More control, less clutter

Improving industrial electric vehicle responsiveness to an operator's command is often a matter of making different components in those vehicles more responsive to one another. For such tasks, **Curtis Instruments**' new enGage IV gauge/panel allows what the company describes as "powerful flexibility and advanced functionality."

Employing a dot-matrix display, users can select each display element and its location on the enGage IV gauge. Display options include a bar graph, numeric display, needle display, and a message center, all which can be custom configured. It accommodates four gauge functions plus additional on-off indicators, warning icons, and a clock.

The new instrumentation is built with solid-state electronics, void of moving parts, so there is nothing to break or wear out, and is protected to IP65 to effectively eliminate dust and moisture. Batteries are unnecessary since the system relies on non-volatile EEPROM (electronically erasable programmable read-only memory) to retain vital user information.

Manufactured under globally stringent requirements, the instrument boosts vehicle responsiveness via its communication abilities. By working in concert with a Curtis motor speed controller, enGage IV is always in touch with what the vehicle is doing or what it needs. Like other Curtis electric-vehicle products, enGage IV relies on industry-standard CAN communications. If operating a vehicle requires the brake on, the keyswitch in neutral, and an operator in the seat, the gauge can be programmed to send a signal to the controller: "Unless all these things happen, don't turn on the motor."

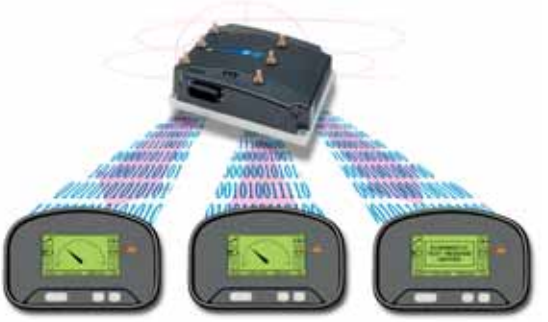
The product's flexibility allows it to be shipped as a blank unit to be customized by the users to their own specifications and application. OEMs that need more than one type of gauge can fulfill that need with just one enGage, allowing not only flexibility but simpler purchasing procedures and bulk-purchase savings.

The instrument, complete with integrated connector, snaps into the panel cutout without hardware. This feature contrasts with older-style gauges that require every measurement indicator to be accompanied by a hardware kit. Because the conventional hardware mounting kits of traditional gauges are also eliminated, the simplified production process reduces labor and inventory costs.

A number of components interface with the microprocessor-based enGage IV. Many are associated with sensors, like those that measure pressure and temperature. Although a number of functions can be incorporated into the panel, it is possible to program the instrument in such a way that all the readings are viewable simultaneously. A backlit LCD makes the contents visible in full sun, total darkness, and dim indoor conditions. Vehicle status, and especially warning signals to the operator, are easy to see and with high impact. Warnings can be displayed as LCD icons, LCD bar graphs, or bi-color front-panel LEDs.

In the four classes of electric vehicles, the first two classes—sit-down rider trucks and reach trucks—are candidates for this advanced instrumentation.

One particular strength of Curtis gauges is their connection to an integrated system of complementary platforms, linked by CAN communications. These offerings include vehicle-management systems, motor speed controllers, battery chargers, dc/dc converters, throttles, dc contactors, disconnect switches, alarms, and more, allowing customers to purchase a package of components that are essentially guaranteed to integrate smoothly.

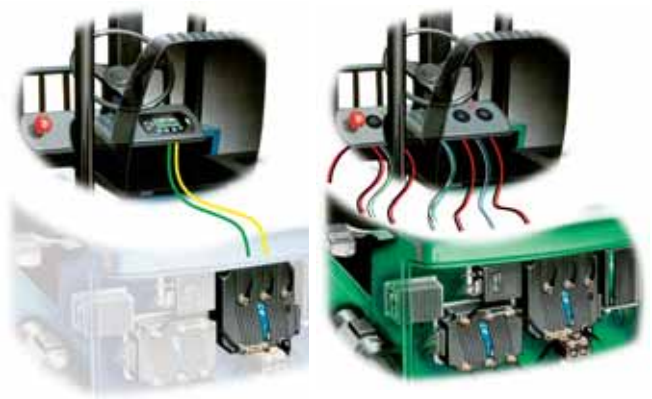


In this depiction of the data stream, Curtis Instruments' model 1238 motor controller transmits battery state-of-charge information to enGage IV via CAN bus (A, left), the vehicle operator pushes a front-panel button to initiate a CAN request to the 1238 for diagnostic information (B, middle), and the 1238 transmits pages of diagnostic history that the operator can scroll through using front-panel buttons (C, right).

Curtis motor speed controllers work in concert with the enGage IV for enhanced vehicle responsiveness and efficiency. The controllers can be tailored to communication in a variety of special applications.

Vehicle Control Language (VCL) software, written by Curtis, combines the power of a motor controller with the flexibility of a programmable logic controller to provide a highly adaptable motor speed drive. VCL commands are communicated via CAN and include I/O functions, feedback-loop blocks and software development tools. This combination enables "nearly limitless" customization. The CAN bus physically connects the vehicle system and allows a virtual network of I/O devices, while reducing expenses associated with wiring and maintenance. Distributed logic and I/O unify the vehicle's resources, making them available to the entire system.

VCL works with flash programmable memory to allow instant modifications at any development phase, from prototyping to final field testing. This particular feature allows for easy vehicle upgrades.

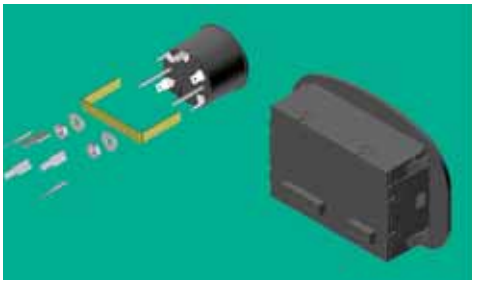


Distributed processing (left) allows simplified vehicle design and wiring by using the two-wire CAN bus to communicate all vehicle information between the enGage IV and model 1238 processing hubs, unlike the multitude of wires it took on older systems (right).

VCL also enables vehicle features such as traction, lift, steering, display, diagnostics, fault handling, and maintenance to be smoothly combined. Efficiencies made possible by VCL let design engineers eliminate or incorporate components, combine or share features, add functionality, and mix and match system resources.

For OEM designers, customization made possible by VCL is vital. They can develop a unique feel for their vehicles, creating functions based on their own intellectual property. VCL can govern the way a vehicle accelerates, turns, and brakes or how these functions are displayed to the operator in the form of messages, warning lights, measurements, and so forth.

Because VCL is easy to program, the OEM's design cycle can be shortened and made more responsive to changing market conditions. Through software code alone, it is now possible to provide improvements to a product that once required multiple hardware configurations. Curtis has developed a VCL "library" comprising blocks of software code that provide commonplace functions like steering and acceleration. Not having to create such functions from scratch promises to ease an OEM programmer's workload. These include input debouncing, proportional integrator differentiator loop, pulse width modulation, and CAN messaging.



The enGage IV is easier to install than previous systems, with snap-fit mounting eliminating various mounting hardware and integrated connectors simplifying wiring.

Curtis ac induction-motor speed controllers represent the next level in drive systems for materials-handling and industrial vehicles. The new ac controller family delivers an enhanced level of sophistication and adaptability for vehicle designers and end-users.

The controllers come in compact, fully sealed housings with advanced thermal management. These motor controllers take on an increasing number of responsibilities beyond operational basics. Functions like temperature, speed, and battery level are also monitored by motor controllers that seamlessly hand off the data to Curtis gauges.

The key to successful integration is distributed processing, which allows connection of key systems components to smart processing hubs. In the past, all items connected to the motor speed controller only, requiring many wires to run throughout the vehicle. Now, enGage IV is the second hub, allowing connection to either the panel or the controller, depending on which is shortest and most convenient. This feature reduces the vehicle's wiring network and simplifies installation and maximizes space.

This article was written for *SAE Off-Highway Engineering* by **Michael Miller**, Director of Product Management, Curtis Instruments.

MAN's engine for the future

The D20 common-rail series diesel engines from MAN are supplied with fuel by a common-rail direct-injection system from Bosch.

Engineers at **MAN** have worked hard to produce reliable and low-maintenance diesel engines with low fuel consumption and environmentally compatible emissions. New limits on exhaust-gas constituents and calls for higher payloads and more economical operation are nevertheless demanding new thinking and new concepts. At Bauma 2004, MAN presented a newly developed engine series that reaches new standards.

The new D20 common-rail engines with ratings from 228 to 316 kW (306 to 424 hp) are more efficient than their predecessors, more compact, significantly lighter, quieter, and lower in fuel consumption. The materials used in them and their design are the basis for reliable compliance with the limits set by the forthcoming Euro 4 and Euro 5 exhaust-gas standards. The in-line, six-cylinder engines in the D20 series—all of which have four-valve technology with overhead camshaft, exhaust-gas turbocharger, and intercooling—are supplied with fuel by a common-rail direct-injection system from **Bosch**. In taking this step, MAN now has common-rail fuel injection in the entire range of engines for its TGA heavy truck range.

The new D20 engines all have the same displacement of 10.5 L, and are more compact than their predecessors. The

The MAN TGA tippers are powered by six-cylinder, common-rail, fuel-injected engines.

higher specific outputs make them up to 5% more economical in operation and they have lower emissions figures too. Compared to the predecessor engine, the D2866, they also save up to 100 kg (220 lb) in mass that the operator can now use for payload.

Combustion pressures have been increased to more than 180 bar (2610 psi) to make ample torque curves and high speeds possible. The engines have been geared to the deployment criteria: they allow short-haul and construction-site vehicles to move off powerfully even at speeds just above idling, while in heavy long-haul transport they are extremely flexible and favor high road speeds at medium revs. A torque increase of up to 35% allows driving with few gearshifts—even at a moderate 1500 rpm the driver can demand full engine power; the maximum torque is available over a range from 1000 to 1400 rpm.

The designers of the D20 engine block used FEA to compute the maximum stresses, which allowed them to save material where it was not needed. For the first time in a commercial-vehicle engine the main bearing caps in the crankcase are cracked, which made it easier to design a very rigid and acoustically optimized crankcase. The full-length, one-piece cylinder head is a highly complex casting of special cast iron and houses all the components for the four-valve timing. An overhead camshaft reduces the number of moving parts, while roller rocker arms minimize internal frictional losses. The charge-air pipe is integrated in the cylinder head to save on screw connections and gaskets.

MAN is the first commercial-vehicle manufacturer to choose second-generation, common-rail technology from Bosch for the fuel-injection system. The main advantage of the common-rail injection system, which operates at system pressures up to 1600 bar (23 ksi), lies in the wide range of variation possible in the injection pressure and injection timing. High injection pressures at low engine speeds guarantee high power for moving off with low smoke emissions. Low pressures under partial load result in optimized NOx figures and low fuel consumption. At full load, high injection pressures permit high exhaust-gas recirculation rates and thus low diesel consumption.

MAN's engineers devoted much attention to eliminating sealing points. The reduction in the number of sealing points, sealing faces, and pipes inherent in the design reduces the risk of leaks. This went with extensive integration of attachments to minimize the number of sealing points for lubrication and cooling. The D2066 has 25% fewer components compared to the current D2866 generation.

The main development target for the D20 common-rail program was to increase both the reliability and the service life. The new engine is designed for a life of up to 1.5 million km (0.93 million mi) in long-distance operation without overhaul.

A great deal of attention was paid to maintenance in the development of the engines. TGA trucks with D2066 engines in long-haul service only have to visit the workshop for servicing at intervals of up to 120,000 km (75,000 mi). Regular maintenance amounts to checks of the valve clearance and the poly-V belt, which have to be carried out at every service. Critical sealing points in the engine have been largely eliminated and the oil and coolant supply optimized.

The D20 engines are featured in the MAN TGA heavy-duty truck range. Like other MAN construction-site vehicles the TGA trucks have been specially developed for comfortable and safe driving off-road and on building sites. Many have multiple driven axles or all-wheel drive. The all-wheel-drive vehicles have newly developed planetary axles with drum brakes. The new axle design uses helical gear profiles for quieter operation. MAN controls the inter-axle and transverse differential locks in a logically correct sequence using a rotary switch to avoid operating errors.

David Alexander

For safety and ease of use, MAN controls the inter-axle and transverse differential locks in a logically correct sequence using a rotary switch.

Club Car takes to the hills

The four-wheel-drive utility vehicle market has new competition with the launch of the Carryall 294 4x4 utility vehicle from **Club Car**, an **Ingersoll-Rand** company. According to Club Car, its exclusive IntelliTrak system delivers the industry's first fully automatic, on-demand four-wheel drive. The Carryall 294 continually senses driving conditions and automatically engages and disengages four-wheel drive without requiring the driver to stop and shift gears or lock differentials. Maximum vehicle speed is 25 mph (40 km/h).

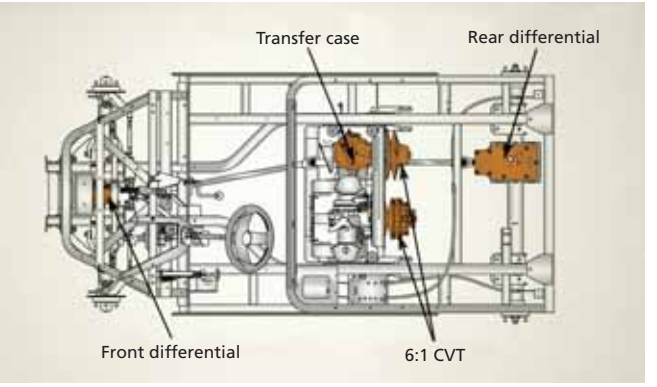
The Carryall 294 has a box-tube frame constructed of 6061 aircraft-quality aluminum, and comes with a choice of 800 or 1050 lb (365 or 475 kg) bed-load capacity. Suspension is independent double A-arm at the front and swing-arm at the rear, to provide 6 in (150 mm) of wheel travel at each corner with minimum camber change. Four-wheel, hydraulic disc brakes with **Wilwood** calipers are standard.

The vehicle is available with a choice of 20-hp (15-kW) powerplants; a 614-cm^3 **Honda** gasoline engine, or a 719-cm^3 **Kubota** liquid-cooled diesel engine. The latter application marks the first Club Car vehicle available with a diesel engine, leveraging the experience of **Bobcat**, another Ingersoll-Rand company. The transmission is a continuously variable unit from Team Industries.

The IntelliTrak four-wheel-drive system does not require separate controls for 4x4 engagement, front/rear differential locks, or high/low range. A single lever engages forward or reverse drive. The fully mechanical system automatically transfers power to the wheel or wheels where traction is needed. On dry, firm ground, 100% of the engine torque is sent to the rear wheels. The rear differential automatically locks when it detects wheel spin, and activation takes place within one quarter of a tire revolution.

The mechanism inside the transfer case monitors the relative speed of the front and rear wheels mechanically through the propshafts, and if it detects the rear wheels spinning faster than the front, then drive to the front wheels is engaged. The differential at the front will also automatically lock when it detects wheel spin. The combination of the front and rear differentials with the transfer case all working mechanically means that the IntelliTrak system can deliver all the engine torque to any or all of the wheels that have traction, and not rely on any electronic sensors for operation.

The Carryall 294 4x4 utility vehicle from Club Car features the IntelliTrak system for fully automatic, on-demand four-wheel drive.



The Club Car IntelliTrak system will automatically transfer 100% of the engine torque to a single wheel if the other three have no traction.

Other benefits of the IntelliTrak system include elimination of torque feedback through the steering wheel, and reduced tire wear and turf damage because the wheels do not spin when traction is lost.

David Alexander

Torotrak goes off highway

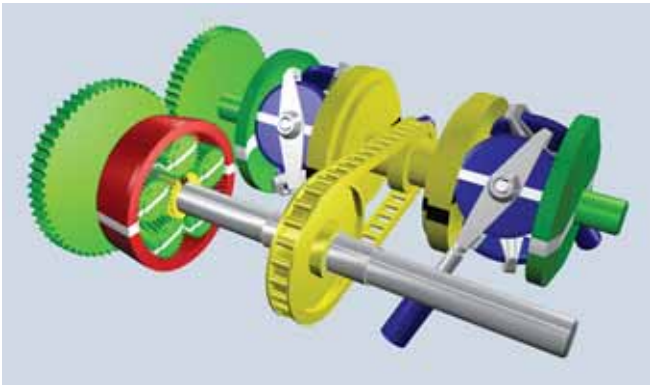
Torotrak may see the first series production application of its toroidal IVT (Infinitely Variable Transmission) on an off-highway vehicle next year. An off-highway application is potentially a significant step forward for Torotrak and could bring a new approach to transmission technology in the sector.

More specific details remain commercially confidential during the prototype trial program, but Chief Executive Dick Elsy says that Torotrak has "found the off-highway industry—already into variable drive systems—hungry for new technology such as ours, which is not only able to offer cost savings but also provide increased efficiency, together with enhanced operator comfort."

The Torotrak transmission's contributions for off-highway applications include "a fully scaleable technology with no torque limitation" and an ability to "shuttle" a vehicle (such as a forklift) backward and forward without having to select neutral and change gears, much like a hydrostatic transmission but with greater efficiency, according to Elsy.

"We will be able to supply a cartridge, or module, to tractor manufacturers that can be simply slotted into the housing for a regular transmission," he said. "It would be a higher efficiency, lower-cost system and could be used on the most powerful off-highway vehicles down to those with 100 kW or 'domestic' tractors down to perhaps 25 kW. Any farmer knows that you really cannot have torque gaps when plowing; wheel torque must be maintained to avoid becoming stuck and to maintain efficiency. Because it is controlled by torque, Torotrak's IVT meets these criteria."

Unlike conventional transmissions, Torotrak's IVT has a variator that provides the ratio range. It comprises a set of discs and rollers with power transmitted from one disc to another across the rollers via fluid. **KOYO** and **Shell** are among companies closely involved with development. Torotrak is also working with **EQUOS**, the research and development subsidiary of transmission designer and manufacturer, **AISIN**.



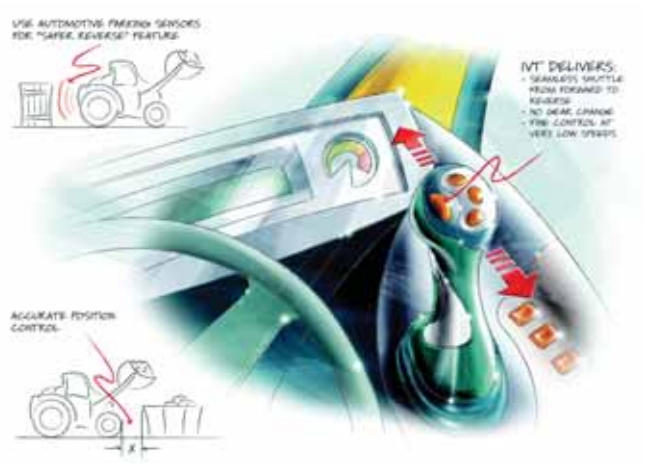
A simplified illustration of Torotrak's Infinitely Variable Transmission (IVT) layshaft layout.

The Torotrak variator "cartridge" can be installed in a construction/agricultural vehicle in place of a hydrostatic unit.

The system is considered a "full toroidal" variator, which allows control of the complete powertrain, enabling optimization of the efficiency of the engine. Unlike a regular ratio-controlled system, Torotrak's IVT is torque-controlled, making it particularly suitable for off-highway vehicles, from tractors and backhoe loaders to SUVs. The system's software determines the torque required at the road wheels and "requests" torque from the transmission rather than setting a specific ratio. The engine can then be used to deliver the power at its most efficient operating point.

In the center of the system as illustrated in the figure is the fixed ratio chain; flanking that in yellow are output discs; next come the rollers (blue) and then the variator input discs (green) connected to the engine. At extreme left is the input gearset connected to the engine, driving the planet carrier (green) of an epicyclic. The sun gear (yellow) of the epicyclic is connected to the output of the variator and the annulus (red) of the epicyclic is connected to the road wheels.

The variator is the heart of the IVT and is the means by which the transmission can deliver an infinite range of ratios. 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 there are three rollers which transmit drive from the outer, engine driven, discs (green) to the output discs (yellow) located in the center. Each roller is attached to a hydraulic piston. The pressure in the pistons can be increased or decreased to create a range of reaction torque within the variator. In the Torotrak variator, the rollers do not actually touch the discs but are separated by special a "traction fluid;" there is no metal-to-metal contact.



A potential application of the Torotrak IVT in the cab of a construction/agricultural vehicle and an indication of its potential applications.

Rolling the edge of the roller against the surface of the discs traps a microscopic oil film between them. The special long-chain molecules used in the traction fluid interlock with each other when the fluid is compressed, becoming highly viscous.

Under pressure, the oil resists the tendency to slide and transmits the power. The use of an epicyclic gearset allows the engine to be connected to the wheels when the vehicle is stationary, therefore, there is no requirement for a starting device.

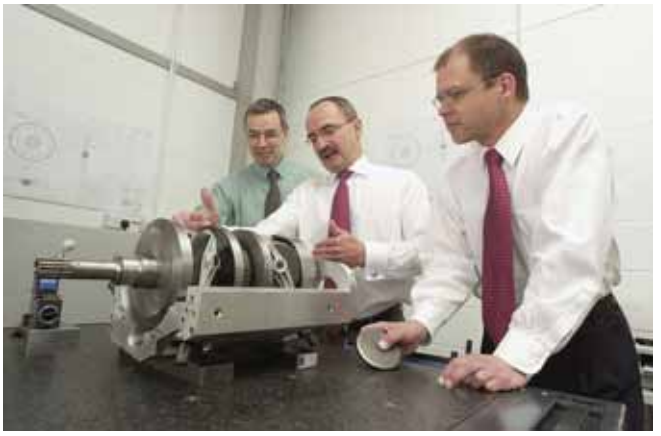
The IVT has no starting clutch or torque converter. It does not need a starting device because it uses an epicyclic gearset "in a parallel shunt arrangement," which enables the engine to be connected to the wheels even when the vehicle is stationary. Torotrak terms this condition "geared neutral."

Although developed initially for on-road vehicles to reduce fuel consumption (benefits of around 10-20% are typical, claims the company) and consequently cut emissions, Torotrak's IVT off-highway potential is now regarded by the company as "very significant." Elsy, who was formerly Engineering Director of **Jaguar** Cars, has also held senior positions with **Land Rover**. He was Project Director for the Land Rover Freelander 4x4 SUV.

The Torotrak IVT has what the company claims is a "unique" hill descent control that operates purely via the transmission and works whether the vehicle is traveling forward or backward, even on a 30% gradient.

"Suppliers and OEMs have been very surprised that this can be done just by the transmission, with no help from the brakes," said Elsy. "We can shuttle forward to reverse without changing the rotational direction of the variator, the operator using a joystick or buttons, for example. There is no clutch actuation so no wearing parts. Conventional transmissions with wet clutches tend to be abused when used for constant forwards to reverse tasks, particularly in the equipment hire world, which means potentially costly mechanical failures and downtime. An IVT will not be damaged even by brutal forwards to reverse treatment—and it will make the maneuver quickly and efficiently."

Its capabilities include speed control (cruise), position control for accurate loading, and a park distance control-linked sensor, which automatically stops the vehicle. Elsy puts emphasis on the IVT's ease of operation, which will help reduce driver fatigue—and frustration.



Dick Elsy, center, believes the off-highway potential for Torotrak's IVT is "very significant."

"A driver arriving at a work site in an air-conditioned, automatic-transmission equipped, comfortable car will not work efficiently or happily in an off-highway vehicle that has a transmission system that is difficult to manage and tiresome to operate," he said. "The IVT is a refined, easy-to-use system."

To effectively manage the IVT's capabilities, Torotrak developed software called TORC (Total Off-Road Control), the key features of which are controlled from a cabin panel, marked simply: Speed control; Position control; Creep control; Hill hold; and Anti-rollback. The system is aimed at SUVs but could be extrapolated to total off-highway vehicles.

There is no disputing that Torotrak's IVT has been a long time coming. Work started on the system 16 years ago, with only seven employees. At that time Torotrak was part of the **British Technology Group**. A member of that pioneering team, Chris Greenwood, is still with the company as its Technology Director. In 1999, Torotrak became a public company in its own right and its research and development expanded rapidly. It now has almost 100 staff, 80 of them engineers.

A major part of the advances made recently has been to improve the packaging and potential production cost of the IVT. Torotrak is the developer of the system, not its manufacturer. That step would be in the hands of established Tier 1 transmission suppliers.

In a configuration suitable for SUV and large sedan applications, the IVT system would be similar in cost, overall weight, and dimensions to current compact six-speed automatic transmissions. "A reduction in roller diameter of 25% more than halves the mass and inertia for the variator compared to early versions of the IVT," said Les Robinson, Torotrak Advanced Design Engineer. He added that the system "now uses compact levers instead of in-line pistons to operate the rollers."

In conventional gearbox terms, the IVT provides the equivalent of a 10-speed ratio spread but a high overdrive and geared neutral means the actual spread is infinite. With an IVT fitted to a 5.4-L **Ford** Expedition test bed vehicle, 75 mph (120 km/h) equates to about 1000 rpm on a level surface. Because of the added heat generated by this downsizing, the IVT's rollers are shrouded to enclose an oil film acting as a coolant without affecting the disc fluid.

Elsy sees the IVT integrating with other technologies, including parallel hybrid vehicles.

Stuart Birch

The bridge between manufacturing and engineering

According to **Polyplan Technologies**, most heavy-equipment manufacturers spend 15-20% of their budget in the pure design phase of a program, but decisions made then will impact 70-80% of the manufacturer's profitability. Collaborative Manufacturing Process Management (MPM) software from Polyplan addresses planning and simulation issues early in the design process by allowing manufacturing engineers to work in a 3-D engineering workbench environment to design processes and control the impact of engineering changes on manufacturing's time, cost, and quality targets.

Bombardier Transportation is using Manufacturing Process Management from Polyplan to improve collaboration with engineering early in the product life cycle.

"For **Bombardier**, MPM is allowing our manufacturing process planners to fully collaborate with engineering early in the product life cycle," said Gaston Hebert, Executive Vice President and Chief Engineer at Bombardier Transportation. "MPM's ability to predict the impact of changes and perform what-if scenarios makes this early collaboration all the more powerful."

MPM bridges the gaps between engineering and manufacturing by combining the information needed from both sides into a single workbench. This feature allows the transformation of engineering requirements focused on form/fit/function into manufacturing information that is focused on time/cost/quality.

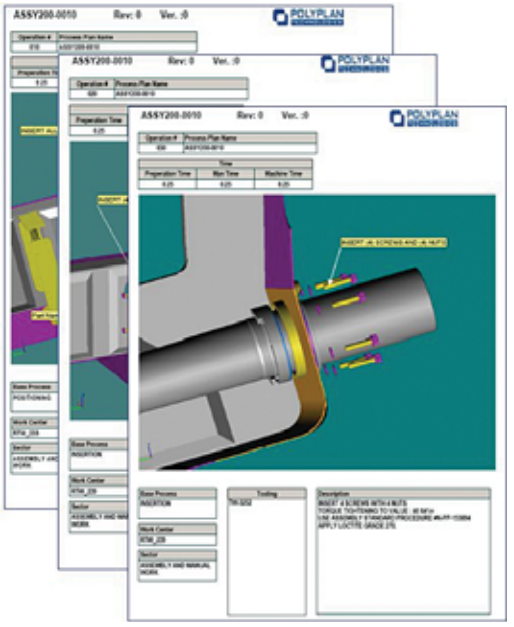
One of the most common causes of new product delays and project cost overruns is the lack of actual manufacturability of the initial design. MPM allows manufacturers to make early and constant assessment and control of manufacturability, reducing downstream changes and ultimately reducing scrap and rework costs.

Manufacturing engineers at Bombardier drag-and-drop components from engineering 3-D mockups into process plans and create manufacturing assemblies from which they create and maintain exploded assembly views that are simple to understand and maintain. The system allows the automatic generation and update of visual instruction packages, reducing the cost to produce work instructions, and monitoring time and cost consumption as process plans are built.

Feedback can be given in a systematic manner through redlining and annotation of 3-D data, permitting manufacturing to respond to engineering very quickly and help reduce product engineering costs. But more importantly, given early access to engineering information, manufacturing engineers are able to concurrently develop process plans while the engineering is on-going, giving a head start to the planning process and reducing time to quality/market.

A systematic approach also means providing search and reuse capabilities so that manufacturing planners don't reinvent processes they had previously designed. Manufacturing cost/time planning permits a clear view of the impact of one design vs. another, giving manufacturing facts to discuss with engineering.

Continuous access to product definition and change events from engineering is needed to ensure that work done is always linked to the right engineering revision and that revision control now extends to the process planning arena. MPM provides control over the impact of changes by linking to the engineering information so that when changes occur, manufacturing engineers are notified electronically; they can then assess immediately the manufacturing cost/time impact caused by specific changes, and also evaluate the effect this change will have on the ability to make or assemble other parts or assemblies.



Manufacturing Process Management software links product development and manufacturing engineering.

This article was written for *SAE Off-Highway Engineering* by **Robert Beauchemin**, President and CEO of Polyplan Technologies.

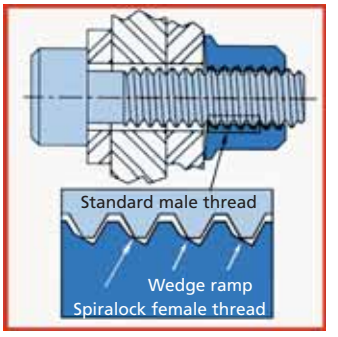
Innovative fastener thread

Imagine harnessing the heat energy of a blast furnace while keeping the vibrational equivalent of a jet fighter's acceleration in check. This scenario is essentially what diesel engine designers worldwide must do to keep diesel-powered equipment productive and on schedule for thousands of operational hours. Yet for engine performance and reliability, as well as for meeting emissions standards, joint integrity must be maintained in critical areas such as turbocharger mounts, exhaust manifold joints, and attachments, where extreme heat and vibration can weaken and shake loose standard fasteners.

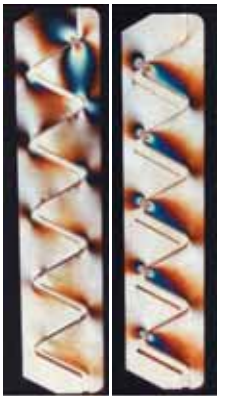
Traditional methods of preventing joint loosening such as nylon rings, adhesives, and deformed threads, simply don't measure up in the high-temperature, high-vibration diesel engine environment.

"At high engine operating temperatures, nylon-coated fasteners will melt or burn, and adhesives aren't effective either," said Sam Sutthiwan, a designer for **Caterpillar**, which designs and manufactures not only construction and mining equipment, but diesel and natural gas engines as well as industrial gas turbines. "Split washers and standard thread-type fasteners tend to yield over repeated cycles of heating and cooling and require lock tabs to prevent them from losing their fastening ability. Prevailing torque fasteners can present assembly and service challenges, especially with stainless steel."

Through the geometry and physics of the thread itself, **Spiralock** offers an alternative thread form designed to address fastener loosening and stripping under high temperature and vibration. Instead of the traditional 60° "vee" thread design, the Spiralock thread form is a 30° "wedge" ramp cut at the root of the female thread. Under clamp load, the crests of the threads on any standard male bolt are drawn tightly against the wedge ramp. Since the Spiralock thread form is a mechanical solution to the loosening problem, it's more tolerant of cyclic temperature changes than 60° threads using nylon or adhesives. It allows for both thermal expansion and contraction without slippage.



Spiralock's unique 30° wedge ramp female thread securely connects standard male thread forms.



This photoelastic comparison illustrates how the load carried by each engaged thread is more uniform with a Spiralock thread (right) compared to a conventional one.

The 30° wedge ramp not only eliminates the sideways motion that causes vibrational loosening, but also distributes the threaded joint's load throughout all engaged threads, a claim supported by a research study conducted by the **Massachusetts Institute of Technology**.

This article was written for *SAE Off-Highway Engineering* by **Jim Gillis**, Vice President of Marketing and Sales for Spiralock Corp.