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Executive Viewpoints

Dynamic cylinder deactivation for diesels

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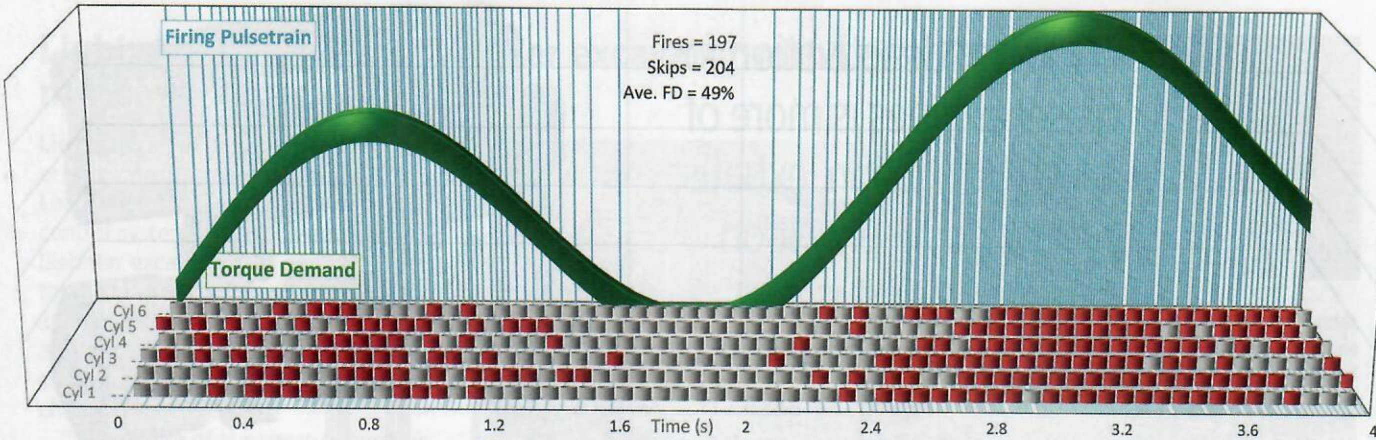
Cummins, Tula test 'dynamic' cylinder deactivation



Actual depiction of what Tula's DSF algorithm would command to match the torque curve over the 4-second period in the image.

Tula's Dynamic Skip Fire technology already used in light-duty gasoline engines shows potential in heavy-duty diesels to significantly reduce NOx emissions.

by Ryan Gehm

Tula Technology has supplied the control software for "dynamic" cylinder deactivation in gasoline engines since 2018, launching in **General Motors'** 5.3- and 6.2-L units powering the **Chevrolet** Silverado and **GMC** Sierra pickup trucks. Compared to the common two-mode implementation in engines, where either all of the cylinders are firing or a fixed number of cylinders are deactivated, Tula's Dynamic Skip Fire (DSF) makes all of the cylinders selectively "deactivateable," according to Scott Bailey, president and CEO of Tula Technology.

Seventeen steady-state patterns are available in the GM gasoline V8s, but the technology continuously operates whether in a "pattern" or not. Cylinder-deactivation fuel-economy gains in gasoline engines can be doubled with dynamic deactivation, Bailey said. In the case of the Silverado's V8, that's an up-to-15% improvement in fuel consumption compared to about 5-7% with two-mode deactivation.

Now, the Silicon Valley-based tech company is turning its attention to diesel engines for commercial-vehicle applications, partnering with **Cummins** to demonstrate diesel Dynamic Skip Fire (dDSF) software on a Cummins X15 Efficiency Series inline six-cylinder. The joint development team began work in early 2019 to integrate dDSF control algorithms to command combustion or deactivation on a cylinder-event basis.

Adapting Dynamic Skip Fire from light-duty gasoline engines to heavy-duty diesels did not present many technical challenges that have not already been solved, John Fuerst, senior VP of engineering at Tula Technology, told *TOHE*. "The challenge is not so much hardware, it's a software and calibration exercise that an OEM needs to go through," he said. "It takes an engine development cycle to make it all happen. It's a matter of going through the work of integrating and implementing."

Deactivation hardware has been in production for decades, but there is a higher durability requirement for deactivation devices for DSF, Fuerst explained, because the system is continuously looking to deactivate or reactivate. Several companies produce the required hardware, including **GM Components Holdings**, **Eaton**, **Schaeffler**, **Aisin**, and **Jacobs Vehicle Systems** for heavy-duty application. Jacobs, which is Tula's development partner for dDSF, already has the hardware designed, validated and "running on rigs."

TULA TECHNOLOGY

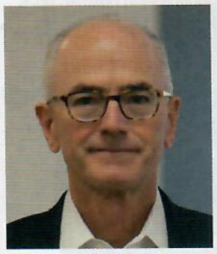
Exhaust temps up, NOx emissions down

Results of the joint development project have been extremely encouraging — not so much for the typical fuel-consumption benefits that result from reduced pumping losses, but rather for significant NOx reductions that could prove helpful in meeting the stringent low-load cycle being proposed by the **California Air Resources Board** (CARB) for model year 2024 heavy-duty trucks — as well as for tighter emissions-reduction regulations pending in other world regions.

In a joint paper for the 2020 Vienna Motor Symposium, Cummins and Tula researchers detailed modeling scenarios that showed NOx reductions of 66% while also improving fuel efficiency by 3.7% or more. "Cylinder deactivation for diesel engines is more of a NOx-reduction, exhaust-temperature-elevation strategy than it is a pumping-loss strategy," Fuerst said. "So there's a fundamental difference, even though the mechanization and the Tula Dynamic Skip Fire concept are really quite the same [for diesel and gasoline engines]."

The reduction of tailpipe NOx is achieved primarily by optimized exhaust temperature control, resulting in "dramatically improved" conversion efficiency of the aftertreatment system. "Because diesels are essentially unthrottled, the opportunity to gain fuel consumption

Cummins, Tula test 'dynamic' cylinder deactivation



John Fuerst, SVP of engineering at Tula Technology.

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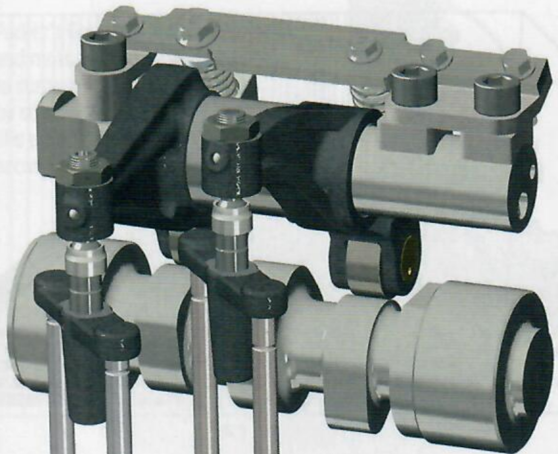

Jacobs Vehicle Systems is Tula's development partner for diesel Dynamic Skip Fire, providing proven cylinder-deactivation hardware that's already running on rigs.

by eliminating throttling is limited to 2-5%," Fuerst explained. "But interestingly, because you're not throttled to begin with, when you deactivate diesel cylinders you're still injecting the same amount of fuel to maintain torque delivery. What you end up doing is significantly reducing the air-fuel ratio in the combusting cylinders."

Instead of running a six-cylinder engine at a 75:1 air-fuel ratio, for example, it could be 40:1 or 30:1 when cylinders are deactivated, he said. Reducing the air-fuel ratio this drastically markedly cuts the airflow through the engine, which in turn significantly elevates the exhaust temperature. The Vienna paper indicates an exhaust-temperature increase in the range of 50 to 90°C by employing dDSF, which improves the conversion efficiency in the SCR (selective catalytic reduction) catalyst by ensuring the threshold for SCR light-off is met, at about 200°C. Fuerst noted that other engine simulations Tula has conducted have shown potential for even greater temperature elevations, as much as 200°C higher.

Many diesels operating under low load only generate exhaust temperatures in the range of 150-170°C, said Fuerst. "That's why the 50 to 90°C increase can be critical. We found it opened up significant swaths of the test cycle and the real-world operating cycle to the opportunity to be at or above the 200-degree SCR conversion threshold," he said. "The temperature elevation is really where the money is in terms of why companies want to do this."

Beyond the direct fuel-consumption benefit with dDSF, there's potential secondary fuel savings, according to Fuerst. If cylinder deactivation isn't used, other strategies will be needed to reduce NOx emissions, such as post-injection in the cylinders to increase exhaust temperature, employing a seventh burner to ensure the SCR catalyst stays active, or electrical heating that also requires diesel fuel for generation. Carbon dioxide reduction in the double digits is possible if the fuel saved by not employing such strategies is considered, he claimed.

"We will continue to innovate the diesel engine system to make it lighter, more reliable, powerful and fuel-efficient, and we are encouraged by the progress demonstrated in this collaboration and what it could mean for future diesel technology," said Lisa Farrell, director of advanced system integration, Cummins Inc.

Cummins and Tula plan to continue their collaboration by conducting a full system optimization and working to minimize cylinder deactivation-generated NVH in commercial-vehicle applications. On-vehicle testing also will occur. A **Freightliner** Cascadia demonstration vehicle will be shared with industry partners later in 2020, Bailey said. Tula holds more than 140 patents and has another 120 patents pending. ■

Graphic shows a fire/skip pattern for a 6-cylinder diesel engine. Red dots are fires and grey dots are skips that would result from a torque demand as shown by the blue curve.

Cummins' X15 Efficiency Series 6-cylinder diesel engine enhanced with Tula's dDSF control algorithms for cylinder deactivation.

CLOCKWISE FROM TOP RIGHT: JACOBS VEHICLE SYSTEMS, CUMMINS, TULA TECHNOLOGY