Free Piston Engine Pneumatic Compressor

The CCEFP free-piston engine compressor program will provide a compact source of power for new fluid power applications. The free- piston engine compressor prototype shown below is a compact and efficient source of compressed air derived from propane, which possesses an energy density 200 times that of batteries. The device has successfully demonstrated 10Hz combustion during testing. Novel design innovations include a “liquid slug” trapped between two high- temperature elastomeric diaphragms acting as its piston in order to exploit dynamics in achieving an efficient and powerful engine within a small package. The free piston engine compressor will be the power source for the rescue robot test bed, demonstrating the possibility of greatly increasing the force and duration achieved for untethered robots.

Rescue Robot

The difficulty with which a conventional electric vehicle traverses a disaster site, such as a collapsed building, results partly from the relatively low power available and partly from the lack of adaptability that wheels or tracks provide. The Rescue Robot will overcome these obstacles. In the process a better understanding of the challenges of more common applications of fluid power to mobile equipment will also be gained. Excavators, backhoes, telehandlers, forest harvesters and other multi-axis devices with fluid actuation currently rely on simple-to-implement operator joysticks. These joysticks are far from simple to operate, however, and require substantial training and impose a high cognitive workload on the operator that could be better employed in completing higher level tasks. The eighteen degree of freedom rescue crawler provides an opportunity for researchers to explore new multimodal interfaces, employing haptics and augmented reality displays. Head trackers will point the crawler’s cameras to provide the operator a “bug’s eye” view of the operation under way. The haptic manual control of the front legs allows the user to test potentially unstable footholds while intelligent autonomous operation of the remaining degrees of freedom reduces the operator workload. The first prototype, based on a current chemofluidic approach, has been completed. The front legs of the prototype have been fabricated and are currently being tested. Custom valves and associated control electronics are also being fabricated so that the legs can be thoroughly tested, prior to full fabrication. Operator interfaces incorporating head tracking camera and helmet mounted display with audio and voice control, and haptically controlled front legs have been implemented.

Multi-mode pump model

One potential solution to the problem of energy efficiency is the development of hydraulic hybrid vehicles. For hydraulic hybrid technology to become a viable option, the efficiency of today’s pumps and motors needs to be increased. Improving pump and hydraulic motor efficiency requires an understanding of the most miniscule of design elements. These design elements, called lubricating gaps, typically have dimensions on the order of tens of microns and are formed between the moving components of the pump. Even small changes in the design of these gaps can have a large impact on the efficiency of the machine. If the gaps are too large the internal leakage will become excessive and the volumetric efficiency will suffer. If the gaps are too small and the mechanical efficiency goes down or, worse yet, catastrophic seizure may occur. With an appropriate gap design energy loss can be minimized. The challenge is to develop sophisticated models and algorithms allowing a fully coupled simulation of fluid-structure-thermal and multi-body dynamic interactions allowing direct calculation of surface deformation. We have created and are currently validating a coupled fluid-structure interaction and multi-body dynamics model for the cylinder block-valve plate and piston-cylinder interfaces of a swash plate axial piston machine.

Seal modeling

Feedback from our industry partners indicates that the number one nuisance and environmental issue facing the fluid power industry is that of seal leakage. Previous models assumed full film lubrication in the sealing interface, greatly simplifying the problem but giving unrealistic results. In our present work, realistic mixed lubrication is being considered. For reciprocating seals, a basic model including analyses of the quasi steady state fluid mechanics, contact mechanics and deformation mechanics must first be developed. The model will be validated by comparison with experimental results in the literature and obtained from industrial collaborators which will lead to the creation of an enhanced model that also takes into account transient and thermal effects which must also be experimentally validated. So far the development of the basic model, including a thermal analysis, has been completed. It has been used to analyze several types of U-cup rod seals and compared with those from an industrial injection molding application.

Self-spinning Rotary PWM valve

A major source of energy loss in current fluid power systems is the use of metering control valves that achieve control function by dissipating energy through partially opened valve orifices. Replacing them with throttle-less methods will increase energy efficiency significantly. Pulse width modulation (PWM) of on/off valves that are either fully open or fully closed is a potential approach for throttle- less control. This approach is analogous to switched mode converters in power electronics. A primary challenge to realizing PWM control of fluid power system is the lack of high speed on/off valves. These on/off valves must have large orifices (to allow large flow to pass through at low pressure drops), have fast transitions (to reduce the time when the valve is partially open), and must operate at high PWM frequencies (to reduce ripples and to achieve high control bandwidth). Typically, a control valve consists of a linear translating element such as a spool or poppet that opens and shuts an orifice. Actuating such valves at high frequency requires rapidly accelerating and decelerating the element requiring large actuators and power input proportional to the third power of the frequency. To overcome this challenge, a self-spinning rotary on/off valve is being developed at CCEFP. The valve is turned on and off as the spool rotates and the PWM duty ratio is adjusted by translating the spool axially. Since the spool is continuously rotating, rapid acceleration and deceleration are not required, and the power input is proportional to the second power of frequency allowing much faster operation. The CCEFP rotary valve uses fluid momentum to achieve rotary motion so that no external rotary actuator is needed. To date, a 3-way version of the rotary on/off valve that is integrated with a (40 lpm) fixed displacement pump to achieve variable displacement function has been prototyped and demonstrated. PWM frequency up to 270Hz, closed loop duty ratio modulation with 0-100% modulation time of less than 0.1sec have been achieved. Further development will consider improved performance and configurations for regenerative applications.

Fluid Power Video

The CCEFP has partnered with NFPA to create two half-hour videos, one to educate the general public on fluid power and the other to inform engineering graduates of the career opportunities in fluid power. The videos feature CCEFP faculty, students and industry members. The main themes of the video for the general public are that fluid power is all around us even though we may not realize it, that fluid power has intrinsic capabilities that are unmatched by any other technology, and that fluid power has the capability of solving many of society's pressing problems in the future. The career opportunity video features graduate students and engineers in fluid power communicating the excitement and importance of their work. Additional financial support for the careers video was provided by fluid power organizations for other countries. The video was produced by Twin Cities Public Television for broadcast in April 2008. It will be made available to all public television stations in the United States by satellite. CCEFP and NFPA hold copyright on the video and are free to distribute it in DVD form for educational purposes. We are developing a plan to widely distribute the video for high impact.

Hydraulic Hybrid Vehicle Exhibit

The CCEFP has developed an interactive hydraulic hybrid vehicle exhibit that allows the operator to witness how energy regeneration is possible for a hydraulic hybrid passenger vehicle. The simulator is currently on display at the Science Museum of Minnesota (SMM) and will ultimately become part of a permanent exhibit on fluid power. The hydraulic hybrid vehicle exhibit was built in spring 2007 by senior mechanical engineering students as a capstone design project. Advisors for the project were CCEFP faculty and staff of the SMM. The exhibit won first prize in the senior design show as the best capstone design project in mechanical engineering at the University of Minnesota. The concept of energy regeneration holds great promise for future hybrid vehicles to greatly improve fuel economy, and is being demonstrated in the small urban vehicle research test bed being built at the University of Minnesota. The CCEFP displayed the exhibit at the 2007 Minnesota State Fair. The photo shows a CCEFP graduate student explaining the exhibit to a young State Fair visitor.

High tech treadmill helps researchers developing fluid-powered orthotic braces

Researchers in the Center for Compact and Efficient Fluid Power (CCEFP) require state of the art movement analysis equipment to assess the efficacy of new fluid-powered orthotic braces. These orthoses are being developed in a CCEFP test bed that focuses on developing challenging, human-scale, un-tethered, fluid-powered orthotic devices. Funds from NSF to the CCEFP were used to purchase a special instrumented treadmill (recently released by Bertec Corporation, Columbus, Ohio) to meet this need. This cutting edge treadmill has many special features enabling researchers to look at contact force measurements under each foot in three directions (vertical, fore-aft, and sideways) for multiple steps and over many minutes. By combining force measurements with motion-capture data of joint and body segment movements, researchers are also able to examine the torques and reaction forces generated by the joints of each leg. From these data, detailed observations about gait behaviors are possible. Most gait analysis labs use one or more force platforms embedded into the floor to record these forces; but that method only allows the examination of a couple of steps at a time and requires precise placement of only one foot on a platform at a time. Thus, test subjects need to make many passes across the platforms to get enough good data. This new treadmill allows researchers to collect good gait data with every step and also allows users to walk in the orthoses for longer assessment periods.

Center for Compact and Efficient Fluid Power

Experimental Setup for Fluid Power Noise Evaluation

CCEFP researchers at Georgia Tech have developed an advanced test rig for fluid power noise measurement. Fluid power components naturally produce fluid-borne noise in their normal operation. This noise can be a major source of vibration as well as adverse human impact in terms of annoyance and even risk to hearing. While modeling methods are under development for the predication and optimization of fluid-borne noise, it is essentially to be able to measure the actual noise production and noise control performance of fluid power devices. When noise propagating in fluid lines encounters a fluid power device, such as a silencer, a portion of the noise is reflected, some is absorbed, and some is transmitted. A technique has been developed that permits the accurate measurement of each of these noise components, using a spectral-based method and multiple sensors. In a fluid power system, pressure sensors take the place of the more familiar microphone for the measurement of noise. Spectral decomposition and application of appropriate transfer function relationships to the pressure signals recorded upstream and downstream of a fluid power device permit the accurate resolution of the noise components. The method also permits the measurement of the input acoustic impedance of fluid power devices. Knowledge of a device's impedance is a invaluable for the modeling of fluid power systems.

When applied to devices such as fluid power silencers, the method yields the frequency- dependent transmission loss of the silencer. For silencers, this characteristic is a measure of how much incident energy actually transmits past the silencer. The test rig developed for this purpose provides the means to assess existing commercial devices as well the prototype components that are being developed by CCEFP.

New Fluid Power Courses and Area of Specialization at Purdue University

In response to the lack of advanced graduate courses in fluid power at American universities, CCEFP faculty have developed several new courses and created a new Area of Specialization in fluid power within the Agricultural and Biological Engineering Department at Purdue. Students are required to choose three courses from a group of existing and newly developed courses. The new courses are *Design and Modeling of Fluid Power Systems* (ABE 591/ME 597) *and Hydraulic Power Trains and Hybrid Systems* (ABE 691/ME 697). These courses complement the existing courses covering hydraulic control systems, sensors and data acquisition, and control systems theory. For further information, visit the MAHA Fluid Power Research Center website at Purdue. (http://cobweb.ecn.purdue.edu/~mahalab/).

Cavitation modeling

Whenever pressures within fluid power systems become too low, cavitation might occur. A common location for this problem is the pump inlet where the fluid is being drawn into the system. High flow rates, highly viscous fluids such as encountered during cold weather start up, operation at high altitudes and abrupt changes in geometry exacerbate the problem. There presently is no truly accurate means of modeling cavitation. Our unique approach is to utilize high-fidelity large eddy simulation (LES) as the computational method employed and laser-based diagnostics, specifically particle imaging velocimetry (PIV), along with fiber-optic probes and piezo-electric pressure transducers to make detailed flow, void fraction, and dynamic pressure measurements in venturi-type flow passages. Significant progress has been made on both the computational and experimental fronts including capturing for the first time the inherently complex 3D vortical structure associated with cavitating internal flows. It is the control of these vortical structures that we hope to exploit in our future studies as a means to control cavitation either passively through geometric changes or actively through flow modification.