automotive testing expo 2006 north america EXHIBITOR

Diesel engine development

Global emission regulations for diesel-powered on- and off-road equipment present engine manufacturers with a dual challenge: First is the requirements for testing and evaluation of new components and new engine designs that will place unprecedented demands on the industry's emissions testing facilities. Second is the extremely low levels of particulate emissions that will have to be detected and measured – something that is well beyond the capabilities of many automotive test facilities in use today.

Both of these challenges have to be overcome in time to meet regulatory mandates scheduled for implementation in the 2007 to 2010 time frame.

Today, most of the industry's particulate material (PM) testing is done using a constant volume sampling (CVS) system, which is also known as a full-flow dilution tunnel. In simple terms, a CVS combines all of the exhaust gas from the engine being tested with a measured amount of clean, temperature-controlled dilution air to achieve a constant volume flow through the device.

After an appropriate mixing distance, a portion of this flow is extracted for analysis of its particulate content. The various testing protocols mandated by such agencies as the US Environmental Protection Agency (EPA) specify a very narrow range of temperatures at the filter face, which only further complicates the entire process.

There are several limitations to this approach to PM testing. First, a CVS system is large, complex and relatively inflexible. The system of fans, heat exchangers, filters and controls that are required to produce a closely controlled diluting air stream maintained at the desired temperature and humidity is relatively slow to respond to changes in the exhaust gas stream.

Second, CVS tunnels tend to be quite expensive. A typical installation able to handle engines of up to 600bhp has a 457 to 610mm diameter and length between 6 and 7m. The system also includes sophisticated dilution air scrubbers, dilution air temperature conditioners, heat exchangers that help maintain uniform blower inlet temperatures and a constant flow blower.

BG-3 particulate, partial flow, sampling system that provides high levels of accurate technical output

The third limitation is that because the CVS has to handle all of the exhaust gas produced by an engine, each system has an upper limit on the size of engine it can handle. Theoretically, there is no lower limit, but that is not the case in practice. As the exhaust stream becomes a smaller portion of the total flow, calibration issues begin to restrict a CVS tunnel's usefulness.

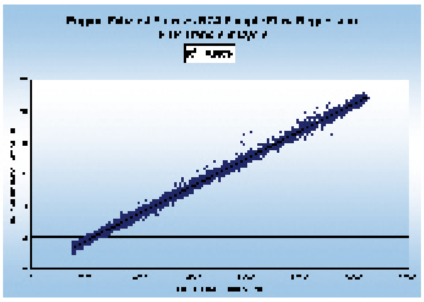
The fourth factor is that for 2007 and Tier IV engine development certification, it is frequently desirable to measure the engine-out particulate matter concentration simultaneously with diesel particulate filter (DPF)-out measurements during the transient cycle. This is a process that is not possible with a CVS system.

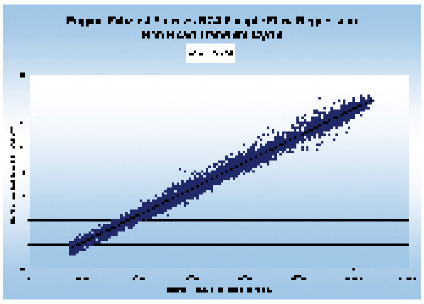
Assuming an engine developer is willing to run tests alternating between bypassing the DPF and running flow through the trap, the higher particulate matter levels obtained during the engine out test condition will contaminate the CVS system. The tunnel will then have to be re-equilibrated by running high-temperature clean exhaust through it.

Even if that is done, however, the very low Tier IV or 2007 results can be biased by desorbed volatile organics from previously deposited particulates on the tunnel walls. Use of a PM 2.5 micron impactor or hatted probe to remove large solid PM for 40CFR Part 1065 compliance will not prevent this.

Finally, it is very difficult to capture and measure transient events during engine development with a CVS because of the physical distance between the exhaust gas input and sampling locations, which may be 4.6 to 6m apart. In one test protocol, for example, the engine is strongly accelerated while the load is simultaneously increased, resulting in a 700 percent change in the exhaust output in only two seconds.

In theory, a transient partial flow sampling system (TPFSS) has almost none of the limitations of a CVS. It can be compact, responsive, flexible and – compared to a CVS – inexpensive. Further more, steady-state PFSS technology was used in the automotive industry in the 1980s, and has been widely applied in the





The above two graphs illustrate engine exhaust flow measurements against a sample flow regression

diesel industry to perform steady-state testing and certification of non-road engines. However, the application of the technology to transient on-highway testing was very limited due to the systems' inability to accurately follow exhaust mass flow excursions and extract a sample mass flow proportional to the exhaust mass flow.

Based on a series of ground-breaking TPFSS developments by a Caterpillar Engine Systems Testing and Solutions (EST&S) team, working with engineers from Sierra Instruments, the Sierra BG-3 TPFSS now appears to be at least part of the answer for PM testing for Tier IV and 2007 compliance.

Instead of using all of the exhaust gas from an engine, a TPFSS uses a probe inserted directly into the exhaust stream to extract a sample for testing. This sample is then mixed with an appropriate amount of clean, temperature-controlled, diluting air to produce a test stream that meets protocol requirements.

The major challenge of a TPFSS has always been modulating the dilution flow to compensate for changes in the exhaust stream to keep the test sample at a constant proportionality. The EST&S team reasoned that since the inputs of air and fuel to the engine determine the amount of exhaust produced, monitoring those two inputs would provide a reliable way to generate the control signals required to modulate the dilution flow. It was later found that monitoring engine combustion air mass flow alone provided results virtually identical to the air and fuel approach.

In practice, the BG-3 system works exactly as predicted and provides a very rapid update rate in the order of 80Hz. To put that in perspective, the BG-3's update rate, fast-response dilution air control valve, and very low pneumatic capacitance permits it to handle a 10 times change in exhaust output in less than a time frame of 300 milliseconds as measured at the sample probe, which is about 10 times faster than the rate of change the engine actually can produce. With this response capability, the 700 percent change in two seconds experienced during the test protocol described above presents no challenge at all to the BG-3 system.

Another advantage of the TPFSS approach is that it accurately mimics the growth of particulates in the atmosphere. In a CVS system, particulates tend to impinge on the tunnel walls where they accumulate and eventually break free. These particles, and the volatile organic compounds they release, become artifacts of the test, which must be accounted for to make the test correspond to observed reality. Since the TPFSS has much less surface for these particles to collect on, this effect is minimized.

As the testing systems needed to meet Tier IV regulations and beyond necessarily grow more sensitive, eliminating artifacts of the test will become increasingly crucial. The BG-3 provides a more technically accurate output, and one that is, in general, more precise and repeatable.

In basic terms, accuracy means the instrument is telling the truth about what is happening, while the repeatability means only that it is telling the same story, regardless of whether or not that story is true. Ideally, an instrument will be both accurate and repeatable; compared to a CVS, the BG-3 TPFSS is just that.

As diesel engine builders struggle to meet Tier IV emission requirements, and the even more stringent regulations that will follow, the ability to test and evaluate new components and new designs with a high degree of confidence in the results will become increasingly important. Moreover, as the demand for testing and validation services grows over the next few years, the cost of providing the necessary facilities will grow as well.

TPFSS technology provides solutions to both challenges. By producing results that closely correspond to real-world observations, the TPFSS testing delivers dependable validation of design alternatives, with a minimum number of repetitions.

This will not only reduce development time, it will also minimize cost. Since a TPFSS system is less expensive to install than a CVS tunnel, while providing the flexibility to test virtually any engine regardless of output, tomorrow's testing facilities using this technology should be far more cost efficient.

The TPFSS technology matters a great deal, as it offers industry a solution to the dual challenges presented by compliance with Tier IV emission regulations and those that will follow. TPFSS will permit new test capacity to be put on-line at reduced cost, and will simultaneously improve the accuracy and reliability of the tests conducted using it. That is precisely why TPFSS represents the future for diesel engines manufacturers.

FURTHER INFORMATION

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