Particulate partial flow sampling

The sampling method of the Sierra Instruments Model BG-3 sets the standard for engine particulate emissions measurement protocols of the future

SIERRA INSTRUMENTS

■ In a study at West Virginia University, evidence showed that the Sierra Model BG-3 partial-flow system is equivalent to full-flow CVS. At the August 2008 DEER conference, the university's Dr Ben Shade presented a paper evaluating the Model BG-3 against a 40 CFR Part 1065-compliant CVS system over a series of non-road transient cycle (NRTC) engine dynamometer tests.

Figures 2 and 3 show the results for each of the 10 cold start NRTC tests and the 50 hot start NRTC tests of a John Deere mule engine fitted with a Johnson-Matthey CCRT to obtain PM levels at or below Tier 4 standards. As can be seen in the figures, there exists no distinct trend in either the CVS or BG-3 PM results.

In this study, Dr Shade concluded that test results show that Sierra's BG-3 passes unpaired t- and F-test statistical evaluation for this step of the alternate system approval process per 40 CFR 1065.12. PM results of 10 cold start NRTC tests yielded a coefficient of variation of 34.3% (CVS) and 22.8% (BG-3). PM results of 50 hot start NRTC tests yielded a coefficient of variation of 33.1% (CVS) and 20.4% (BG-3).

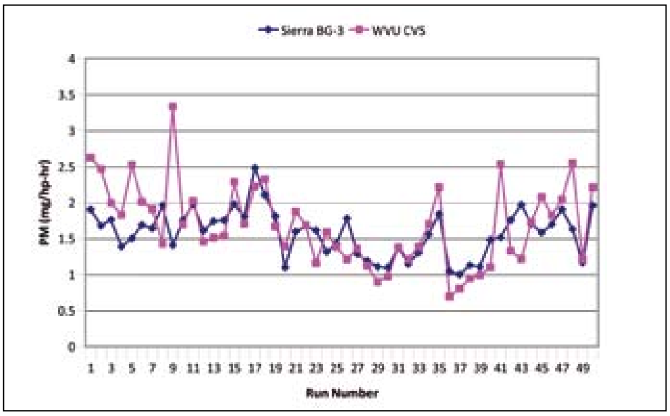
The fundamental conclusion was that when compared with a laboratory CVS system, the BG-3 can accurately measure PM emissions, statistically similar mean results, with lower variability from a heavy-duty diesel engine over transient operation. In addition, Dr Shade's results showed that the BG-3 can accurately measure PM emissions, at better than 25% repeatability, at a PM level of over 85% below the Tier 4 PM emissions standard.

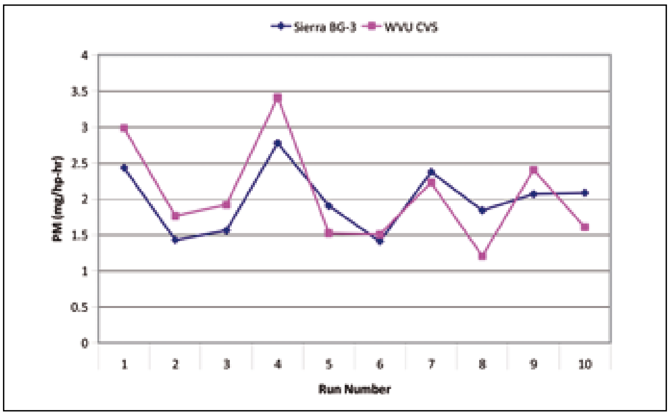
With the BG-3's partial flow sampling technology, engine manufacturers now have a world-class system for engine development at a fraction of the cost of a CVS system, with proven equivalent mean results and improved repeatability, which ultimately translates into lower engine development costs. According to Rob Graze, senior engineering specialist at Caterpillar, "the big money isn't spent on certification; it's spent in development". But when engine manufacturers have improved repeatability, fewer runs are required to make statistically defensible decisions on hardware and software combinations. Therefore, either less money is spent to develop an engine for market or a better engine can be developed for the same cost.

Improved repeatability also streamlines engine development efforts and reduces costs by either requiring fewer samples to determine a given difference in dataset means or by enabling determination of a smaller difference between mean values. For example, if a manufacturer is evaluating two turbocharger designs, he may be hoping to discern a 5% difference in particulate emissions means (or greater) at 90% confidence. If his data has a 5% coefficient of variance (one standard deviation divided by the mean) on both sample sets, he needs to run seven sets of runs on each design to reliably discern a 5% difference in means. If an improved particulate measurement system can reduce the coefficient of variance to 3.5%, he reduces the required number of run pairs to four. Lab test results show the use of a Sierra BG-3 has produced a reduction in coefficient of variation of 20% or more on pre-DPF engines and up to 50% on tailpipe emissions measurements on engines equipped with a DPF. In both cases, improved repeatability means fewer test runs, translating to lower engine development cost for engine manufacturers.

Key proprietary and patented technology allows the BG-3 to have improved repeatability and accuracy over CVS systems, which, being built as per regulatory requirements, have none of these advancements. The flow system components in the BG-3 were selected for accuracy, response, and stability. The BG-3 cabinet temperature is closely controlled to further minimize transducer drift.

Figure 1: The BG-3 offers a world-class system for engine development at a fraction of the cost of a CVS system





Figures 2 and 3 above show the results for each of the 10 cold start NRTC tests and the 50 hot start NRTC tests of a John Deere mule engine fitted with a Johnson-Matthey CCRT

Sierra is on a continuous innovation path with the BG-3. A number of key innovations enable improved repeatability and accuracy. The first is a patented Partial Flow Dilution Tunnel. The BG-3 dilution tunnel minimizes particulate buildup on its walls by virtue of its patented design that enables control of the tunnel wall boundary layer by radial infusion of dilution air through the porous dilution tunnel walls. As a result, the susceptibility of the tunnel to coating by the diesel particles is minimized by the comparatively substantial velocity of air emanating through the tunnel walls. This minimizes the instances of re-entrainment of previously deposited particulate and reduces sensitivity to tunnel 'history'.

The second innovation is the proprietary mirror calibration of the BG-3, which removes relative errors between the total and dilute sides of the system. Daily mirror calibration check routines enable unprecedented sample mass flow accuracy at dilution ratios of 50:1 and greater.

With its patented sample flow check system (shown in Figure 4), the BG-3 can also provide engine developers with documentation of sample flow rate integrity between transient test cycles, analogous to zero-span check performed between runs by gaseous emissions analyzers.

The BG-3 not only lowers engine development costs, but also allows developers to perform important engine development work that a CVS system simply can't perform – more quickly, with lower maintenance costs and fewer man-hours. This makes the BG-3 a superior system for engine development at a much lower initial investment and lower cost of ownership.

When developing an engine, manufacturers must prove their engine and aftertreatment systems will meet the tough emissions standards during testing and remain compliant over a period of years, even decades. The most efficient way to perform this development is to simultaneously sample emissions upstream and downstream of the after-treatment device. This method of engine and DPF development is impossible to perform with a CVS system, but easily handled with either a dual-head BG-3 or a pair of BG-3s located upstream and downstream of after-treatment technology for efficiency studies.

Troubleshooting a wide range of engine sizes on any existing test cycle is easily handled with the BG-3. The physical size, cost, and relative difficulty in maintaining, operating, and troubleshooting a CVS system, however, is intensified as attempts are made to extend the use of a CVS to engines with greater power output. Since CVS shows a 'history' to engines previously sampled due to mass transfer from the tunnel walls, troubleshooting becomes particularly difficult when attempting to quickly switch back and forth between sources with significantly disparate particulate levels. With a CVS system, test organizations may need to run an engine at a comparatively high load for several hours to recondition the tunnel, while periodically sampling particulates to monitor the progress of the re-equilibration. With the BG-3, engine developers simply use a dedicated upstream-DPF probe and dedicated downstream-DPF probe to swiftly relocate sampling zones.

Figure 4: A Smart-Trak mass-flow meter and controller

Engine manufacturers are also required to either re-ingest crankcase fumes (blow-by) or add their emissions contribution to the total engine exhaust emissions level. The BG-3 has been effectively used in crankcase blow-by separation system development efforts, whereas a CVS system is incapable of providing relevant data due to the very low blow-by flow rates.

When conducting so many different tests, the CVS system and the BG-3 need to be periodically calibrated to minimize failing flow checks and leak checks, which results in countless hours of troubleshooting. The BG-3 is easy to calibrate, plus the on-board leak check and flow checks can be run after every test. A CVS system cannot be checked as frequently, increasing the probability that the BG-3 is accurate and the CVS drifts.

Sierra has a number of initiatives underway that are focused on expanding the role of BG-3 in the test lab of tomorrow. A dual-head BG-3 has been joined by a triple-head BG-3 for simultaneous pre-, mid-, and post-after-treatment particulate sampling.

Due to the BG-3's speed of response and minimal hysteresis, it is an excellent dilution device for particle size studies. While the existing software compensates for extraction of a known flow-rate upstream of the gravimetric filter for simultaneous size and gravimetric studies, an upcoming version will allow expanded capability for additional emissions measurement components, while maintaining the integrity of the core gravimetric filter measurement. A recent development uses a characterization for real-time soot quantification.

In conclusion, recent advancements in Model BG-3 functionality have provided a line-of-sight toward it becoming a full replacement for CVS – as a gaseous diluter, a PM sampler, and a dilution method for PM and/or soot size and speciation.

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