Hydraulic energy storage:

Squeezing the most from your juice

Discovering ways of cutting fuel use has almost become a national pastime – not least in the agricultural industry where such costs can have a strong bearing on the sector's overall profitability. Andy Collings reports on a fuel saving system that uses a combination of compressed gas and hydraulic fluid to store energy during the braking process

The amount of fuel used to run pick-ups, lorries, tractors, along with a whole host of self-propelled machinery, could be reduced significantly if a project being developed by Eaton Hydraulics comes on stream. And if the results of initial tests made with prototype systems are indicative of what is eventually to come, such fuel savings could be as high as 30% – almost a third less fuel consumed, and a figure that the farming industry would clearly welcome.

Speaking at a conference organised by the National Fluid Power Centre, Eaton Hydraulics' Steve Skinner outlined his company's latest developments.

"This project is not about developing some hi-tech system that needs years of testing or the redesign of an engine," he said. "It is a system that utilises products that are currently in operation and well proven along with technology that has existed for years."

Key to the new system is the subject of regenerative braking, which aims to re-use the energy normally wasted when brakes are applied to bring a vehicle to a halt or reduce its speed. But before going into a detailed explanation of how the new system works, it makes sense to look at a few basics.

When a farm pick-up is pounding down the road at, say, 70mph and then needs to stop at some traffic lights, the brakes have to be applied. Bringing the vehicle to a standstill means that its energy – its kinetic energy – has to be dissipated. This is achieved through applying the brakes which, through friction, convert the vehicle's energy into heat. Just for the record, a 1.8t pick-up motoring along at 70mph produces 120kW – the equivalent of 120 bars on an electric fire – when it brakes to a stop. This wasted vehicle energy can amount to 40% of the fuel consumed. In the same vein, a 40t lorry stopping from 56mph generates sufficient energy to run 840 bars on an electric fire – 0.84MW of power. And when the lights turn to green, there is the fuel required to accelerate

There is significant future potential for tractor manufacturers to derive benefit from hydraulic energy storage systems. And that particularly applies to those tractor types that spend much of their time on transport applications.

back up to speed again. In terms of emissions, this is when the most pollution is also created.
The challenge, then, is to now develop a system that can store kinetic energy – the rolling momentum of the lorry, pick-up or tractor – as the vehicle slows and then reuse it to get the same vehicle moving again and reduce the fuel consumption overall. This, in short, is what is meant by the term 'regenerative braking system'.
It is a challenge that has taxed the minds of design engineers for decades and has led to some pretty intriguing, if largely unworkable end results. But clearly if the energy that is wasted when brakes are applied can be stored for later use, the potential for fuel saving is significant.

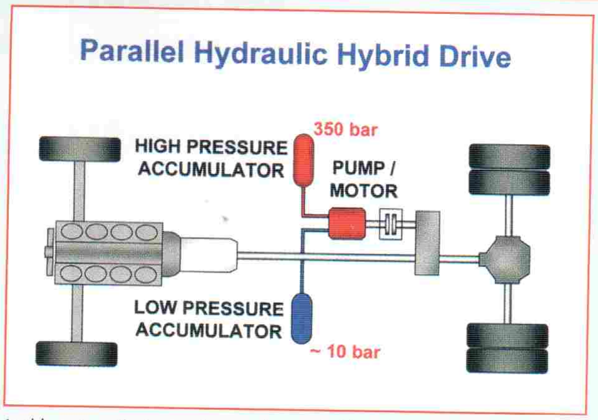
So, how can this energy be stored on a vehicle? The vast majority of vehicles run on chemical fuel – petrol, diesel or LPG – which, as we know, is burnt when used and, as a result, cannot be put back in the tank. Assuming that vehicles are likely to continue to be powered by chemical fuel for the foreseeable future, there needs to be a secondary system that can store energy for reuse.
One of the earliest attempts at storing energy was to fit a flywheel. This hefty lump of metal was spun up to very high speeds as a vehicle was braked and then, as the vehicle was required to accelerate, fed all its kinetic energy back into the transmission.

On the plus side, the flywheel means of energy storage was clean and relatively efficient, in that the energy that was put in was mostly recovered. Against these advantages, however, was the fact that it was a heavy weight rotating at high speed. This created gyroscopic forces and made vehicles reluctant to change their direction. And there was always the danger that in an accident a flywheel would become an unstoppable projectile.
Not good news for the flywheel concept then, but perhaps better news for electrical storage. Electrically powered vehicles, after all, have been around for years as milk floats, industrial forklifts – and more recently as hybrid-powered cars such as the Toyota Prius and Honda Civic.
There has certainly been a significant amount of work put into the development of efficient and workable electric-power systems, but earlier designs suffered from the fact that batteries were heavy, slow to charge, had a limited life and were difficult to dispose of safely.

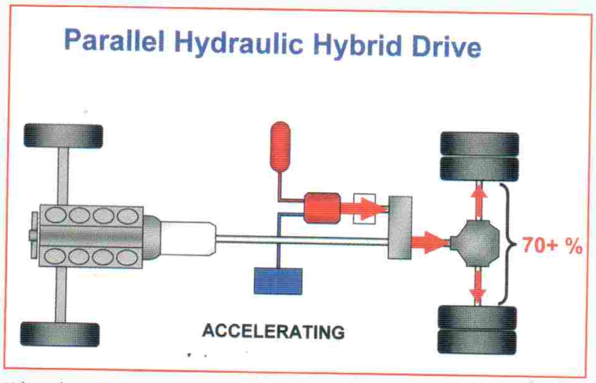
Having said that, the latest developments in battery technology have created batteries with faster charge cycles and longer life. In particular, the Supercapacitor, which is incorporated within Honda's FCX car, looks to be a hopeful contender for the future. Currently, however, it is very expensive and, due to its high voltage release, needs a complex control system to operate it.

So, while electrical storage systems, such as on those in hybrid-powered vehicles, continue to be developed, what choices are there available? The answer, according to Eaton Hydraulics, is hydraulic energy storage.
The company calls the technology the Eaton Hydraulic Launch Assist System, and says that it now has vehicles up and running fitted with this new technology.
Described simply, the Eaton system uses hydraulic oil to transfer braking energy to a gas accumulator in which the gas is compressed to high pressure. When the energy is called on to be reused by the vehicle, the pressurised gas pushes the powering oil back through the pump which, now acting as a motor, assists with the vehicle's acceleration.

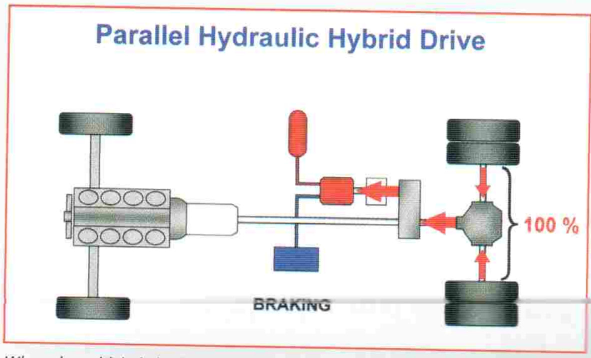
In practice, the pump/motor is positioned on the propshaft, taking the drive from the transmission to the vehicle rear axle, and is activated when the brake pedal is depressed. The rotation of the propshaft, now being driven by the back axle as the vehicle slows down from travel speed, drives the pump/motor and oil is forced into the accumulator.



In this system, the hydraulic pump/motor is driven from the propshaft via a clutch system that allows the system to be disengaged when the vehicle is being driven normally i.e. not braking or accelerating. Note the pressurised oil reservoir, which permits fast oil movement to the accumulator.

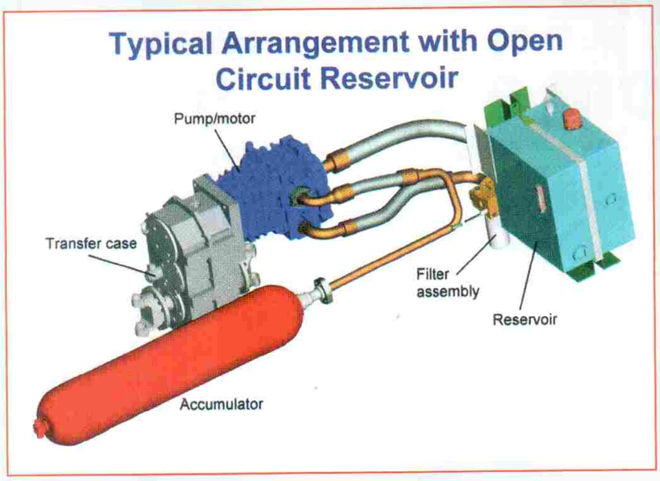


When the vehicle is accelerating, 70% of the energy that would have been lost when the vehicle was braked is available to power the drive axle.



When the vehicle is braked, the drive to the pump is engaged and the kinetic energy – the momentum – is converted into pressurised gas in the accumulator. This stored energy is then available when the vehicle starts.

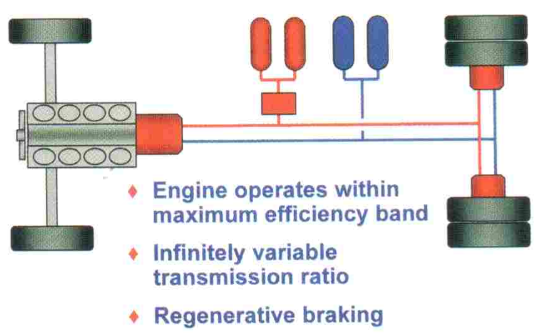
Once the braking action is complete and the vehicle needs to accelerate, the oil powers what has now become the motor, which drives the propshaft and, via the differential, the back axle.
Most will appreciate that the components employed within this system – the pump, accumulator and plumbing, for example – are widely used throughout the mechanical world and, as such, are proven and, in the main, reasonably priced and reliable.



This shows a typical system that uses an open circuit reservoir - rather than a contained one depicted in the other diagrams. The accumulator holds the nitrogen gas, which is compressed under braking and released to drive the motor when acceleration is required. The UJ connectors to the prop shaft can be seen on the lower half of the transfer case; the transfer case engages the drive to the pump/motor.

This is the ultimate in hydraulic energy storage/use arrangement, says Eaton Hydraulics - a hydrostatically driven vehicle using standard wheel motors. When the brakes are applied, the oil is pumped by the wheel motors into the accumulators (red), with oil supplied from the reservoir (blue). On acceleration the pressurised oil is allowed back into the system to help drive the wheel motors. This system avoids having a pump/motor, because these items are already in situ.

Series Hydraulic Hybrid Drive (The Ultimate Objective)



- Engine operates within maximum efficiency band
- Infinitely variable transmission ratio
- Regenerative braking

Other advantages of the system include rapid energy transfer - both pressurisation and pressure release are quick - long component life, no disposal issues, low leakage loss and, above all, it is simple technology.

For heavier duty, working applications - such as within a lorry or a tractor - drive for the pump/motor is taken indirectly from the propshaft so that a clutch system can be incorporated. This assists with the overall control of the system and allows the drive to be better managed. It is an arrangement that also enables the pump to be at a standstill during normal driving conditions when there is no demand for braking or acceleration.

While talking about control systems, it is this area that has particularly taxed the developers of the system. Why? Most importantly, the operating system clearly needs to be fail-safe and able to detect any changes in braking requirements. For example, in emergencies a rapid deceleration is needed, while on other occasions - say, during a long downhill run - the braking action tends to be more gradual. No simple task, then. Which is why Eaton Hydraulics stresses that its new Hydraulic Launch Assist system has only been made possible by the development of modern, sophisticated and dependable electronic sensing. So, let's now see how the system works in greater detail.

At the point when a vehicle needs to be stopped and the brakes are applied, 100% of its kinetic energy is available initially for channelling through to power the pump, this forcing oil into the nitrogen-filled accumulator. In a short period of time, this accumulator reaches a maximum pressure of about 350 bar, after which further braking is then down to the brakes alone.

A point to note here is that the oil is pumped very rapidly from the reservoir and, as a result, the pump inlet pressure is a serious consideration. With inadequate pressure, oil may cavitate, causing problems of flow and pump damage. To stop this from happening, the hydraulic oil reservoir is maintained at a pressure of about 10 bar to ensure a sufficient supply of oil to power into the accumulator.

With braking completed and the traffic lights now turned to green, the brakes are released and the accelerator depressed. This activates opening of the valve to release the oil from the accumulator to drive the pump which, in turn, feeds power back into the driveline to the machine's rear axle.

According to Eaton Hydraulics, about 70% of the initial braking energy is retrieved in this way - wastage of only 30% rather than the 100% expelled by conventional braking systems - and also results in an impressive amount of fuel being saved, a significant advantage of this set-up.

Indeed, Eaton claims that payback time for such a system could be within three years and probably even less.

And there's more. The company has also taken its hydraulic accumulator system one step further, to what it considers to be the 'ultimate objective' - a hydrostatically driven machine incorporating the energy storing system, such as a self-propelled sprayer. When accelerating with this type of machine, rather than having a separate pump and motor unit, the system now feeds pressurised oil from the accumulator directly into the hydrostatic motor as an assist to that being delivered by the engine-driven pump. The pipes delivering driving oil to the wheel motors would have accumulators linked to them and, by opening a valve when the brakes are applied, would allow pressurised oil created by the wheel motors to be stored in the accumulators as before.

Once again, hydrostatic transmissions are not new; they are widely used but not so much in on-road vehicles where their efficiency is generally considered questionable for these applications. Even so, there are advantages in having an engine that operates at an optimum speed and, with infinitely variable transmission ratios available, the energy storage may just tip the balance in their favour.

At this point it's interesting to ask why it has taken so long to develop an energy storage system. After all, vehicles have been applying brakes for as long as they have been moving.

As ever, the answer is mainly one of cost or, ironically, the lack of it. Until recently fuel, particularly in the US, has been a reasonably cheap commodity, so there has been little, if any, incentive to spend money on developing energy storage technology. But how those times have changed. Among other factors, a fuel price increase and the threat of severe environmental changes through the excessive burning of fossil fuels have now inspired new thinking.

Hydraulic Energy Storage

The benefits

- Rapid energy transfer
- Long component life
- No disposal issues
- Low leakage loss
- Simple technology

As illustrated in the 'Hydraulic Hybrid Drive' diagram, hydrostatically driven sprayers are particularly suited to utilising hydraulic energy storage technology. On acceleration, pressurised oil helps to drive the wheel motors.

In terms of machine performance, Eaton Hydraulics says that a 4.5t vehicle can be accelerated to around 30mph using the stored energy alone – without the engine. But with the engine adding its power there could be some pretty impressive 0-60mph figures to look forward to in the future, although there are bound to be some limiting safety factors that will have a bearing on the final result.

Other trials reveal that fuel savings in a 5.4-litre pick-up – a Ford F-350 – can be as high as 35%, while for a 28.5t/315hp lorry the fuel savings were up to 28%. And, as an extra bonus, less dependence on the brakes for stopping the vehicle meant that brake pad life was doubled.

Summary: Hydraulic energy storage has the potential to bring significant benefits to all industries involved in transport and machinery operation. And that includes the agricultural sector.

It's clearly still early days for this technology and its applications, but Eaton says such systems have the potential to make a major contribution to fuel economy in a broad range of vehicle types. No longer will valuable energy be irretrievably lost when brakes are applied.