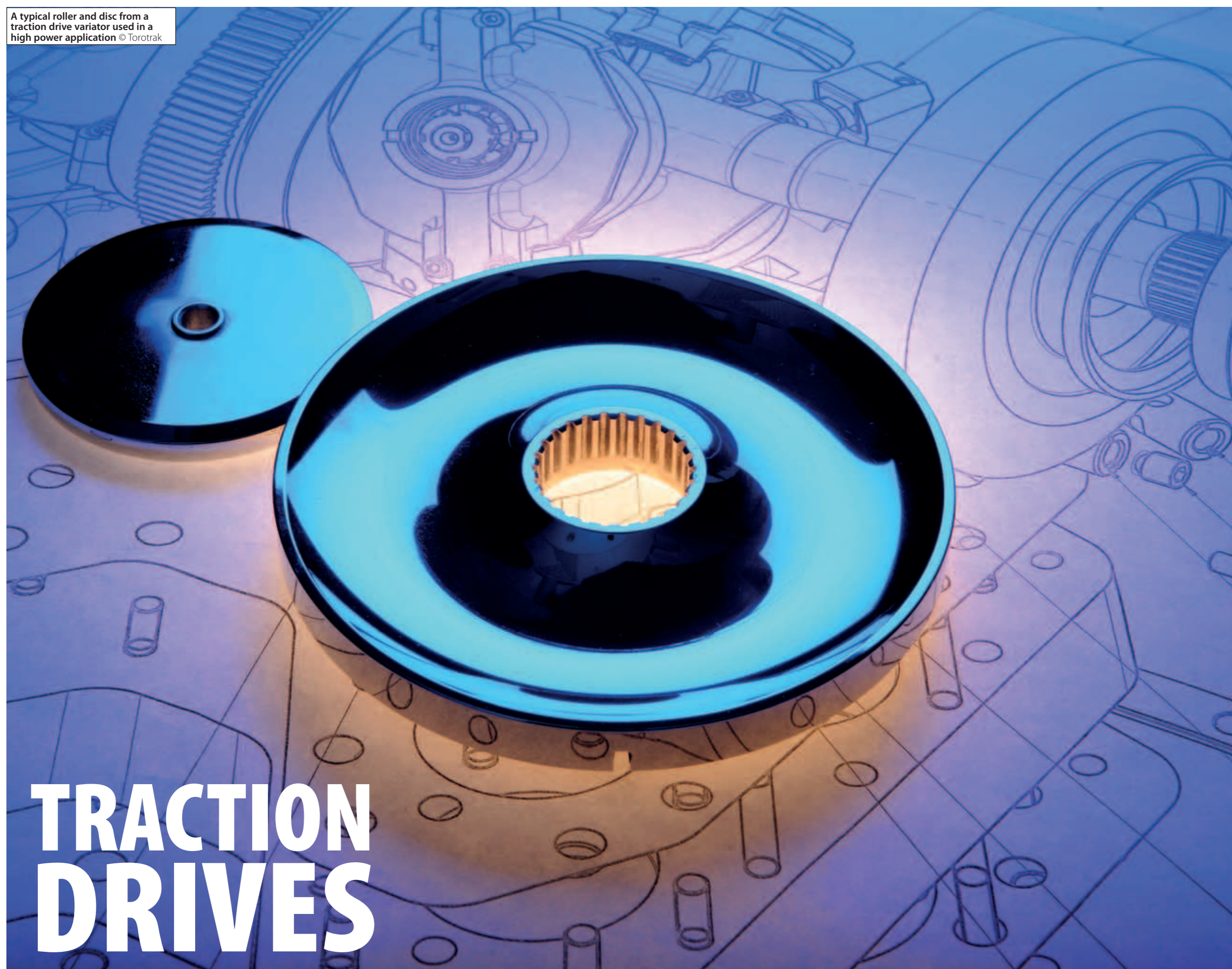


A typical roller and disc from a traction drive variator used in a high power application © Torotrak



TRACTION DRIVES

A new design of transmission drive is set to help vehicle manufacturers reduce carbon dioxide emissions. Dick Elsy is CEO of Torotrak, a UK developer of transmission systems based on traction drive. He explains how his company has developed a range of drives for lawn mowers, cars, tractors, trucks and buses.

Today's vehicle manufacturers face a dilemma: how to cut fuel consumption and carbon emissions while preserving the performance characteristics that consumers have become accustomed to. A new breed of variable transmission known as traction drive could have the answer.

UK company Torotrak has developed a transmission system based on a variable traction drive that boosts fuel efficiency and delivers improvements in acceleration over conventional step-ratio automatic transmissions. It does this by enabling the engine to operate close to optimum efficiency, regardless of vehicle road speed, which conventional transmissions do not.

To demonstrate the advantages, Torotrak recently fitted its transmission system into a mid-sized city bus and ran the vehicle on the industry-benchmark London fuel economy test cycle; the result was a 19% improvement in fuel economy. The variable drive technology is flexible enough to also be used for applications such as variable fan drives and supercharger

drives which can improve the operating efficiency of internal combustion engines and yield further fuel economy benefit.

THE PRINCIPLES OF TRACTION DRIVE

The management of friction between moving metal surfaces through the use of fluid lubricant is at the heart of the field of engineering known as tribology.

In this field of work, engineers focus almost entirely on the task to minimise the levels of friction between moving surfaces.

Another branch of this field of engineering applies the same technical principles but uses them to *transmit* power through the lubricating medium in a process called 'traction drive'.

Torotrak have put these principles of traction drive into practical use by developing a variable drive device known as a 'variator'. The drive transmits torque, using specially developed traction fluid, between loaded rollers and discs (see *The contact patch*). This gives a simple and robust continuously variable transmission (CVT) that changes

ratio continuously, unlike a conventional transmission that changes its gear ratio in steps.

When configuring the variator, the development team adopted a 'full-toroidal' variator layout as this represented the most stable and simple geometry for practical application (figure 1).

Inside the variator are two pairs of discs. The space between each pair of discs forms a hollow doughnut shape or 'toroid'. Within each toroidal space, three rollers transmit drive from the outer engine-driven discs to the output discs located in the centre. The rollers transfer power between the input discs and the output discs via the traction fluid.

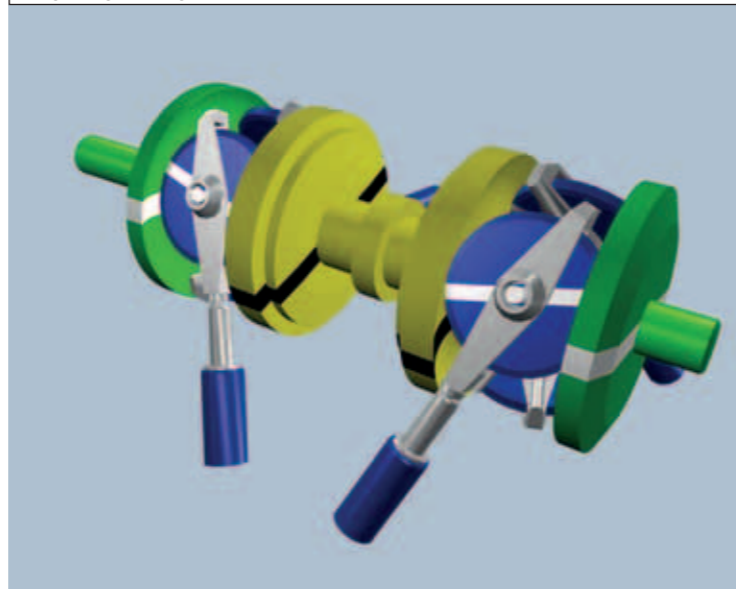
Each roller is attached to a hydraulic piston (or control rod). The pressure in the pistons can be increased or decreased to create a range of reaction torque within the variator (see *Variator at work*).

PRACTICAL RESULTS

For a vehicle manufacturer, the full-toroidal variator has two key advantages. First, it is inherently stable, and second, the device is torque-controlled rather than ratio-controlled. This means the torque at the output is directly proportional to the amount of force applied to the control rods. The ratios, and therefore the roller positions, effectively self-compensate to deliver the required torque. The end result is a traction drive transmission that can deliver 94% mechanical efficiency in terms of power in and power out.

In the continuously variable transmission drive, the input of

Figure 1. A typical 'full-toroidal variator' showing the relationship between the principal components: the discs and rollers



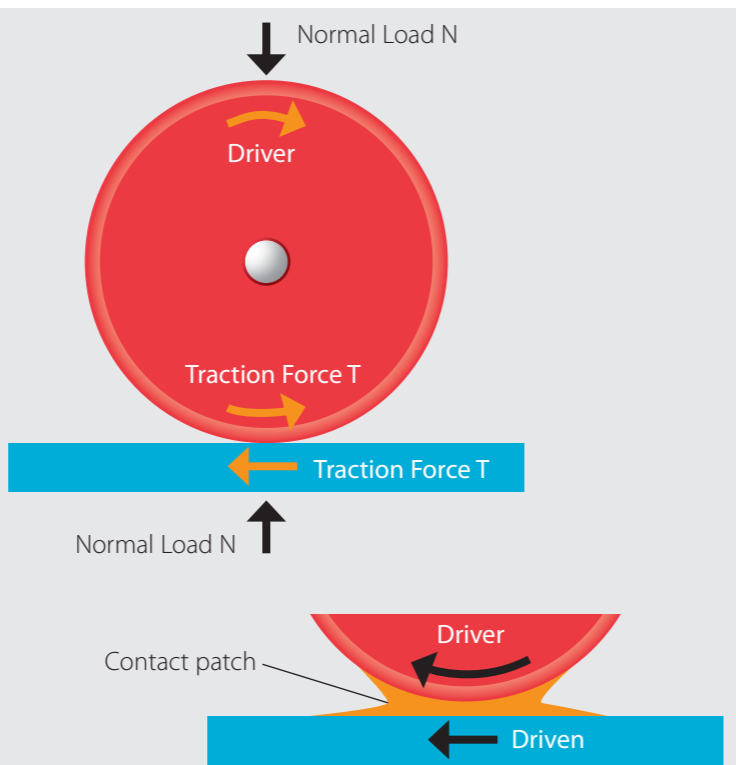
THE CONTACT PATCH

The heart of the traction drive transmission lies in the contact patch, a very small volume of lubricant fluid trapped between the two rolling metal surfaces that is able to transmit power from one of the rolling surfaces to the other. This fluid is kept in the contact by the relative movement of the two surfaces.

In traction drive, the power transmission characteristics are achieved through a high force that squeezes the rolling surfaces together. The rolling elements are not in direct contact but are separated by the now highly compressed, thin film of lubricant.

The traction performance of the lubricant is crucial to the efficiency of traction drive. Standard mineral oils can be used but durable and moisture-resistant lubricants known as cycloaliphatic-based fluids have been specifically designed for traction drives. These enable significant power to be transferred efficiently across a traction drive contact. For example, some 60 kW, or the power of a small family car, can be passed across a 20 mm, 2 x 1 micron contact patch, with a volume of only 0.00002 cc.

As well as providing efficient power transfer, traction fluids also lubricate and cool traction drive transmission components such as bearings, chains, epicyclic gear sets and clutch. Tests also indicate that today's traction fluids retain their required properties over the lifetime of the traction drive.



the variator is driven by a power source, such as an engine, and the output speed is determined by the position of the rollers in the toroid. This direct connection between input and output would be suitable for a continuous drive system such as a fan drive or, with the use of a clutch or other decoupling device, in a vehicle drive transmission.

The CVT can also be configured with an epicyclic gear train to give an infinitely variable transmission, which provides a smooth spread of ratio from forward to reverse. From a vehicle manufacturer's point of view, this is beneficial as it eliminates the need for a vehicle to have a clutch or torque converter to decouple the transmission from the engine before the vehicle can stop. This so-called 'geared neutral' condition also enables a seamless shuttling effect, sweeping the transmission from forwards to reverse, ideal for use in vehicles such as fork-lift trucks and wheeled loaders.

WHY USE TRACTION DRIVES?

A number of types of variable drive technology are used today, the main incumbents are hydrostatic drives and belt or chain continuously variable drives.

Hydrostatic drives make use of hydraulic pumps and motors and are typically found in agriculture, construction and industrial products. These drives have been

in use for at least 50 years, are durable and offer high torque and power. However, they are expensive and mechanically inefficient, making them unsuitable for use as the main transmission in road transport such as cars and trucks.

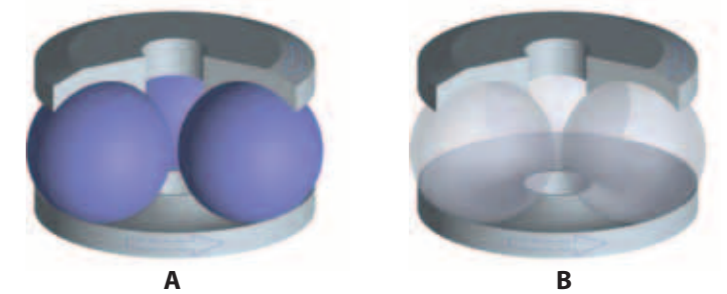
A number of car manufacturers offer belt or chain continuously variable transmissions, which comprise metallic belts running on a pair of conical drums. While reliable and well-established, having been developed over the last 30 years, these transmission drives are relatively expensive and difficult to package due to the spacing of the two conical drums. The systems are also limited in power and torque capacity and can't be scaled up for use in heavier vehicles such as trucks.

In contrast, the full-toroidal variable traction drive is mechanically efficient. A unique feature of traction drive is the way it maintains high levels of efficiency with scale. Unlike other forms of variable drive technology, it can be sized to work efficiently in the main drive transmissions of everything from lawn mowers to 40-tonne trucks.

Full-toroidal traction drive systems are already being used in a unique zero-turn ride-on lawn mower. Here, a novel steering system is linked to a pair of toroidal transmissions to allow the mower to turn through 360 degrees within its own length. The system is also soon to be available in a new range of tractor transmissions that offer

VARIATOR AT WORK

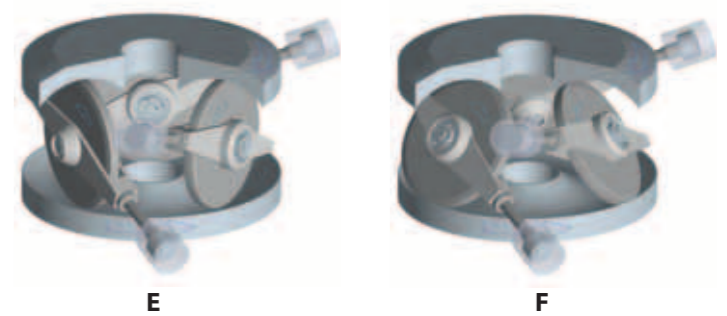
The full-toroidal geometry of the variator is based on a similar configuration to a conventional ball bearing arrangement, made up of three ball bearings running in corresponding deep grooves (see figures A and B). These grooved bearing surfaces form the hollow doughnut shape or 'toroid'.



Rather than ball bearings, the actual variator consists of three rollers, as if sliced from the ball-bearings (figures C and D).



Each roller is connected to a control rod, set at an angle to the rotational axis of the device (figures E and F).



Applying a force to these rods generates a torque (or turning force) through the variator, which accelerates the input or output and induces a ratio change as the rollers 'steer' across the toroidal bearing surface. This change of position has the effect of changing the ratio of the drive, as the rollers run on differing circumferential running tracks on the input and output toroidal surfaces.



Figure 2a: Torotrak's zero-turn ride-on lawn mower transmission is already in production in the US

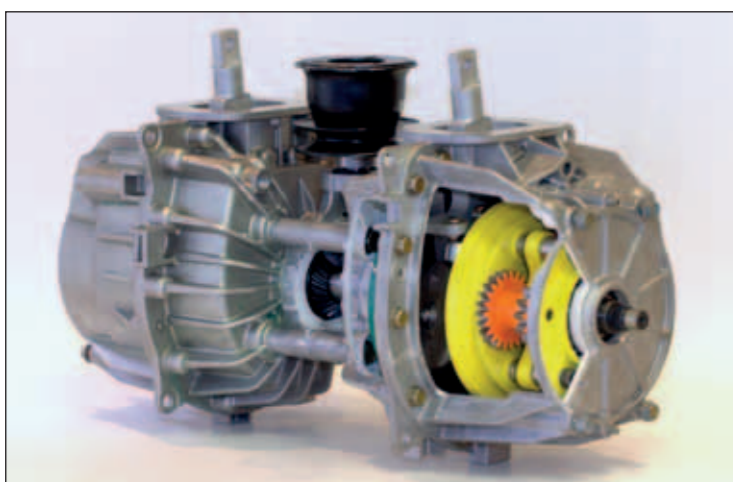


Figure 2b: A cutaway of the lawn mower's twin toroidal transmission

high levels of speed control, fuel savings and class-leading efficiency (figures 2a and 2b).

On a larger scale, main drive transmissions capable of handling 350 kW are currently under development for larger vehicles including trucks and buses.

The Torotrak engineering team is also developing very small variable traction drives for automotive engine auxiliaries such as air-conditioning compressors and superchargers. These drives could help the automotive industry reduce engine size without compromising performance and power.

HYBRID HOPES

A further potential use of traction drive is in the kinetic energy recovery systems (KERS) of mechanical hybrid vehicles. Here, the traction drive is being developed to work in conjunction with lightweight, high-speed flywheels to store and recover braking energy in a range of vehicles from small cars to buses. It could provide a cheaper and more energy efficient alternative to the conventional hybrid-electric power train.

The hybrid system comprises a flywheel connected via the traction drive variator to the base powertrain (see figure 3)

When a vehicle is slowing, kinetic energy is transferred through the traction drive variator and into the flywheel, maintaining the energy in its

kinetic state. To recover this energy, the power flow in the variator is reversed and the kinetic energy is released to the vehicle's road wheels. During this process energy remains in a kinetic state.

In contrast, during electrical regeneration, the kinetic energy is converted to electrical energy and then to chemical energy as it is stored in the vehicle battery pack; to recover the energy, this process is then reversed. Efficiency losses take place at each energy state change.

As a result, the purely mechanical flywheel configuration has much greater efficiency than the electrical systems, which spells good news for manufacturers striving to cut CO₂ emissions from buses and urban commercial vehicles. The first buses and commercial vehicles to have been developed with conventional hybrid-electric powertrains with regenerative braking are heavy and costly. In some cases, incorporating the powertrain can double the cost of the base vehicle.

However, a recent programme of work started with automotive technology developer Ricardo and coach and bus manufacturer Optare on a demonstrator bus as part of the *Flybus* project looks promising (figure 4). Mathematical modelling indicates that enough braking energy can be recovered to cut fuel use by more than 20% on a typical city route.

MAKING PLANS

Be it in a conventional transmission system delivering significant fuel savings or part of a hybrid system that can recover otherwise wasted energy, the traction drive will prove crucial to the challenges facing engineering communities. The drives are already in use in the highly cost-competitive lawn and garden market and are poised to penetrate the commercial vehicle market as a main drive transmission technology. The technology could also bring benefits to the construction and material handling markets, and in each case significant carbon dioxide savings could be made.

Small traction drives for superchargers and air-conditioning compressors will help to improve the efficiency of conventional internal

combustion engines as well as reduce carbon emissions. As well as having great potential in the kinetic energy recovery systems of mechanical hybrid vehicles, the technology could be used in electric vehicles, enabling electric motors to run at steady state conditions and reduce current draw. Already, two-speed (ratio) gearboxes are being used to enhance electric vehicle performance – imagine what can be done with an infinite number of ratios.

Further information: www.torotrak.com

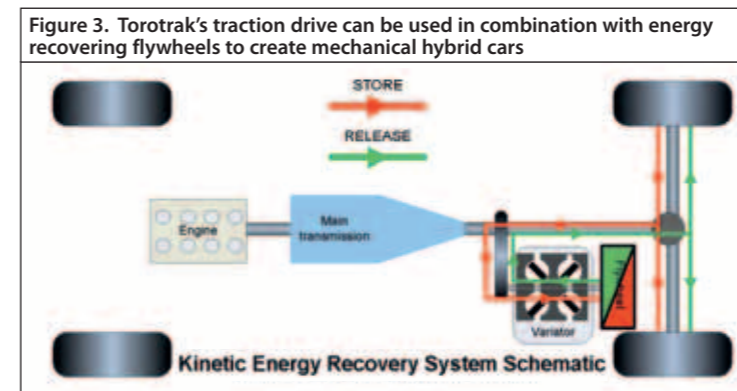


Figure 3: Torotrak's traction drive can be used in combination with energy recovering flywheels to create mechanical hybrid cars

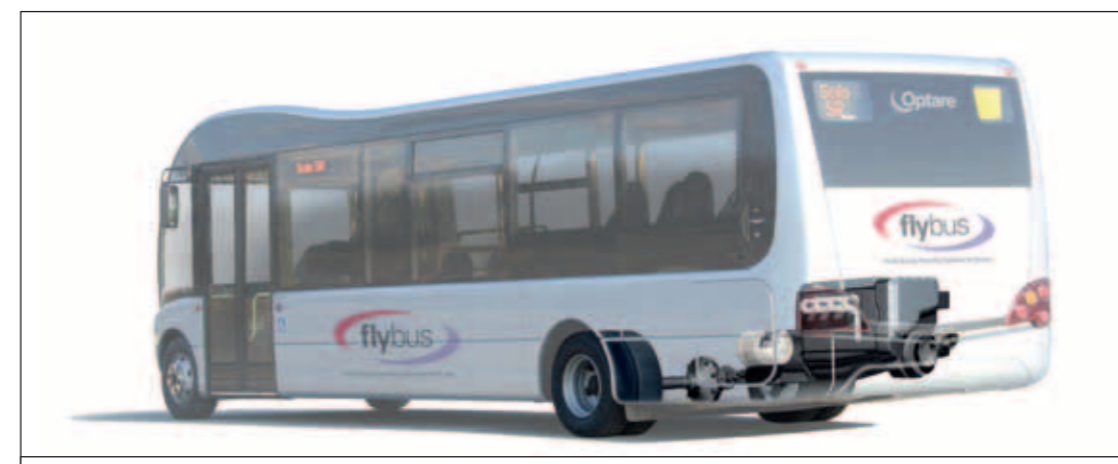


Figure 4: The Torotrak-led *Flybus* project aims to cut fuel costs and emissions. The *Flybus* consortium will use their CVT technology together with a high-speed composite flywheel for energy storage, known as 'Kinergy'

BIOGRAPHY – Dick Elsy

Dick Elsy is Chief Executive of Torotrak plc. He previously held a number of senior positions in the car industry and gained extensive experience in the process of innovation management and of the introduction of new technologies to market. Dick Elsy is a Fellow of the Institution of Mechanical Engineers and is also a trustee and director of Engineering UK.

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