CCEFP Director Visits Mesabi Wind Turbine Project

Wind energy researchers from University of Minnesota (UMN) visited Mesabi Range Community and Technical College (MRCTC) in Eveleth, Minn. The purpose of the visit was to inspect the Vestas V27 225 kW wind turbine that MRCTC recently installed and to discuss its use for potential collaborations. Both UMN and MRCTC are interested in installing a hydrostatic transmission (HST) in the wind turbine and conducting research.

MRCTC offers a two-year training program for wind turbine technicians and installed the V27 to offer students hands-on experience. The turbine was purchased directly from Vestas in Denmark and is designed to operate at 50 Hz AC output. An HST fills the need for a method to convert the output to the 60 Hz power used in the U.S. and offers a test bed for research in applying HSTs to wind turbines. UMN is soliciting support from its industry partners to build, commission, and perform research on the HST.

Participating in the visit from the the UMN Mechanical Engineering (ME) Department were Prof. Kim Stelson, Dr. Feng Wang, Rahul Dutta, and Brad Bohlmann. Matt Lueker and Chris Feist represented the Saint Anthony Falls Laboratory's Eolos team.

Prof. Kim Stelson exiting the tower of the V27 wind turbine at Mesabi Range Community and Technical College

CCEFP Research

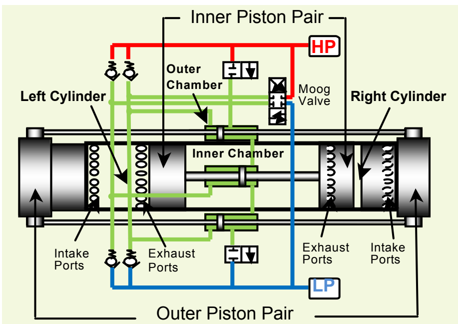
A FREE PISTON ENGINE-DRIVEN HYDRAULIC PUMP FOR MOBILE APPLICATIONS

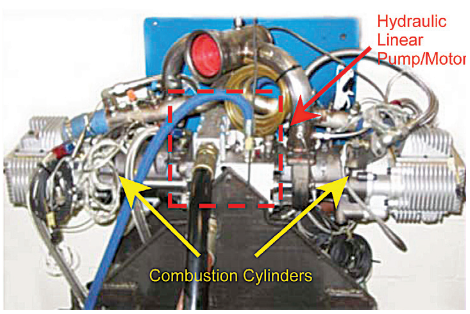
By Prof. Zongxuan Sun, University of Minnesota

In recent years, the rising demand for energy and the increasing concerns of the environmental impact have triggered more strict governmental regulations on fuel economy and emissions for personal and commercial transportations, as well as other mobile applications. The new CAFE (corporate average fuel economy) standard in the U.S. almost doubles the fuel economy by year 2025. Similarly, the fuel consumption of the heavy-duty vehicles is required to reduce 20% by year 2018. Obviously, significant technical innovations are required to achieve these ambitious goals.

For mobile applications including both highway vehicles and mobile heavy equipment, fluid power is currently generated onboard using a crankshaft-based internal combustion engine (ICE) with a rotational hydraulic pump. The main drawbacks of this configuration are the relatively low efficiency

(Top) FIG. 1: Diagram of the FPE-driven hydraulic pump
(Bottom) FIG. 2: Picture of the pump





and complex design of both the ICE and the hydraulic pumping system due to the dynamic operating requirements. An alternative approach is to supply fluid power using a free piston engine (FPE) with a linear hydraulic pump. As shown in *Fig. 1*, combustion in the right cylinder will push the inner piston to the left and outer piston to the right, which will compress the gas in the left cylinder and generate high-pressure fluid in the inner hydraulic chamber. Similarly, combustion in the left cylinder will return the inner piston to the right and outer piston to the left. This configuration has the potential to significantly increase the ICE and pump efficiency while increasing system modularity. Specifically, the ICE efficiency can be improved with the variable compression ratio, advanced combustion such as homogeneous charge compression ignition (HCCI), and less friction due to a simpler design. The dynamic and modular nature of the free piston engine-driven hydraulic pump makes it very attractive for mobile applications by converting liquid fuel to fluid power on demand without a large energy storage device.

The proposed technology will not only revolutionize the automotive propulsion system, but can also be transitioned into different classes of on-road and off-road vehicles, heavy machinery, and power generation equipment. Given that hydraulic hybrid systems are well suited for heavy commercial vehicles, the technology could in the future be incorporated into commercial vehicle fleets. At the same time, retrofitting existing vehicles with the hybrid systems will allow for additional reduction in fuel consumption and emissions.

So far we have developed detailed models for the system, including the hydraulic model, the gas exchange model, and the HCCI combustion model. We have also compared its performance to a linear alternator free piston engine. Detailed stability analysis and control design have also been conducted and currently been implemented in the test cell on a hydraulic free piston engine donated by Ford Motor Company (*Fig. 2*). Preliminary results are very promising, and engaging the FPE technology with specific applications is also being investigated.

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ENERGY-EFFICIENT FLUIDS

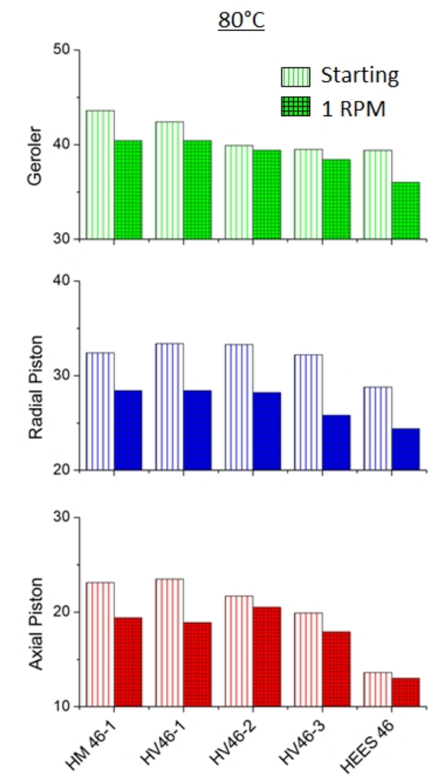
By Paul Michael, Research Chemist, Milwaukee School of Engineering

The research objective of Project 1G.1 is to understand how fluid properties affect hydraulic motor efficiency.

Hydraulic fluid plays a critical role in the efficiency of fluid power systems; insufficient viscosity can compromise volumetric efficiency, while excessive viscosity can compromise hydromechanical efficiency. A seminal moment in the development of energy-efficient hydraulic fluids occurred in 1999, when Steve Herzog of RohMaz, Thelma Marougy of Eaton, and I drafted the NFPA Recommended Practice T2.13.13 – *Viscosity Selection for Hydraulic Motors and Pumps* under the guidance of Fluids Committee Chair Paul Schact of Bosch-Rexroth. This document provides a means of selecting the right viscosity fluid to assure hydraulic system reliability. From that moment, with the noteworthy leadership of Mr. Herzog and his colleagues of RohMax, energy-efficient hydraulic fluid technology was launched. These products, many of which incorporate shear-stable viscosity index improvers, have been found to yield significant efficiency improvement in pump tests and field trials. Today, CCEFP members ExxonMobil and Shell are marketing energy-efficient fluids formulated with additives produced by CCEFP members RohMax, Afton Chemical, and Lubrizol.

While viscosity is certainly a key factor in hydraulic system efficiency, Project 1.G.1's investigations with hydraulic motors from Eaton, Poclain, Parker Hannifin, and Sauer-Danfoss have shown that viscosity doesn't tell the whole story. All of the oils in *Fig. 1* have the same kinematic viscosity at 40°C, yet motor efficiency varies significantly from fluid to fluid.

FIG. 1: Torque losses under starting and 1 RPM conditions in hydraulic motors



When examining fluid-efficiency interactions in hydraulic motors, one soon realizes that multiple lubrication regimes are present. A handful of researchers in the CCEFP have teamed-up to unravel these interactions:

- Boundary Lubrication: Mark Devlin and Jeff Guevremont, Afton Chemical
- Elastohydrodynamic Lubrication: Scott Bair, Georgia Tech
- Hydrodynamic Lubrication: Steve Herzog, RohMax
- Static Friction: Ashlie Martini and Daniel Brant, Purdue University
- Surface Texture: Bill King, University of Illinois at Urbana-Champaign (UIUC)

These investigators found that improved motor performance at start-up may be obtained by formulating a fluid with low static and boundary friction coefficients while minimizing viscosity change at increased temperature and pressure. Bill King of UIUC is a relatively recent addition to the research team. We anticipate that his surface texture modifications to the geroler will uncover a whole new approach to improving starting efficiency.

Project 1G.1 is currently investigating tribofilm structure and chemistry in motors by comparing the tribochemical films formed in a reciprocating tribometer to those formed in an operating hydraulic system. We now have analytical evidence that ashless antiwear additives form phosphorus-containing tribofilms in motors. Detecting this nanometer-scale tribofilm proved to be a challenge; three laboratories failed before Jeffery Guevremont from Afton Chemical succeeded. The discovery of a phosphorus tribofilm on motor surfaces is an important step in linking tribology research to fluid power applications. Understanding the nature of tribofilms formed by different additives is one of the keys to reducing friction.

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HYDROSTATIC TRANSMISSION USE IN WIND POWER APPLICATIONS

By Brad Bohlmann, University of Minnesota

Wind power research is ongoing at the University of Minnesota to investigate and answer three questions:

1. Can wind turbine reliability be improved by replacing the conventional drivetrain with a hydrostatic transmission (HST)?
2. Is it possible to extract more energy from a given wind profile through the use of a variable HST?
3. Can a wind turbine with an HST drivetrain have a lower life cycle cost of ownership than a conventional wind turbine?

The work includes modeling and simulation and lab-scale testing of systems. The goals for the testing include validation of the modeling results and optimization of the system components and control systems.

The drivetrain technology under investigation is called a hydrostatic transmission (HST). HSTs have been the dominant choice for off-highway propulsion systems for more than 50 years. In fact, they are installed in the vast majority of agricultural, construction, and forestry vehicles in use today. There are literally millions of HSTs currently in use worldwide in very demanding commercial applications where performance, durability, and reliability are critical.

Thus, the core technology of the system has a long and successful track record, and the wind turbine drivetrain technology proposed herein builds on that legacy of success.

Fig. 1 shows the main components of an HST. In the case of a wind turbine, a fixed-displacement pump converts the rotational motions of the wind turbine's blades into fluid flow. This fluid flow is converted back to rotary motion by a variable displacement hydraulic motor that is attached to the wind turbine's generator. This type of HST is one embodiment of a continuously variable transmission (CVT). In a CVT, the ratio of the rotational speeds of the input (wind turbine blades) and output (wind turbine generator) components in the transmission can vary over a broad RPM range in a continuous manner without discrete gear steps. This allows the transmission to be used at speed ratios that can optimize system efficiency. In a wind turbine, this generally means allowing the wind turbine's blades to rotate and their optimum tip speed ratio.

Several other unique features are enabled by the "fluid link" between the input and output components of the HST. One is the ability to physically separate the input and output, such has having the hydraulic pump in the wind turbine nacelle, and the hydraulic motor and generator on the ground. Another advantage is that the fluid link provides more compliance, which reduces the shock loading and associated fatigue failures that occur in mechanically linked wind turbine systems.

Replacing the conventional, gearbox-driven drivetrain in a wind turbine with a hydrostatic transmission has the potential to simultaneously improve reliability and increase system efficiency. The result should be a lower cost of electricity.

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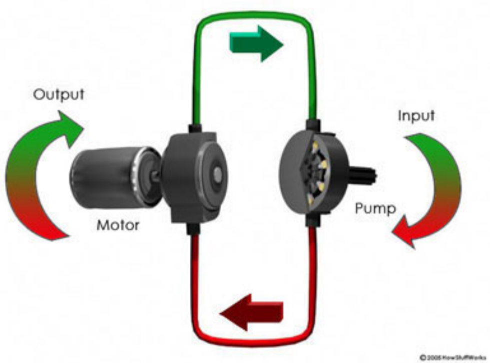

FIG. 1: Hydrostatic transmission (Source: howstuffworks.com)