum area profile which will have the minimum possible FBNS and SBNS over a wide range of operating conditions.



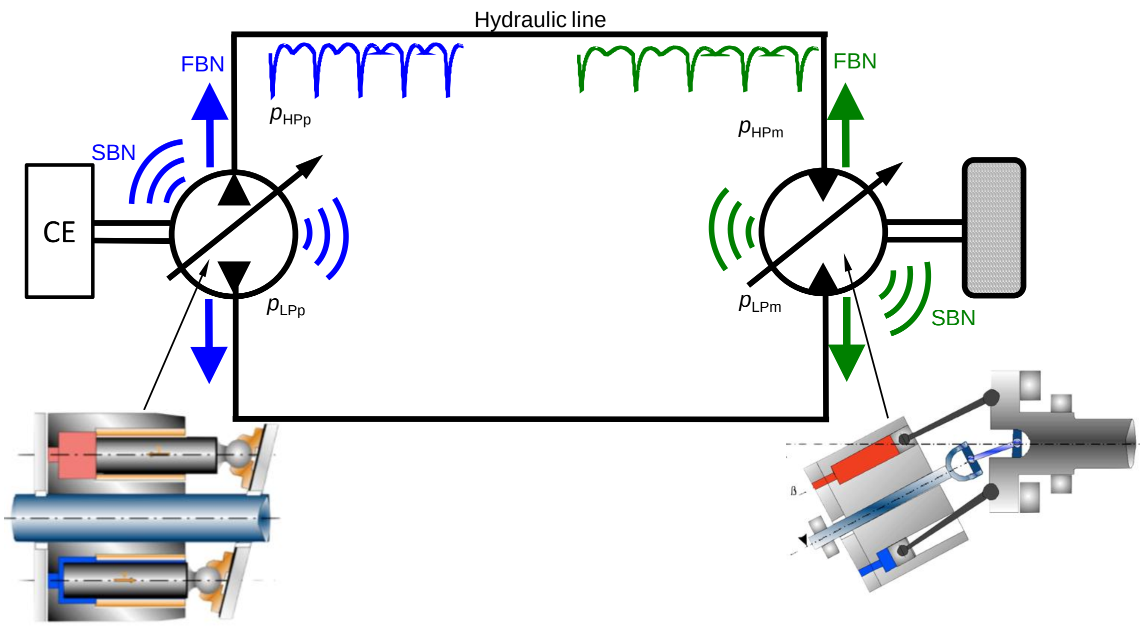
Axial piston pump showing the fluid borne and structure borne noise sources



Schematic of the process flow inside VpOptim

TransModel

TransModel is a GUI based software program to simulate a complete hydrostatic transmission containing pump and motor connected using a line in time-domain. The line model chosen involves a solution of continuity and momentum equations based on method of characteristics. This approach is selected because superimposed pressure and flow pulsations can be predicted and both noise sources are quantified. In particular, a time domain line model is necessary to couple time domain dynamic pump and motor models. TransModel is able to estimate both fluid and structure borne noise sources. Fluid borne noise source (FBNS) is quantified by calculating instantaneous pressure and flow ripples throughout the HP line between the pump and motor. Structure borne noise source (SBNS) is characterized by calculating instantaneous swash plate moments in all directions, for both units.

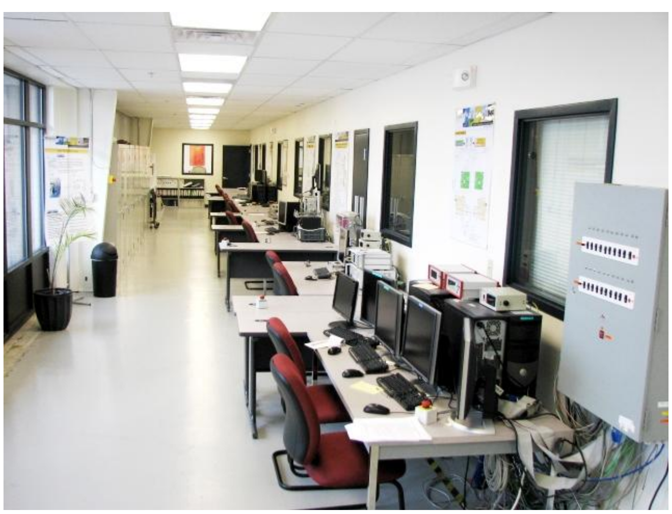


Schematic of hydrostatic transmission implemented in TransModel

3 Research Center Overview

Lab Space and Test Rigs at Maha
The lab currently houses ten test rigs designed to support our research.

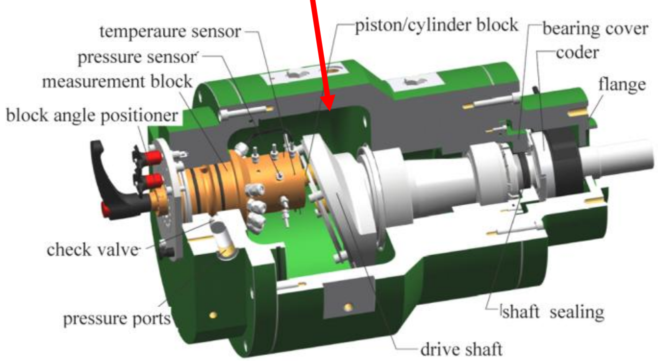
Test Beds for Technological Demonstration (Above)



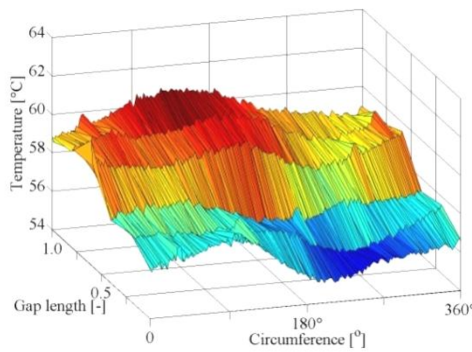
Test Rigs and Control Room (Above and Left)

EHD test rig

The EHD test rig is designed to measure 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.



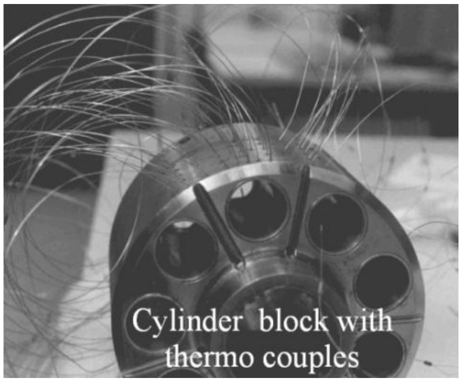
EHD Pump

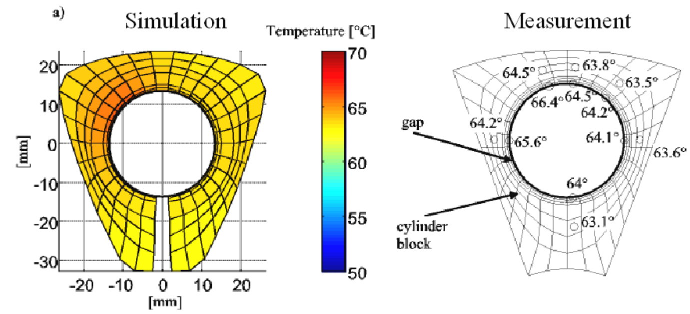


Measured Temperature Field in the Piston/Cylinder Gap

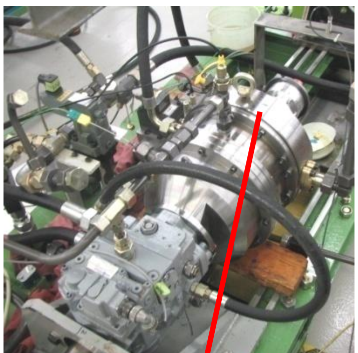
OLEMS test rig

This rig is designed to investigate the temperature behavior in swash plate axial piston pumps. Sixty thermocouples are mounted around a single cylinder to measure the temperature field during operation of the pump. Telemetry is used for data transfer from the rotating cylinder block to the data acquisition board. The measured results are used for the development of a more precise method to calculate the non-isothermal gap flow between piston and cylinder in swash plate type axial piston machines.





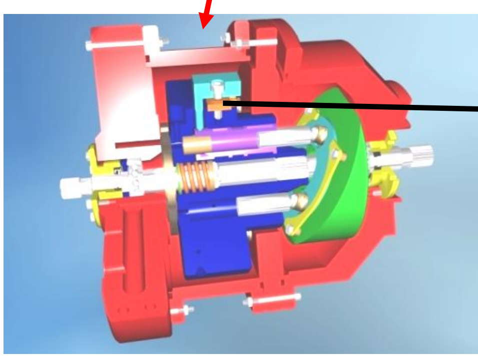
Temperature distribution in the assembly near the slipper side

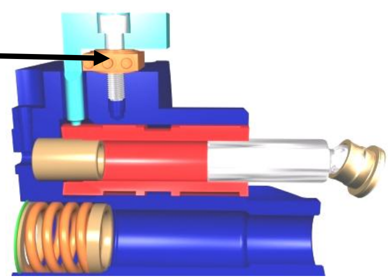


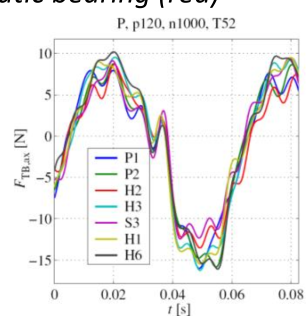
Tribo test rig

The heart of the test rig, the Tribo pump, is designed to measure the dynamic axial and the circumferential friction force between the piston and cylinder. The data can be processed during high speed using a telemetry system. The Tribo pump can be operated in either pumping or motoring mode from 1 rpm up to 1800 rpm. The measurements can be taken during steady state conditions at different oil viscosities.

Tribo pump - Hydrostatic bearing (red)







Cavitation/PIV test rig

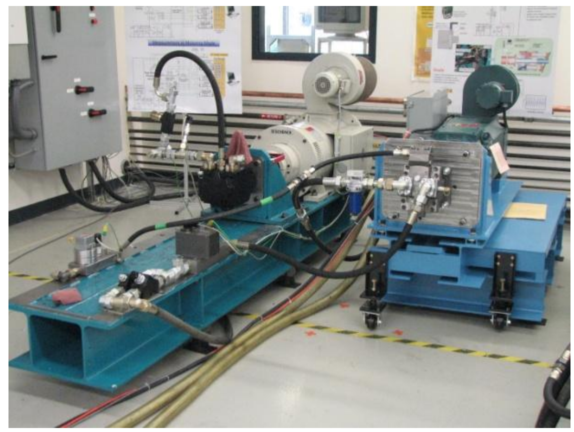
This test rig was designed to visualize and conduct Particle Image Velocimetry (PIV) analysis of cavitation in hydraulic oil. This test rig was designed in support of CCEFP project 3C and will support the computational studies in modeling cavitation in hydraulic components.

Transmission test rig

The test rig is designed to determine the efficiency of a hydrostatic car transmission at different loads and gear ratios. The transmission is driven by a diesel engine and a secondary controlled unit simulates the driving resistance of the vehicle.

Test rigs for steady state measurements

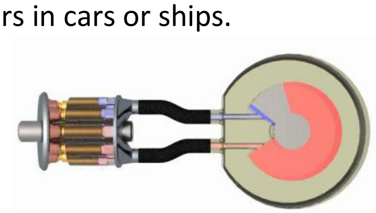
Two electric motor driven test rigs have been designed to measure steady state and dynamic characteristics for different pump and motor types including 1 rpm tests. The test rigs are equipped with temperature and pressure sensors as well as speed, flow and torque meters.



Performance Characteristics
Max. installed electric power: 2 x 120 kW
Max. speed: n1 = 7000 rpm/n2 = 3000 rpm
Max. pressure: 450 bar
Max. torque: M1 = 300 Nm/ M2 = 500 Nm

JIRA test rig

The joint integrated 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 such as stabilizers in cars or ships.

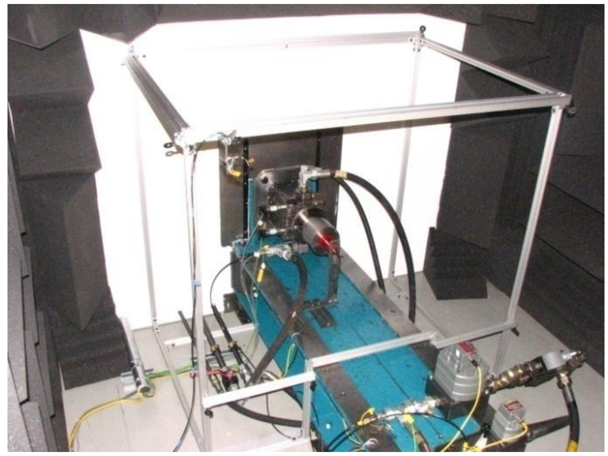


Rotary Actuator

Performance
Max. Torque: 30000 Nm
Max. Pressure: 350 bar
Max. Power: 30 kW

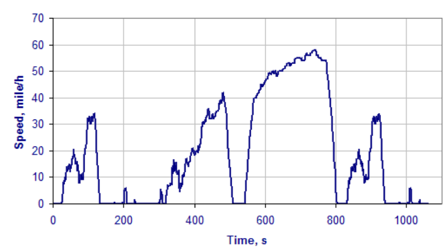
Semi-Anechoic Chamber

This test rig is designed for noise measurements on pumps, motors and hydrostatic transmissions. The noise measurements are used to support the research in noise reduction conducted at the Maha lab. This test rig has recently been used to quantify the sound power level emitted from the individual units of a hydrostatic transmission using three microphones and a positioning grid.



Power Train test rig

This test rig has been designed for the purpose of testing power trains and power train control concepts developed here at the Maha lab. A hydraulic motor supplies input shaft power to the power train being tested, while a hydraulic pump creates a simulated load at the output shaft of the power train. Pictured is a series hydraulic hybrid transmission intended for use in a Toyota Prius. The test rig can be used to accurately simulate given drive cycles such as the UDDS drive cycle shown below.



Power Supply

The above test rigs are powered by a 320 kW central hydraulic power supply unit with a 2000 liter tank, a water cooler and heating elements with five individually controlled pressure compensated pumps, 350 bar and 450 lpm output flow and a 60 l/min low pressure installed in 2005. A second medium pressure 63 kW hydraulic power supply, with a maximum flow rate of 250 l/min and pressure differential of 60 bar, has also been added. This supply is equipped with a 300 liter tank. 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 to 1200 kW.

Test Beds

In addition to the stationary test rigs, the Maha Fluid Power Research Center also houses several vehicles that either have been used or are being used currently as platforms for demonstrating and/or investigating new fluid power systems concepts.

Front Wheel Loaders

Displacement control, the concept of controlling hydraulic actuators with variable displacement pumps instead of throttling valves, was first tested and demonstrated using this front wheel loader. Due to the elimination of throttling valves, displacement control technology is also sometimes referred to as “valve less” technology.

This smaller front wheel loader serves as a platform for diagnostics and prognostics on hydraulic systems.

Bobcat Skid-Steer Loader

Pump-controlled technology has also been demonstrated on compact machinery. A Bobcat skid-steer loader has been modified so that the boom and bucket functions are controlled by variable displacement hydraulic pumps. Shinok Lee used this machine to demonstrate the implementation of active vibration damping using the displacement controlled hydraulic system as part of his thesis work.

Bobcat Mini Excavator

The excavator is being used for the purpose of testing displacement controlled technology and engine power management concepts to improve fuel economy developed here at the Maha lab. The excavator serves as the CCEFP test bed #1. This excavator has been compared side by side with the production valve controlled version and has demonstrated fuel to work efficiency gains of nearly 70%. This excavator is also the basis for thermodynamic modeling performed this past summer by Enrique Busquets, one of our SURF students. This research was performed to estimate the achievable reduction in cooling capacity due to implementation of the displacement controlled technology. Research is also being performed to investigate the power management potential of the system including possible engine downsizing.

4 Industrial Partners & Sponsors

We are proud of and grateful for our newest additions to our list of partners/sponsors. We would like to thank all our partners for their fruitful co-operation and support of our research

Actia, Toulouse, France
Airbus Deutschland GmbH, Hamburg, Germany
AM General, South Bend, USA
Bobcat, West Fargo, USA
Bosch-Rexroth AG, Elchingen, Germany
Bosch-Rexroth Corporation, Sturtevant, USA
B+V (Blohm+Voss) Industrietechnik, Hamburg, Germany
Borg Warner, Inc., Auburn Hills, Minnesota, USA
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
Doosan Infracore, Seoul, South Korea
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
Fairfield, Lafayette, USA
Gates Corporation, Denver, USA
Hägglunds Drives Inc., Columbus, USA
Hense Systems, Bochum, Germany
Honda R&D Americas Inc., Raymond, USA
Honeywell Aerospace, South Bend, USA
HYDAC International GmbH, Sulzbach/Saar, Germany
INNAS, Breda, Netherlands
Jungheinrich AG, Norderstedt, Germany
Komatsu Ltd., Tokyo, Japan
Liebherr, Bulle, Switzerland
Linde AG, Aschaffenburg, Germany
Linde Hydraulics Corp, Canfield, USA
Mecalac, Annecy-le-Vieux, France
Moog GmbH, Böblingen, Germany
Moog Inc., East Aurora, USA
National Fluid Power Association (NFPA)
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
Sauer-Danfoss, Aimes, Iowa, USA
Sun Hydraulics, Sarasota, USA
TRW Automotive, Lafayette, USA
WIKA Instruments Corporation, Lawrencewille, USA
ZF Luftfahrttechnik, Kassel, Germany

5 Publications

Journal Articles

Vacca, A. , Klop R. and Ivantysynova, M. 2010. A Numerical Approach for The Evaluation of The Effects of Air Release And Vapour Cavitation on Effective Flow Rate of Axial Piston Machines International Journal of Fluid Power, Vol. 11, No. 1, pp. 33 - 46.

Ivantysynova, M. 2010. Maha Fluid Power Research Center—Future Trends in Fluid Power. Journal of the Japan Fluid Power System Society, Vol. 41, No 1, pp. 31-34.

Conference Proceedings

Kumar, R. and Ivantysynova, M. 2010. Investigation of Various Power Management Strategies for a Class of Hydraulic Hybrid Powertrains: Theory and Experiments Proc. of the 6th FPNI PhD Symposium, West Lafayette, USA, pp 87 - 99.

Zimmerman, J. and Ivantysynova, M. 2010. Reduction of Engine and Cooling Power by Displacement Control Proc. of the 6th FPNI PhD Symposium, West Lafayette, USA, pp 339 - 352.

Pelosi, M. and Ivantysynova, M. 2010. A Simulation Study on the Impact of Material Properties on Piston/Cylinder Lubricating Gap Performance Proc. of the 6th FPNI PhD Symposium, West Lafayette, USA, pp 373 - 386.

Williamson, C. and Ivantysynova, M. 2010. Stability and Motion Control of Inertial Loads with Displacement Controlled Hydraulic Actuators Proc. of the 6th FPNI PhD Symposium, West Lafayette, USA, pp 499 - 514.

Klop, R. and Ivantysynova, M. 2010. Validation of a Coupled Pump-Motor-Line Model to Predict Noise Sources of Hydrostatic Transmissions Proc. of the 6th FPNI PhD Symposium, West Lafayette, USA, pp 665 - 680.

Pelosi, M., Zecchi, M., and Ivantysynova, M. 2010. A fully-coupled thermo-elastic model for the rotating kit of axial piston machines. Bath ASME Symposium on Fluid Power and Motion Control. pp 217 - 234.

Williamson, C. and Ivantysynova, M. 2010. Power Optimization for Multi-Actuator Pump-Controlled Systems Proceedings of the 7th International Fluid Power Conference Aachen 2010 (7IFK), Vol 1. pp.91-102

Klop, R. and Ivantysynova, M. 2010. Sound Intensity Measurements to Investigate Noise Generation of Hydrostatic Transmissions Proceedings of the 7th International Fluid Power Conference Aachen 2010 (7IFK), Vol. 2, 229-242

Kumar, R. and Ivantysynova, M. 2010. The Hydraulic Hybrid Alternative for Toyota Prius - A Power Management Strategy for Improved Fuel Economy Proceedings of the 7th International Fluid Power Conference Aachen 2010 (7IFK), Vol. 2, pp.329-341

Invited Lectures

Ivantysynova, M. Fuel savings through advanced fluid power systems. 3rd Annual Purdue Systems Integrity for Defense Technology Summit 2010, Purdue University, March 30-31, 2010

Posters Presented

6th FPNI PhD Symposium, June 15-19, 2010. West Lafayette, IN

A Hydraulic Hybrid for a Class 1 Vehicle, Michael Cross

Development of CASPAR tool for Bent Axis Machines, Najoua Jouini

Displacement Control for Multi-Actuator Machines, Matt Kronlage

Active Vibration Damping for Skid-Steer Loaders, Shinok Lee

Pump Control Systems for “Smart” Pumps, Jess Rose

Fluid-Structure-Thermal Model of the Slipper Swash Plate Interface, Andrew Schenk

Class 4 Hydraulic Hybrid Vehicle, Brent Warr

Fluid-Structure-Thermal Model of the Cylinder Block Valve Plate Interface, Marco Zecchi

6 Theses Completed in 2010

PhD Thesis

Williamson, Christopher 2010. Power Management for Multi-Actuator Mobile Machines with Displacement Controlled Hydraulic Actuators. PhD thesis, Purdue University.

Kumar, Rajneesh 2010. A Power Management Strategy for Hybrid Output Coupled Power-Split Transmission to Minimize Fuel Consumption. PhD thesis, Purdue University.

Klop, Richard 2010. Investigation of Hydraulic Transmission Noise Sources. PhD thesis, Purdue University.

Master's Theses

Lee, Shinok 2010. Controller Design and Measurement for Active Damping of Skid-Steer Loader via Displacement Controlled Actuators

7 International Co-operation

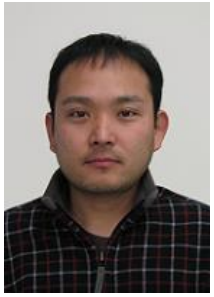
Every year, the Maha lab is pleased to host international scholars for a period of some months. Our successful international co-operations with fluid power research centers worldwide is strengthened even further by using our membership in the international network "Fluid Power Net International" (FPNI), which is currently joined by members from 26 countries, refer to http://fluid.power.net

International students and researchers

In 2010, the following international students and researchers have worked in our team:

Zhao

Philipp



Toyohito

Minming

Zhao Hui, Wuhan University of Science and Technology (zhao111@purdue.edu)

Philipp Koppold, Karlsruhe Institute of Technology (pkoppold@purdue.edu)

Toyohito Uchizono, Japan (Tuchizono@purdue.edu)

Minming Zhao, Jiaotong University China (zhao90@purdue.edu)

8 International and National Conferences Attended

7th International Fluid Power Conference (7th IFK). Aachen, Germany, March 22-24, 2010.
Attendees:

Monika Ivantysynova
Richard Klop (Presenter)
Rajneesh Kumar (Presenter)
Christopher Williamson (Presenter)

6th FPNI Ph.D Symposium. West Lafayette, Indiana. June 15 - 19, 2010.
Attendees:

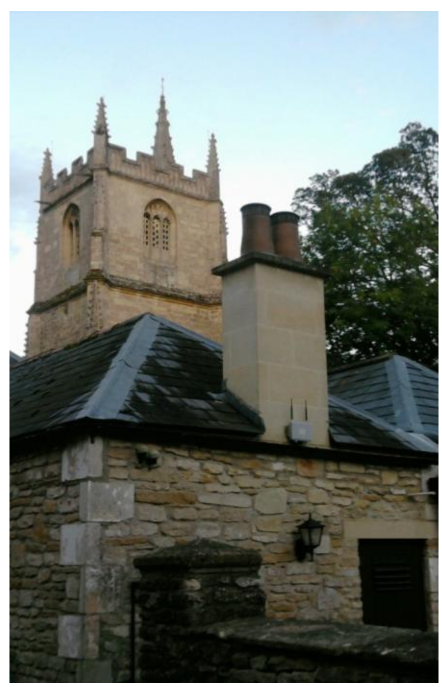
Monika Ivantysynova (Chairman of Organizing Committee)
Najoua Jouini (Secretariat and Poster Presentation)
Roman Ivantysyn (Secretariat and Poster Presentation)
Shinok Lee (Website Administrator and Poster Presentation)
Richard Klop (Presenter)
Rajneesh Kumar (Presenter)
Matteo Pelosi (Presenter)
Christopher Williamson (Presenter)
Josh Zimmerman (Presenter)
Michael Cross (Poster Presentation)
Andrew Schenk (Poster Presentation)
Jess Rose (Poster Presentation)
Brent Warr (Poster Presentation)
Matt Kronlage (Poster Presentation)
Marco Zecchi (Poster Presentation)

4th CCEFP Annual Conference. (Held in conjunction with the 6th FPNI Ph.D Symposium).
Attendees:

Monika Ivantysynova
Josh Zimmerman (Test Bed 1 Presenter and Poster Presentation)
Jess Rose (Poster Presentation)
Matteo Pelosi (Poster Presentation)
Andrew Schenk (Poster Presentation)
Chris Williamson

Bath/ASME Symposium on Fluid Power & Motion Control (FPMC 2011). September 15 – 17, 2010, Bath, UK.
Attendees:

Monika Ivantysynova
Matteo Pelosi (Presenter)
Marco Zecchi (Presenter)



9 6th FPNI – PhD Symposium

The Symposium

The Maha Lab at Purdue University hosted the 6th biannual FPNI PhD Symposium June 15-19 2010. The objective of the symposium is to provide a forum for young scientists, especially PhD students from all over the world, to exchange ideas and opinions on current research and future developments in fluid power technology. The symposium was attended by 96 students from 23 different Universities, and 11 different countries. All students presented a poster or a paper with their own research.

Special thanks go to Najoua Jouini who did a fantastic job organizing the event so that it could run smoothly.

The Symposium was enlightening for both presenters and listeners alike, below is a list of events and pictures taken throughout the event.

Symposium Reception & Opening

(Top Left) **Prof. Monika Ivantysynova,** Maha Prof. Fluid Power Systems, Purdue University, Chair of the Organizing Committee (Top Right) **Dr. Robert Rahmfeld,** Chairman of the Scientific Board of FPNI, Invited Speaker (Bottom Left) **Carol and Eddie Sturman,** STURMAN INDUSTRIES, Inc. “DIGITAL HYDRAULICS - Transforming Mechanical Systems”

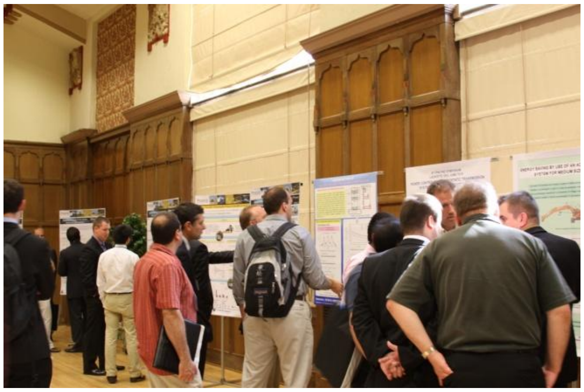
Reception
Maha Fluid Power Research Center

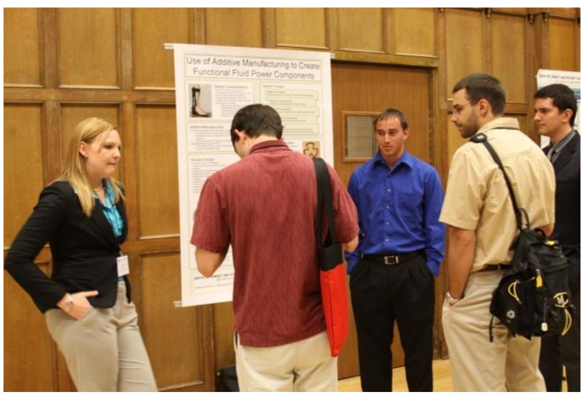


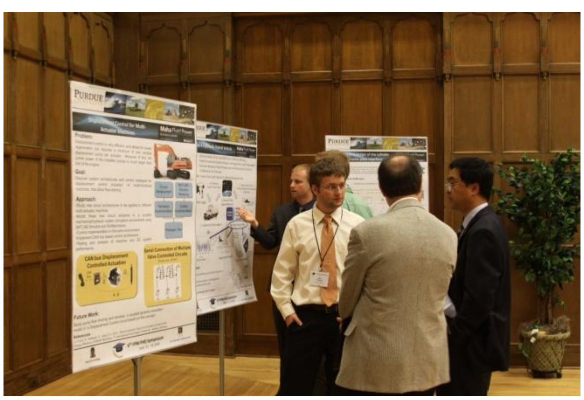



BBQ Dinner- *Sgt. Preston's*

Poster Session

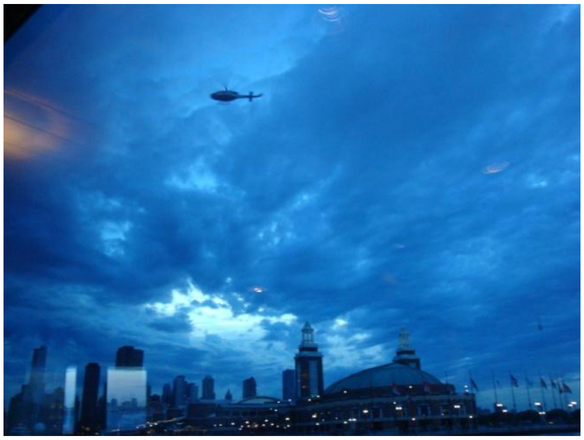






Gala Dinner

Dinner Boat Tour on Lake Michigan



Best Paper Awards

10 Awards and Honors

Joseph Bramah Medal Recipient 2009

Institution of Mechanical Engineers, United Kingdom

Monika has been awarded the Joseph Bramah Medal 2009. This medal is awarded by the Institution of Mechanical Engineers' (UK) - Mechatronics Informatics and Control Group. The medal has been awarded for her outstanding commitment to international fluid power research and education, particularly in the field of hydrostatic pumps and motors. Below is a photo of her receiving the award at the 2010 Bath/ASME Symposium on Fluid Power & Motion Control. The Joseph Bramah fund was established in 1968 at the instigation of Mr. Frank Towler, a Fellow of the Institution of Mechanical Engineers (1932 - 1977), who arranged for its support by industry to commemorate Joseph Bramah, the inventor of a patent lock, the hydraulic press and other inventions concerned with pumps, water supply and the production of pipes and tubes by the extrusion process.

Doctor Honoris Causa

Slovak University of Technology, Bratislava

Monika received a *Doctor Honoris Causa* (Honorary Doctorate) degree from her Alma mater, the Slovak University of Technology in Bratislava on Oct. 20, 2010. The degree was awarded for her outstanding lifetime achievements in fluid power and dedication to the university. Below are photos of Monika receiving the degree and giving her acceptance speech.

Purdue University School of Engineering Faculty Award 2009

Honorable mentions for Backe Medal

Richard Klop, “Validation of a Coupled Pump-Motor-Line Model to Predict Noise Sources of Hydrostatic Transmissions” Purdue University, West Lafayette, USA

Christopher Williamson, “Stability and Motion Control of Inertial Loads with Displacement Controlled Hydraulic Actuators” Purdue University, West Lafayette, USA

Joshua Zimmerman, “Reduction of Engine and Cooling Power by Displacement Control” Purdue University, West Lafayette, USA

Fluid Power and Motion Control (FPMC) Best Paper Award 2009

Joshua Zimmerman, “Effect of Installed Hydraulic Corner Power on the Energy Consumption and Performance of Multi-Actuator Displacement Controlled Mobile Machines” Purdue University, West Lafayette, USA

11 Educational Activities

Dr. Ivantysynova has taught, developed or been advisor to several courses in her time thus far at Purdue:

- ABE 691 / ME 697 – Hydraulic Power Trains and Hybrid Systems *(Spring 2008, 2009)*
- ME 597/ABE 591 – Design and Modeling of Fluid Power Systems *(Fall 2005, 2006, 2007, 2008, 2009, and 2010)*
- ME 463 – Senior Design Project *(Spring 2006, 2007, 2008 and 2009)*
- ABE 697 – Seminar *(Fall 2009)*

ME 597 /ABE 591 – Design and Modeling of Fluid Power Systems Fall Semester 2010

2010 marked the sixth consecutive year of ME 597/ABE 591 being offered.

Course Description:
ME 597/ABE 591 Design and Modeling of Fluid Power Systems
1 Semester, 3 Lecture/week, 3 Credits
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 of 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:
Fluid Mechanics
Modeling and analysis of physical systems
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
14. Hydrostatic transmissions

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

Laboratory Experiments
1. Assembly of an Axial Piston Pump
2. Steady State Measurements of an Axial Piston Pump
3. Measurements on a Test-Rig with Displacement Control Implemented

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.

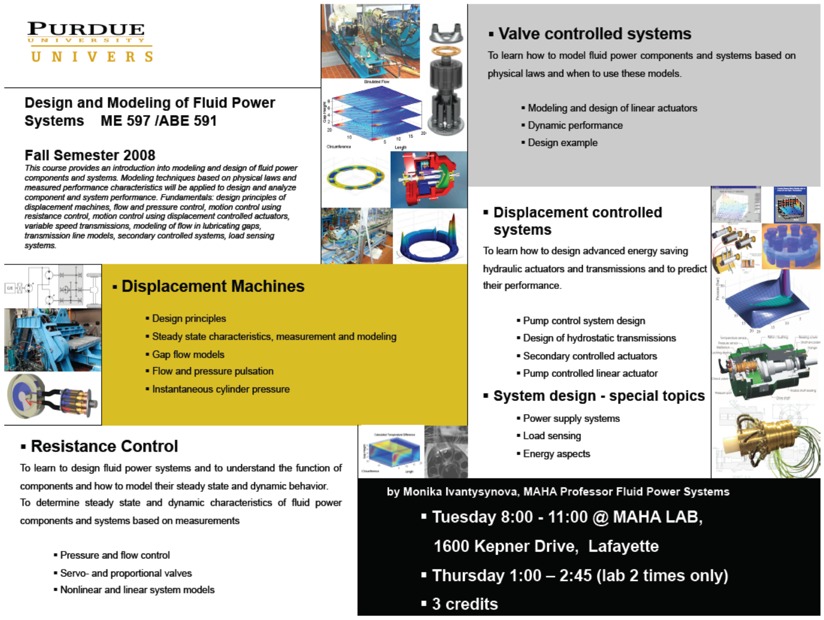
Method:
Students will solve several sub problems of the entire system design work as part of the regular course homework.

Formulation of problem:
Students are requested to perform the following work:

1. 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.
2. 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 the first chapter of your project report.
3. Remember to apply individual course topics to your system
4. 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 at a minimum one rotary and one linear drive system.
5. It is also necessary that you investigate and compare at least 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).
6. Define system structure, draw circuit diagram and a scheme showing the interfaces between your fluid power system and the entire machine/vehicle.
7. Select type and size of components
8. Create models to describe the loss behavior, energy consumption
9. Create models to predict system behavior including dynamics (system parameter as function of time)
10. Define measurement methods and test procedure for a selected component and your whole actuation system
11. 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



ABE 691 / ME 697 – Hydraulic Power Trains and Hybrid Systems Spring Semester 2010

2010 marked the third consecutive year of ABE 691M / ME 697M – Hydraulic Power Trains and Hybrid Systems being offered.

Course Description:
ME 697M/ABE 691M Hydraulic Power Trains and Hybrid Systems
1 Semester, 2 Lecture/2 Lab/week, 3 Credits
Prerequisites: ME 475, 575 or ABE 460, ABE 591/ME 597 or ABE 435 or consent of instructor.

The course provides a thorough understanding of continuously variable transmissions and hydraulic hybrid power train systems. It covers the design and modelling techniques for analyzing, predicting, and specifying the performance of continuously variable transmissions, hybrid power trains and complex hydraulic machine systems including transmission and power train controls.

It also provides an introductory treatment of vehicle steering, braking and active vibration damping systems based on displacement control. Fundamentals of power train control and machine power management concepts are discussed.

Textbook: Course Notes

Coordinator: M. Ivantysynova, Maha Professor of Fluid Power Systems
Lecturers: M. Ivantysynova, G. Seeniraj, R. Klop,, R. Kumar, and C. Williamson

Goals:

1. To learn to design, model and analyze continuously variable transmissions (CVT) and hybrid power train systems.
2. To determine steady state and dynamic characteristics of CVT's.
3. To learn how to apply computer software to predict performance of CVT systems and power train structures including controls.
4. To learn how to model and simulate coupled hydraulic-mechanical systems of off-road vehicles and to predict their performance.
5. To become familiar with machine power management strategies for hydraulically powered machinery.

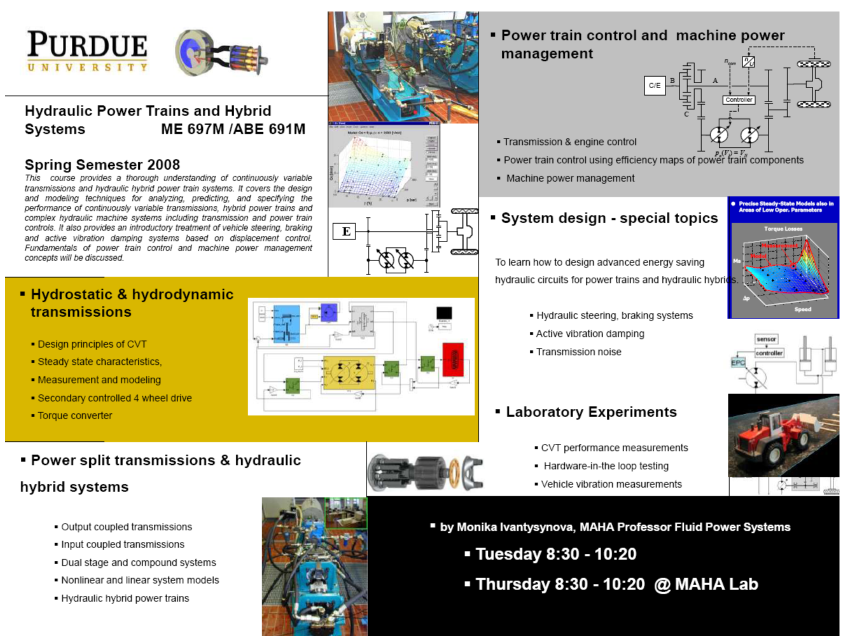
Topics

1. Hydrostatic and Hydrodynamic Transmissions
2. Power Split Transmissions and Hydraulic Hybrid Systems
3. Power Train Control and Machine Power Management
4. System Design – Special Topics

Laboratory Experiments

4. Hydrostatic Transmission Performance Measurements
5. Hydraulic Pump/Motor Noise Characteristic Measurements
6. Hardware in-the-loop Power Train Performance Measurements
7. Excavator Machine Performance Measurements (Power Management)

Grading: 30 % for each of two design projects and 10 % for each of four measurement reports.



12 Maha Social Events

The Maha team isn't always working. Occasionally we get out and have some fun together. Below are some highlights of Maha social events this past year.

Celebrating Chris's PhD Thesis Defense

Chris in his excavator costume

Excavator obstacle

Chris and Roman in a mini-excavator relay

Celebrating Rick's PhD Thesis Defense

Rich in his Semi-anechoic chamber hat

Rick enjoying his favorite past time

Getting ready for duck hunt with a dart gun

Rajneesh's PhD Thesis Defense

Rajneesh loves organic chicken

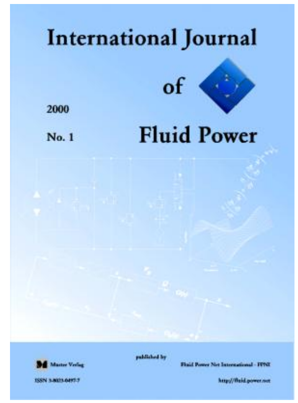
Feats of strength

Rajneesh Playing his favorite game "Smash the Hybrid"

Annual Party at Monika's House

13 International Journal of Fluid Power

Dear Associate Editors and Members of Editorial Board,



I announce with great pride that the International Journal of Fluid Power has completed its 11th year of publication. The third and final issue of the eleventh volume, a special issue dedicated to digital hydraulics, was printed and sent to our readers this past November. This was the 33rd issue of the Journal, and we look forward to the 34th to be published this coming March.

I would like to express my gratitude to all of the members of the fluid power community for your continuous support for the Journal, especially for reviewing papers and submitting manuscripts. In addition, I would like to thank all of the Associate Editors for their great assistance and advice. Having such a wonderful and knowledgeable group of reviewers has helped to further ensure the work published in the Journal is only of the highest quality. The list of reviewers will be published again in the first issue of 2011.

The journal has been online since 2006 at http://journal.fluid-power.net. This online access has definitely strengthened the position of the journal and increased the number of citations.

I would like to add some statistical information regarding the Journal's progress this past year. Since the establishment of the Journal in 2000 we have presented 31 different fluid power software tools and introduced 31 fluid power research center spanning 4 different continents. There have been authors from 32 different countries that have submitted papers to the International Journal of Fluid Power during the last eleven years. Twenty-five papers were submitted to the journal in 2010, which is a slight increase from the 20 papers submitted last year. Approximately half of the papers submitted came from the United States and Canada. All papers that were received by the Journal were sent to at least two experts and in many cases a third reviewer was involved to ensure the review process is fair and the Journal's final publication is only of the highest quality. The rate of successfully approved papers in the past year was approximately 40%.

Again, I would like to express my thanks to all for your continuous support of the Journal. I wish you and your family a happy and healthy Holiday Season, a Happy New Year, and all the best for 2011.

Best regards,

Monika Ivantysynova
Editor-in-Chief

14 Maha Team in 2010

Maha Faculty

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Maha Professor of Fluid Power Systems
Joint appointment in ABE/ME
Supervisor of the Maha Fluid Power Research and Education Center

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June 2010-present

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May 2009-present

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September 2007-present

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August 2006-present

Visiting Researchers

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Phillip Koppold
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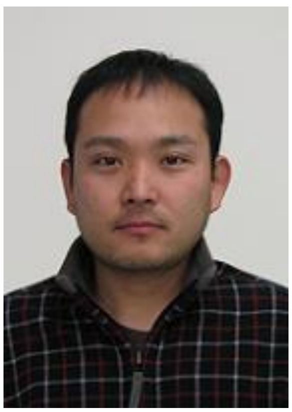

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Jan 2010-present

Visiting High School Students

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Origin: Lafayette, IN
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Origin: Torreon, Mexico
SURF Summer 2009

James Hancock
Undergraduate
BS: Purdue University
Origin: Illinois, USA
SURF Summer 2009

Ben Walke
Undergraduate
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Origin: Pennsylvania, USA
SURF Summer 2009

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Origin: Germany
August 2005-present

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Origin: Kokomo, IN
November 2008-present

15 Visitors & Guests

Brent Rajaniemi – AM General
Joe Fuehne – Purdue MET, Columbus, IN
Thomas Burkes – Distinguished ABE Alum
Michael Brammer – John Deere
Kyung Yong Shin – Doosan Infracore Construction Equipment (Senior Research Engineer)
Hyeon Sik Ahn – Doosan Infracore Construction Equipment (Chief Research Engineer)
George E. Donaldson – Caterpillar Inc. (Technical Manager)
Brad Edler – Caterpillar Inc. (Engineer)
Jeffrey L. Kuehn – Caterpillar Inc. (Senior Engineer)
Viral Mehta – Caterpillar Inc. (Engineer)
James M. Welter – Caterpillar Inc. (Engineering Manager)
W. Kent Rutan – Caterpillar Inc. (Engineering Manager)
Michael A. Flinn – Caterpillar Inc. (Division Manager)
Larry Blackman – Eaton Corporation (Control Systems Engineer)
Doug Scott – Eaton Corporation (Analysis Group Manager)
Gary Strand – HUSCO Company
Jane Frankenberger – Purdue Ag and Biosystems Engineering Department (Professor)
Tom I-P Shih – Purdue School of Aeronautics and Astronautics (Professor and Department Head)
Andi Udris -- President, Fort Wayne-Allen County Economic Development Alliance
John Urbahns - Director, Community Development, City of Fort Wayne
Ron Glotzbach - Director, Product Development Process and Facilities, Navistar (retired)
V.K. Sharma - Dean, Allen School of Engineering and Technology, Trine University
Director Global Product Development and Advanced Technology, Navistar (retired)
Sean Ryan - Director, IPFW Office of University Engagement