Project Summary – 1G Energy Efficient Fluids

1. Statement of Project Goals

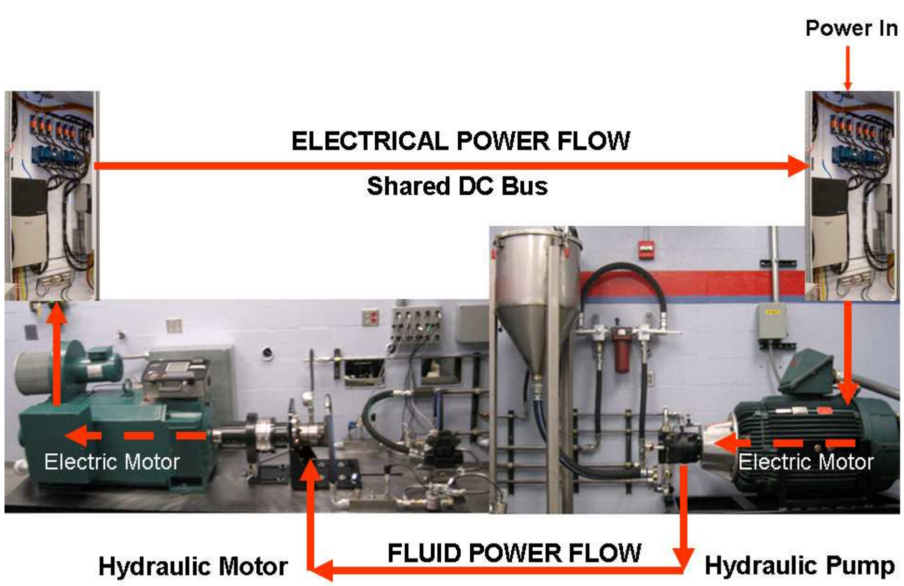
The research objective of this project is to apply high pressure rheology and boundary lubrication science within the disciplinary area of tribology to solve the problem of low-speed hydraulic motor efficiency.

2. Project Role in Support of Strategic Plan

This project will increase the efficiency and energy density of hydraulic fluid power systems by identifying how fundamental fluid properties affect starting torque and low-speed efficiency in hydraulic motors. This is of strategic importance within the CCEFP because low-speed motor efficiency often determines the minimum displacement (size) and operating pressure of mobile hydraulic equipment. The findings of this investigation will be incorporated into formulations of energy efficient fluids for the sUV and excavator test beds.

3. Research Barriers and Methodology

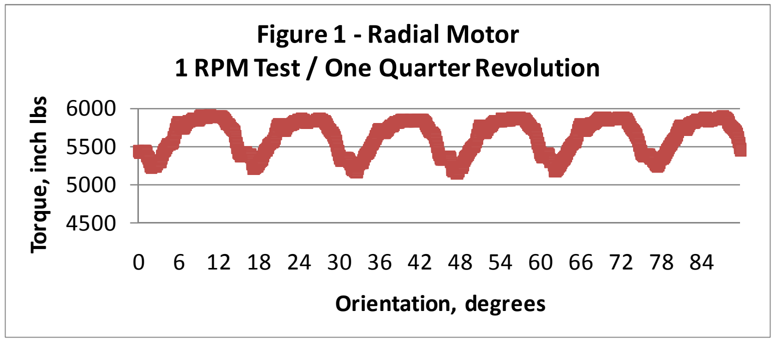
This project investigates the fundamental fluid properties that affect the torque output of hydraulic motors by evaluating prototype mineral oil and synthetic base hydraulic fluids in a full-scale hydraulic dynamometer. The pressure-viscosity (piezoviscosity) properties of the prototype fluids have been evaluated at the Georgia Tech Center for High Pressure Rheology. The friction and wear prevention characteristics of the prototype fluids will be evaluated in High Frequency Reciprocating Rig (HFRR) tests later this year. These fluids are being evaluated in the dynamometer shown below. Motor designs with different metallurgy, surface interactions and contact mechanics are included in this investigation. While commercial components may not be ideal for tribology research, full-scale dynamometer testing can improve the understanding of tribological conditions when combined with an analysis of fundamental fluid properties.



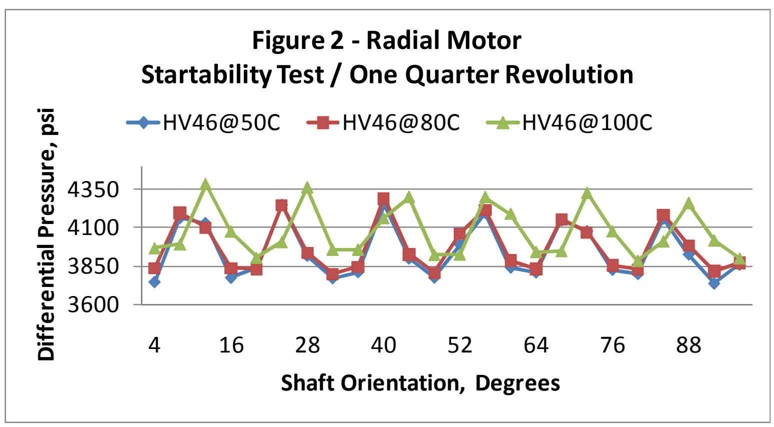
Paul Michael michael@msoe.edu January 22, 2009

4. Achievements to Date

A dynamometer has been constructed for LS/HT testing of hydraulic motors. The dynamometer incorporates a pressure-compensated axial piston pump, a digital torque transducer, two 200 horsepower variable frequency drives (VFD) and an 18-channel data acquisition system. This year, the VFD controllers were programmed for automated startability and low-speed testing. Low-speed (1 RPM) testing is performed under constant pressure conditions in accordance with the ISO 4392-1 standard test method. In this test method, fluids may be compared by measuring the torque output of the hydraulic motor as it rotates at 1 RPM with a constant supply pressure. A typical torque trace for one quarter revolution is shown in **figure 1**. One unexpected finding of 1 RPM testing is that a reduction in the torque ripple can result from use of a polymer containing fluid. A patent application has been filed with the USPTO.



Startability testing is performed under constant load conditions in accordance with ISO 4392-2. In startability testing, fluids may be compared by measuring the pressure required to initiate rotation, or start, a hydraulic motor that is held in a fixed position under constant load. This simulates conditions encountered when starting a vehicle parked against a curb or on a hill. Since the starting efficiency of a motor varies with shaft orientation, similar to the pattern shown in 1 RPM tests, it is necessary to measure starting torque at different orientations. Automating the test stand to index to a precise shaft position after each measurement and developing a method to consistently identify the onset of hydraulic movement proved to be challenging. As can be seen in the startability data shown in **figure 2,** a higher differential pressure is required to start the motor when oil temperature is 100C.



Two hydraulic fluid formulations have been evaluated in geroler, axial piston and radial piston motors; a conventional ISO viscosity grade 46 hydraulic fluid (HM46) and an ISO 46 fluid that incorporates polymethacrylate additive (HV46). These fluids utilize the same antiwear additives but have different high temperature viscosities. As a result they have similar boundary lubrication properties but differ in their hydrodynamic film forming characteristics at high temperatures. In startability and 1 RPM testing, the axial piston motor exhibited a 3.6 to 7.7 % efficiency improvement with the HV46 fluid. The radial piston and geroler motors showed less of an improvement. These results provide evidence that isoviscous hydrodynamic lubrication is larger factor in axial piston motors than in the radial piston and geroler motors. We postulate that boundary lubrication will be a significant factor in radial piston and geroler motors.

5. Other Relevant Work

MSOE continues to collaborate with researchers at Illinois (Loth) and Purdue (Martini). Martini's investigation of stick-slip friction in geroler motors and Loth's nanotexturing research are excellent complements to our research. Collaboration with industrial partners Afton, Eaton, Poclain, Rohmax, Sauer Danfoss and Shell has proven to be exceptionally beneficial this year. Not only have papers been published in collaboration with industry, but industrial researchers have provided valuable insights into the process of tribology research.

6. Plans for the Next Year

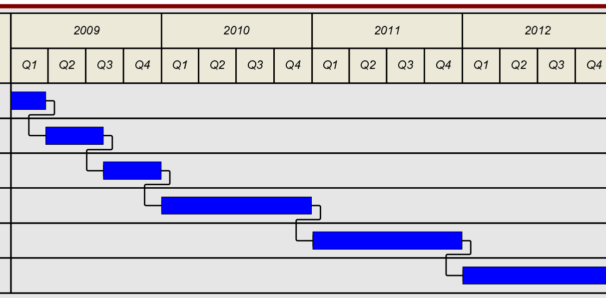
Piezoviscosity effects in hydraulic motors will be investigated by testing fluids that have been characterized in high-pressure rheology tests. HFRR tests will be performed on test fluids in order to gain insight into their boundary film forming characteristics. The critical tribological contacts in a geroler motor will be identified and a preliminary model will be produced. In this way we will combine fundamental fluid property testing, dynamometer evaluations and motor modeling to improve the understanding of tribological contacts in hydraulic motors.

7. Expected Milestones and Deliverables

Definitive information regarding the role of piezoviscosity in motor lubrication is expected by the end of 2009. Based upon contact conditions and the tests performed thus far, we theorize that low-speed piston motor lubrication is isoviscous and piezoviscosity plays a minor role in the geroler and radial motors. In theory boundary lubrication should play a large role in LS/HT motor lubrication. In boundary lubrication, the composition and morphology of the surface film is critical. In 2010 and 2011, project 1G is expected to focus on the surface-chemical interactions of boundary lubrication and friction modifying additives. Analysis of boundary film strength and composition of tribofilms formed by anti-wear/friction modifier combinations will be necessary. Concurrent research by Purdue and Illinois is expected to reveal micro and nano-scale surface texturing technologies that will be implemented in fluid power equipment. In 2012 and 2013, project 1G anticipates that hydraulic motors incorporating these surface modifications will be evaluated in the LS/HT dynamometer.

- December 2009 – Report on piezoviscous/isoviscous lubrication in motors
- December 2011 – Report on boundary lubrication in motors
- December 2013 – Report on integration of nanotextured parts into motors

ID	Task Name	Start	Duration
1	Finish HM46 testing and repeat HV46 testing to verify results	1/1/2009	12w
2	Test TMP Trioleate	3/26/2009	20w
3	Test Functionalized PMA	8/13/2009	20w
4	Test Friction Modifiers	1/1/2010	52w
5	Test Moly type friction modifiers	1/3/2011	52w
6	Integrate Nanotextured surfaces into motors	1/2/2012	104w



8. Member Company Benefits

New patentable IP has been developed in collaboration with industry. Since hydraulic system modifications are not required to implement this technology, it can benefit the existing equipment of member companies and their customers. In addition, students in the research team gain practical experience in fluid power system design, control and testing. These students provide a pool of experienced men and women that will be the future leaders in fluid power.

9. Research Team

Project Leader:	Paul Michael, Research Chemist, Fluid Power Institute, MSOE
Industrial Partners:	Afton Chemical, Eaton, Gates Rubber, Parker, Poclain, RohMax USA, Sauer-Danfoss, Shell, Sun Hydraulics
Faculty:	Tom Wanke, Director, Fluid Power Institute, MSOE Tim Kerrigan, Project Engineer, Fluid Power Institute, MSOE
Graduate Students:	Aaron Kimball, MS Engineering, MSOE Kelly Burgess, MS Engineering, MSOE Sarah Johnson, MS Engineering, MSOE
Undergraduate Students:	Brian Blazel, ME Junior, MSOE Chelsey Jelinski, ME Senior, MSOE Dan Moldenhauer, EE Junior, MSOE