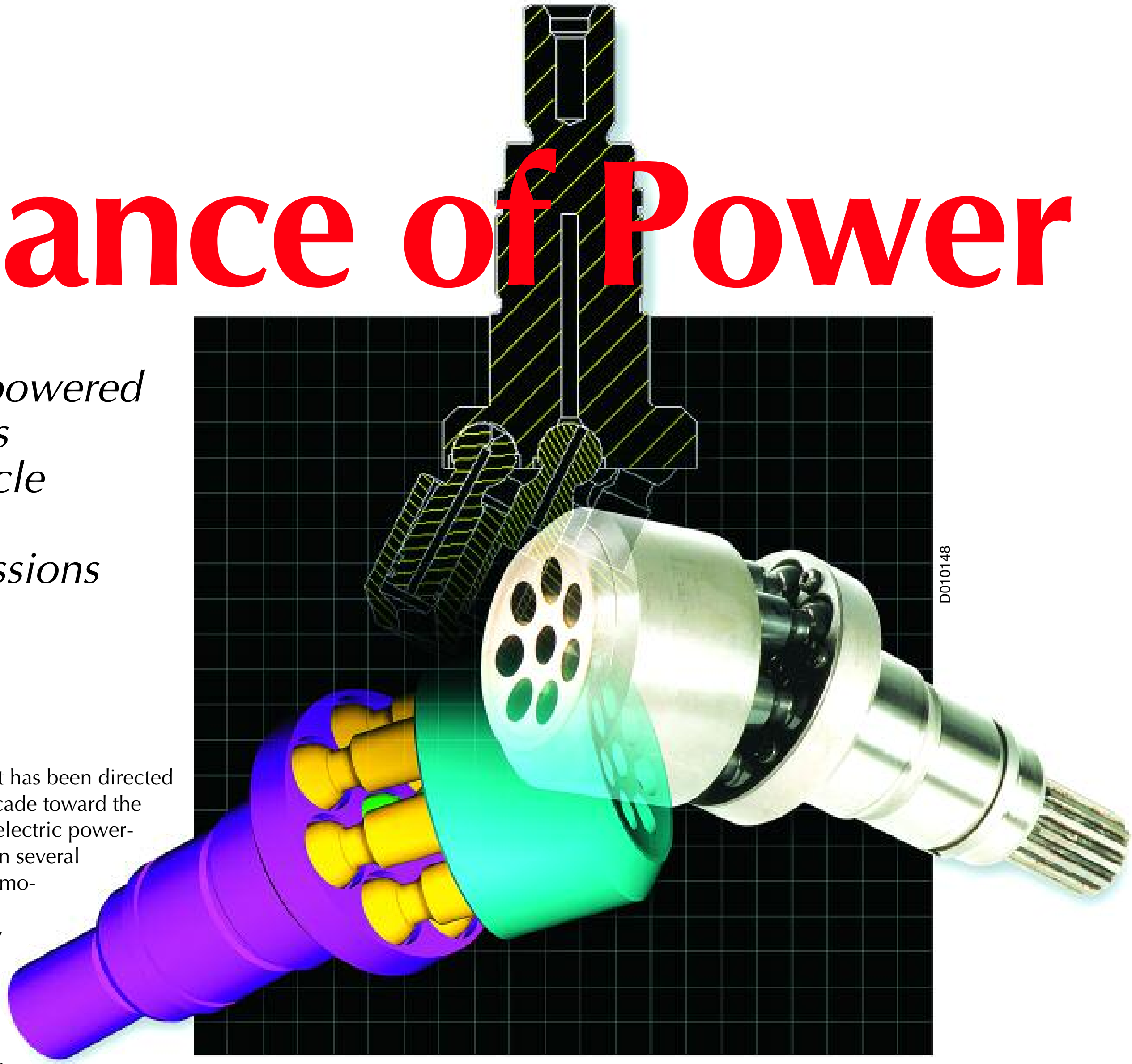
Balance of Power

Hydraulic-powered components add to vehicle efficiency, reduce emissions

By Glenn R. Wendel and Travis W. Jackson



Creating a new hydraulic component system at SwRI is reflected in the process (counterclockwise from top center) that begins with design drawings and progresses through computer modeling to prototype construction.

Considerable effort has been directed over the past decade toward the development of hybrid electric powertrains such as are used in several current production automobiles. This effort has improved fuel efficiency and reduced emissions by integrating electric motors and batteries into the powertrain, reducing the engine size while still maintaining vehicle performance and handling.

During this time, Southwest Research Institute (SwRI) engineers have been working with the U.S. Environmental Protection Agency (EPA) to develop hybrid technology for larger vehicles utilizing hydraulic, rather than electric, components. Hydraulic hybrid vehicles make sense because of their ability to absorb and deliver high levels of power from small components, referred to as high power density, and because of the maturity of the technology. As with hybrid electric vehicles, however, the effective use of hybrid hydraulic technology depends on the duty cycle of the vehicle; that is, the way the vehicle is to be used.

Hybrid technology generally affords improved vehicle efficiency and reduced emissions through two processes. The first is associated with recovering the energy that is typically lost through the brakes during stopping. The second is associated with operating the engine at conditions of inherently high efficiency most of the time. The powertrain of a hybrid hydraulic vehicle consists of an engine, a hydraulic transmission and a set of hydraulic accumulators. Accumulators store hydraulic energy just as batteries store electrical energy. During braking the hydraulic transmission is able to pump hydraulic fluid from the low pressure accumulator to the high pressure accumulator, where it is stored in anticipation of the next vehicle acceleration. Accumulators allow the high power levels associated with braking to be absorbed efficiently for later reuse.

The amount of brake energy that can be recovered during vehicle operation, again, depends on the vehicle's duty cycle. The more stop-and-go operation is included in the cycle, the more brake energy that can be recovered and reused, and the greater the fuel efficiency improvement. Conversely, owners of hybrid automobiles may discover lower-than-expected fuel efficiency improvements if their vehicle does not undergo as much stop-and-go driving as the manufacturer anticipated. With that in mind, conversion to hybrid technology is less advantageous for 18-wheel trucks that spend most of their time cruising on the highway at 65 miles per hour, because this class of trucks already has been finely developed over many years to be very efficient at this driving condition. However, place this same vehicle in stop-and-go operation, and hybrid technology can

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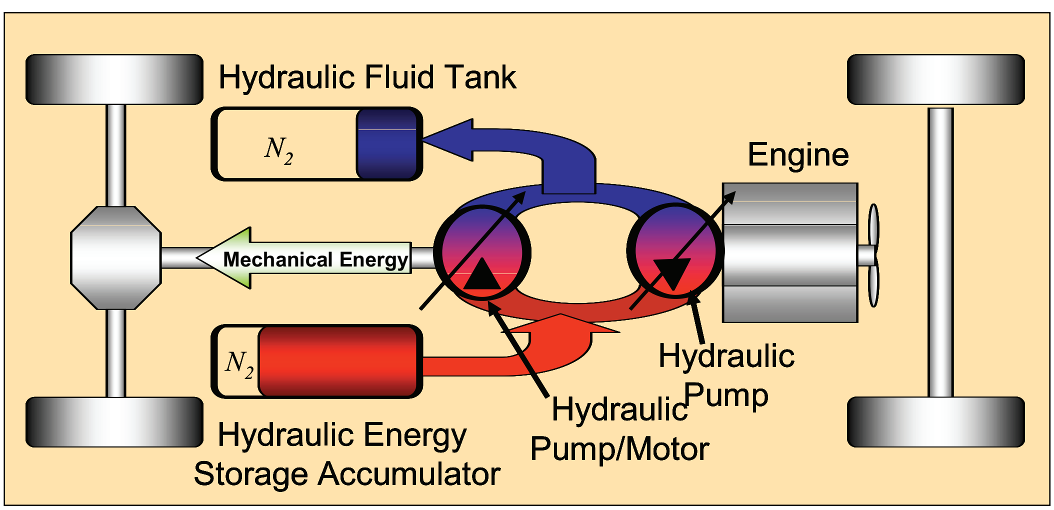
reduce fuel consumption as much as 50 percent or more.

So, which vehicles are likely candidates for the effective use of hybrid technology? Generally, those that undergo a lot of stop-and-go driving, such as transit buses, delivery vehicles, refuse vehicles and most automobiles used in commuting. The hybrid hydraulic version of this technology seems to make the most sense for larger vehicles with lower production volumes, in commercial use, because the economics of commercial vehicle operation favor lowest-cost solutions to technical problems and hydraulics can provide this lowest-cost solution.

Development efforts during the past decade have been focused on component development and system integration, with emphasis on storing hydraulic energy in accumulators. Accumulators are simple in concept, but as with most other powertrain components, they are highly engineered devices. Inside the accumulators, nitrogen gas is used to pressurize the hydraulic oil as it flows in from the hydraulic transmission during braking. The oil and gas must be kept separate in the accumulator to ensure that the oil does not carry gas through the hydraulic system. The loss of gas, particularly in the high-pressure accumulator, will diminish the ability of the system to store energy effectively.

An important characteristic of nitrogen gas is that as oil is pumped into the high-pressure accumulator during braking, the gas pressure increases exponentially. Energy is stored as more and more fluid is pumped into the accumulator at higher and higher pressures. In addition to increased pressure, the nitrogen gas also generally heats during compression, and this typically results in energy being lost to the environment. However, the integration of open-cell foam into the accumulator has improved the efficiency of accumulators significantly. Today, accumulators can have efficiencies as high as 98 percent when brake energy is stored for the period that most commuters spend in stop-and-go traffic.

The safety of accumulators is extremely important, and SwRI has worked with manufacturers of composite pressure vessels for many years to ensure that they meet stringent safety regulations. Tests have been performed to ensure that they have sufficient ultimate strength to withstand several times the expected maximum internal pressure. Other evaluations have been performed to ensure that accumulators have the endurance to withstand the cyclical pressure loading over their expected service life. Other evaluations have been undertaken to ensure that the accumulators do not react with automotive fluids, including gasoline and diesel fuels, such that their overall performance and



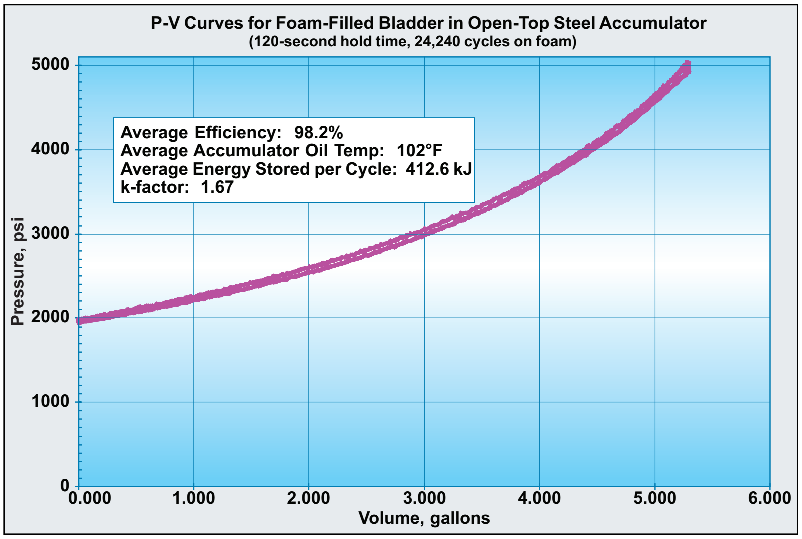
Hybrid hydraulic powertrains typically consist of an engine, hydraulic transmission and accumulators that store energy normally lost during braking.

reliability might be affected.

While hydraulic components have been used in off-highway vehicles for decades, their on-highway use thus far has been somewhat limited because of a number of factors. For example, major development activities are being directed toward reducing the noise associated with hydraulic systems to improve their acceptance by the general public.

In addition to the efficiency gains realized by the recovery and reuse of brake energy, hydraulic systems are also being developed to drive engine accessories on these hybrid hydraulic vehicles. A single engine-driven, variable-displacement pump can power several hydraulic motors of different displacements to drive the fan, alternator, air conditioning compressor, water pump, engine oil pump and power steering system. This arrangement can improve the efficiency of the vehicle by matching the power demanded by each component to the power supplied by the engine.

For example, radiator fan speed can be decoupled from the engine speed using this system so that the fan can operate at whatever speed is needed to provide optimal air flow across the radiator to adequately cool the engine. At the same time, the engine water pump can be run at its optimal speed to provide the required flow of coolant through the engine. Thus, if the engine is operating at partial power or if the outside air temperature is low, the power directed to these and other engine accessories can be optimized and thus energy, and fuel, can be saved.



Accumulator efficiencies in excess of 98 percent, represented by the very small area between the curves, have been obtained using open cell foam installed into the accumulator.

Institute engineers have determined that a ball pump is ideally suited to this hydraulic circuit, because it uses very high production-volume, low-cost ball bearing components and is highly efficient at moderate pressures of 1,500 pounds per square inch (psi) or less. At these pressures, the efficiency of this pump can actually be higher than that of a much more expensive piston pump.

Hydraulic systems used in construction equipment likewise are receiving additional consideration pertaining to operational efficiency. The hydraulics industry has migrated from open-center, fixed-displacement pumps to pressure and pressure/flow- compensated pumps in an attempt to improve efficiency of the hydraulic system by providing the flow needed for the maximum pressure required by the hydraulic system. The problem with this current best-practices approach is that the hydraulic system requirements typically vary from component to component.

The SwRI team has recommended that the off-highway equipment industry instead consider using multiple hydraulic pumps to satisfy the needs of the various circuits used in equipment such as excavators. One SwRI simulation study, involving a hydraulic excavator undergoing a truck loading cycle, showed a 46 percent reduction in fuel consumption using this regenerative hydraulic circuit.

The concept of regenerative hydraulics is not new to the Institute. The concept was patented at SwRI in 1991 as applied to a gas-oil suspension system for large vehicles. SwRI conceived of the use of multiple hydraulic pumps and motors, each connected to a separate gas-oil suspension strut, for control of vehicle heave, pitch and roll. This system was demonstrated on a

Hydraulic accumulators built of composite materials provide the strength-to-weight ratios needed for efficient use in vehicles.

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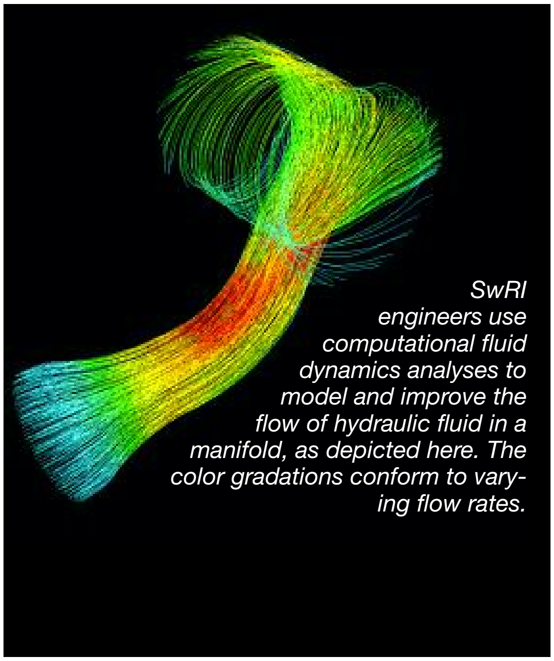
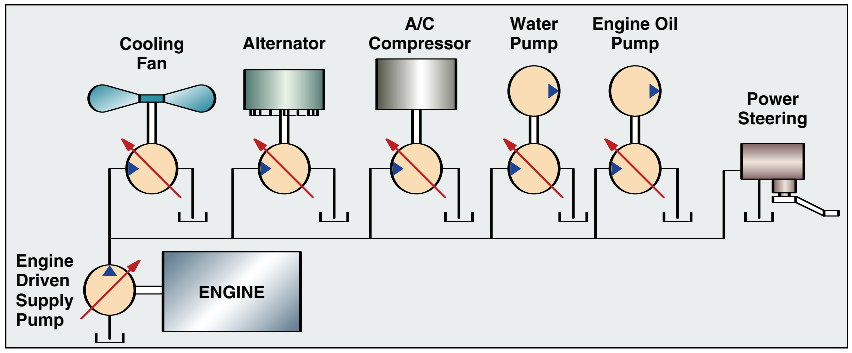


SwRI engineers use computational fluid dynamics analyses to model and improve the flow of hydraulic fluid in a manifold, as depicted here. The color gradations conform to varying flow rates.



The hydraulic circuit for a hydraulic accessory drive system maximizes the drive effiiciency for each accessory. It consist of an engine-driven, variable-displacement pump and multiple variable-displacement hydraulic motors along the flow loop.

tour bus. Four hydraulic pumps or motors were installed into the bus with an in-line torque transducer to acquire operational information. The bus manufacturer had requested that the passive spring stiffness of the vehicle be reduced by half, and that body pitch and roll also be reduced by half, using the regenerative active hydraulic system. The project goals were achieved, and 75 percent of the actuation energy for the suspension system was recovered during operation.

Because they allow engine speed to be decoupled from vehicle speed, hybrid hydraulic powertrains allow the engine to operate at maximum efficiency as the hydraulic components provide the required variability of operation. All engines have an optimum efficiency point for each combination of power and speed; hybrid hydraulic vehicles can keep the engine operating along this optimum efficiency curve over many different operating conditions.

The EPA, supported by SwRI, has placed into service a hybrid hydraulic commercial delivery vehicle to verify the fuel efficiency gains that have been predicted through modeling and simulation and obtained in laboratory tests. EPA anticipates that the cost/benefit ratio of this hybrid powertrain will be better than that of an equivalent-size hybrid electric powertrain because of the proven performance, reliabilty and relatively low cost of hydraulic components. Future development will include reductions in the noise associated with these components and further improvement in the efficiency associated with this powertrain system.❖

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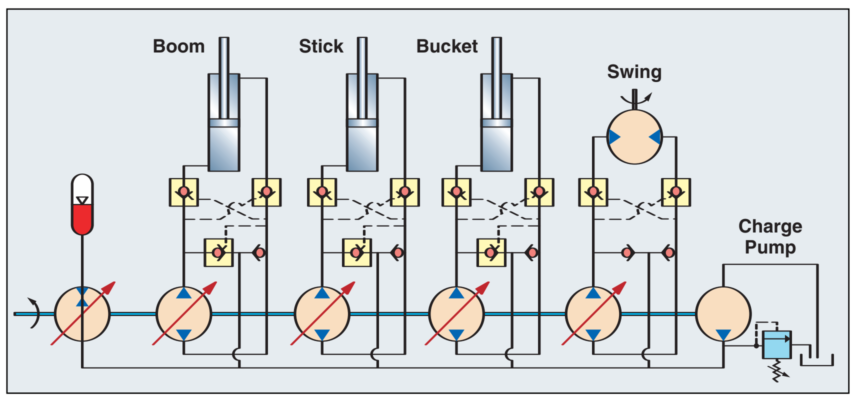
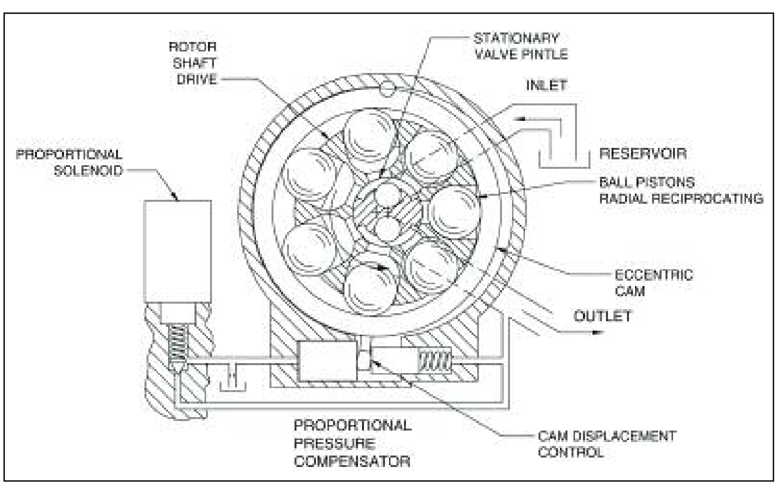


A hydraulic regenerative circuit designed for an excavator satisfies the needs of various circuits and provided a 46-percent reduction in fuel consumption when evaluated using a standard truck loading cycle.



This schematic depicts a low-cost, high-efficiency ball pump/motor intended for use in a vehicle's hydraulic circuit.

The Fluid Properties Meter

SwRI researchers develop innovative energy meter to determine natural gas properties

By Eric Kelner, P.E.

In recent years, a combination of rising demand and changing natural gas supplies has created variations in the properties of natural gas. This has raised safety concerns and operational issues for transporters, as well as questions about the ability of natural gas-fired end-use equipment to perform. If the current strong demand trend and variation in natural gas quality continue, producers and marketers will need more accurate, real-time monitoring of gas properties.

Prior to the 1990s, low gas prices and a growing natural gas-liquids market motivated producers to extract liquids such as propane and butane from the gas and sell them. This created a fairly lean (containing low concentrations of condensable hydrocarbons) and uniform natural gas composition, with essentially no risk that natural-gas liquids would condense in a pipeline system. Since then, the narrowing price difference between natural gas liquids and natural gas itself has reduced interest in extracting and selling the liquids, thereby increasing the amount of unprocessed gas (containing relatively high concentrations of condensable hydrocarbons) flowing through the nation's pipelines. Unprocessed gas, which is more likely to contain condensed hydrocarbon liquids, increases the cost of transportation system operation and also creates safety concerns.

The problem is compounded because many gas producing reservoirs are becoming depleted and are producing gas with increasing concentrations of condensable hydrocarbons. New resources, such as liquefied natural gas and coal-seam gas, bring additional variation in gas quality.

Gas quality variations also impact end-use equipment such as domestic burners and gas-fired turbines. Technologies that were created to reduce the amount of combustion-related emissions tend to increase the equipment's sensitivity to natural gas properties. Quality variations can increase emissions, reduce efficiency, cause flame instability and create engine knock.

Flexible, accurate, real-time monitoring will improve the infrastructure's ability to respond to variations in gas properties. However, because of high equipment costs, real-time gas quality monitoring only occurs at large-volume locations.