TECHNICAL DATA SHEET

SOOT-TRAK™

REAL-TIME ENGINE SOOT MASS EMISSIONS

SIERRA®

EMISSIONS SAMPLING SYSTEMS

Description

The Sierra Instruments Soot-Trak™ laser measures real-time engine soot particle mass emissions and performs characterization of soot particle size, primary particle surface area and number. Soot-Trak provides researchers and engine developers the accurate information they require about particle transport. With measurement accuracy of 5% using a known calibration source, Soot-Trak also sets itself apart from other real-time soot mass measurement techniques with its rangability, application flexibility and resolution. Soot-Trak measures real-time soot particle mass emissions concentrations from 1 - 10^6 µg/m^3 for mean agglomerate sizes ranging from 50 - 500nm at data rates up to 10 Hz. Obtaining ±1 µg/m^3 detectability requires 0.1 seconds of measurement time giving Soot-Trak the best sensitivity and resolution available.

With over five years of development and patents pending combined with field-proven results in other emissions markets, Sierra has partnered with Process Metrix to introduce Soot-Trak technology to the engine emissions measurement community for the first time. Soot-Trak is available in two versions: as a plug-and-play version integrating with Sierra's Model BG-3 partial flow dilution system and as a stand-alone version for integration with other types of dilution systems such as CVS or other brands of partial flow sampling systems.

Soot-Trak measurements are based on first principles similar to gravimetric, optical absorption, and mobility methods, giving comparable mass and size accuracies without calibration. Soot-Trak can also be used for correlation to gravimetric PM filter measurements, soot modeling, PM filter cross-checking, as well as determination of soot number limits. Soot-Trak has a dilution ratio rangability exceeding 50:1 when operated with the Model BG-3, which is capable of sampling PM from any engine regardless of horsepower, fuel, and PM concentrations. Soot-Trak is housed inside a portable, height-adjustable cabinet that includes the sample extraction vacuum source and 1065 compliant temperature control. A microprocessor measures temperature and pressure automatically to convert to STP conditions. The instrument includes features for remote operation and includes user-friendly software that is unmatched in the industry.

Technology Overview

Soot-Trak™ (Real-Time Scattering by Two Angle Ratio) : While there are other scattering techniques, the Soot-Trak method is unique in calculating soot concentration from first principles, (patent pending), without the need for gravimetric calibration. Soot-Trak operates at near ambient pressure to prevent evaporation of volatile and semi-volatile particles, and it requires no consumables.

Soot-Trak measures soot particle mass emissions concentrations from 1 - 10^6 µg/m^3 for mean agglomerate geometric sizes ranging from 50 - 500nm at data rates up to 10 Hz. When interfaced with Sierra's Model BG-3, Soot-Trak is able to provide accurate measurements for all transient test cycles. Obtaining ±1 µg/m^3 detectability requires 0.1 seconds of measurement time giving Soot-Trak the best resolution available.

Technology Overview (Continued)

Engineers can study the dynamic behavior of particle emissions that occur during transient test cycles, for example, during the first few seconds of a cold start, or during regeneration of a particle trap or diesel particulate filter (DPF). In addition, Soot-Trak gives the user the ability to cross-check gravimetric PM filter weights (immediate analyses of test particulates prior to the filter weight measurement) and is also an exceptional soot modeling tool. Because Soot-Trak is a sensitive measuring method, Soot-Trak uses ambient clean air rayleigh scattering to confirm instrument accuracy in less than a minute prior to each measurement sequence.

Other Techniques Compared & Contrasted:

Nephelometry: Has been used for both ambient dust sampling and soot measurements, but generally relies on specific calibration correlations to obtain particle concentrations. Single detector nephelometry cannot provide agglomerate size information or correctly determine mass concentrations as the agglomerate size varies. Soot-Trak has the ability to provide real time performance characterization of soot particle size.

Two Wavelength: Uses one detector and combined with two LED illumination wavelengths (Typically = 660nm and 880nm). While this is satisfactory for measurement of ambient aerosol mean sizes that are near transparent, measurement of soot requires a broader range of the scattering vector q, which is provided by Soot-Trak.

Laser Induced Incandescence (LII): LII has been available since the 1990's and has been implemented as a sampling and in situ instrument. Although fast (20 Hz), the method is complex, and has a lower concentration measurement limit of 10 µg/m^3. There remain many questions about the fundamental interpretation of the measurements, which depend on a range of heat transfer properties in addition to all the primary particle soot properties.

Photo Acoustic Soot Sensor (PASS): This sampling method measures soot particle absorption in the gas phase, with minimum detection levels of 2 µg/m^3 and a time response of 1 Hz. Other optical absorption methods use filter collection to concentrate and enhance the measured opacity. However, to obtain ±1 µg/m^3 detectability requires approximately 100 seconds of measurement time, compared to 0.1 seconds for Soot-Trak.

Tapered Element Oscillating Microbalance (TEOM): This method measures soot mass directly, but requires approximately 1000 seconds to obtain ±1 µg/m^3 detectability, compared to 0.1 seconds for Soot-Trak. In addition, the fragile TEOM element has limitations in an industrial environment.

Features

- **Accuracy: ±5% error**
- **Repeatability: ±3% of reading**
- **Wide Measurement Range of 1 - 10^6 µg/m^3**
- **Minimum Detection Limit: ~ 0.5 µg/m^3**
- **Fast Response Time: ≤ 0.1 sec**
- **Plug and Play with the Model BG-3**
- **Continuous Real-Time Soot Curve**
- **High Sensitivity for Future Regs (Tier 5, EURO 5, 2012 & later)**
- **Correlation to Gravimetric Measurements**
- **PM Filter Cross-Checking**
- **Soot Modeling**
- **Soot Number Limits**
- **Unlimited Dilution Ratio Rangeability**
- **Portable compact size**
- **Simple and fast calibration with ambient clean air**

Common Applications

- **For any engine size and fuel**
- **Steady state, ramp modal and transient test cycles**
- **On engine and chassis dyno test beds**
- **Measurement upstream and downstream of particulate filters**
- **Research & development**

Application Benefits

Correlation to Gravimetric Filter Measurements: A fundamental model (patent pending) is used to relate the fast and sensitive optical scattering measurements of Soot-Trak to equivalent mass concentration measurements at EPA-defined partial dilution conditions provided by the BG-3. Concentration measurements agree with gravimetric filter results (see Correlation Testing section).

PM Filter Cross-Checking: Soot-Trak gives the user the ability to cross-check gravimetric PM filter measurements of concentration. Soot-Trak is incorporated with the BG-3 sampled emissions flow stream, operating at the EPA-required temperature of 47C just prior to the filter sample. The uncertainty of PM gravimetric results after DPF and partial dilution is in the range of ± 30-50%. (*Kittleson, et al., AST, October 2009*). Soot-Trak can help identify consistency of engine test cycle conditions in real time, saving valuable test cell time, and can help identify errant filter measurements following the measurements.

Soot Modeling with Soot-Trak: When building a soot model, the engine is run through hours of operating conditions where engineers adjust a wide range of combustion parameters. Acquisition of detailed gravimetric filter samples at each mode is time-consuming and costly. With the BG-3, Soot-Trak can rapidly and continuously build a detailed and accurate map of engine soot production.

Soot Number Limits: Upcoming European regulations will require soot number limits along with standard gravimetric sampling. In addition, the California Air Resources Board is moving towards soot number limits as well, and the EPA will follow. Unlike other systems that only provide soot number or mass, Soot-Trak gives total mass, agglomerate size, and primary particle number, for carbon PM >30nm.

Unlimited Dilution Ratio Rangeability: When Soot-Trak is run in tandem with the BG-3, the user can set any dilution ratio desired well over 50:1 through the BG-3 user software. The BG-3 is capable of sampling PM from any engine regardless of horsepower, fuel, and PM concentrations.

Measurement Range: Soot-Trak has a wide soot concentration measurement range of 1 – 10^6 µg/m^3, providing a flexible instrument for an array of applications.

Business Advantage

• Observing the realtime concentration graph during a transient test cycle allows optimization of performance and emissions reduction

• User friendly software interface for a seamless integration "plug and play" with the BG-3 control software.

• Stand-alone Soot-Trak version can be used with other dilution systems (CVS or non-Sierra brand partial flow dilution systems).

• Real-time simultaneous gas & gravimetric sampling

• Low maintenance instrument

• Portable compact size

• High sensitivity and measurement value resolution permit transient measurements of 1 – 10^6 µg/m^3 range, allowing measurements downstream of exhaust aftertreatment systems and particulate filters.

• High sensitivity makes the Soot-Trak solution suitable for future statutory requirements (e.g. Tier 5, EURO 5, 2012 and later).

• Simple and fast calibration with ambient clean air as a reference scattering source to confirm instrument accuracy in less than a minute prior to each measurement sequence.

Performance Specifications

Accuracy: Comparable to gravimetric, optical absorption, and mobility, (±25%); ±5% with specific calibration source.

Repeatability, Precision: ±3% of reading

Measured Value: Concentration of soot (µg/m^3) in the diluted exhaust gas

Mass Concentrations: 1 – 10^6 µg/m^3

Display Resolution: 1 µg/m^3

Minimum Detection Limit: ~ 0.5 µg/m^3

Measured Mean Agglomerate Size: 50 – 500nm

Measurement Data Rate: 10 Hz

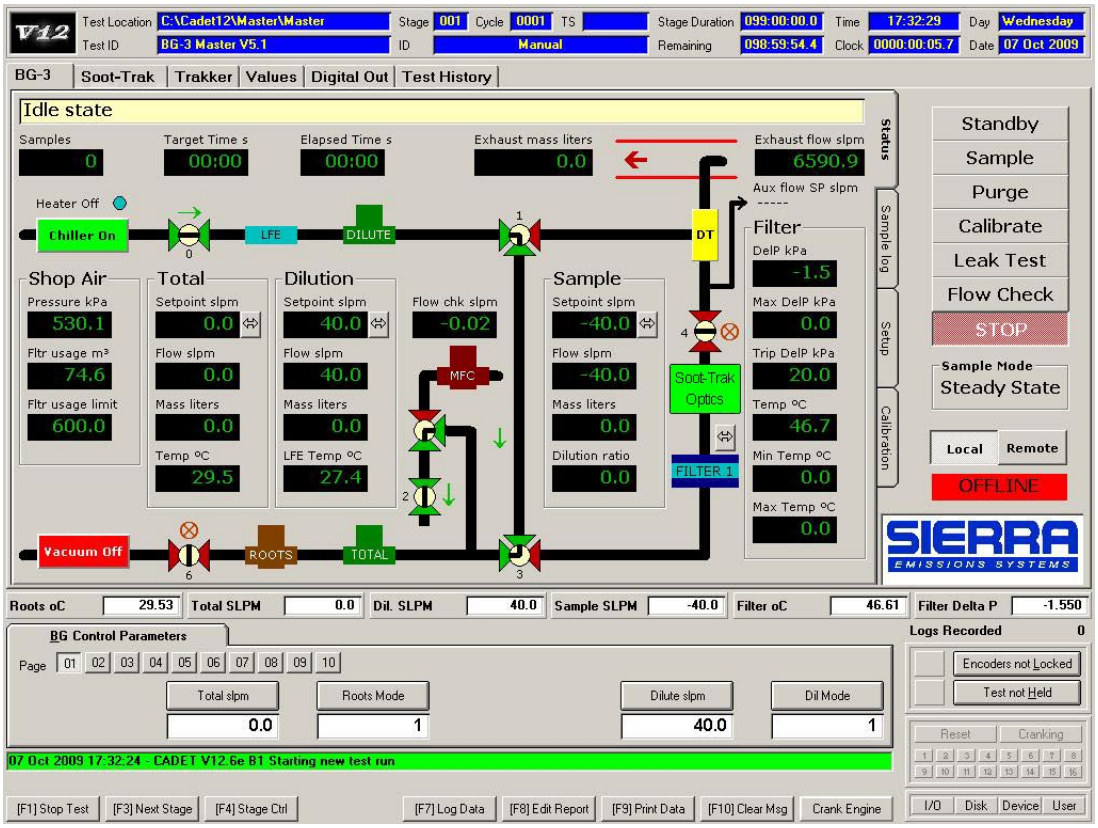
Response Time: ≤ 0.1 sec

Operation Temperature: Same as BG-3

Interfaces: RS232, Digital I/O, Analog I/O, Ethernet, NOTE: need to discuss data transfer to Test cell controller (We will have to be able to give A-K to customers)

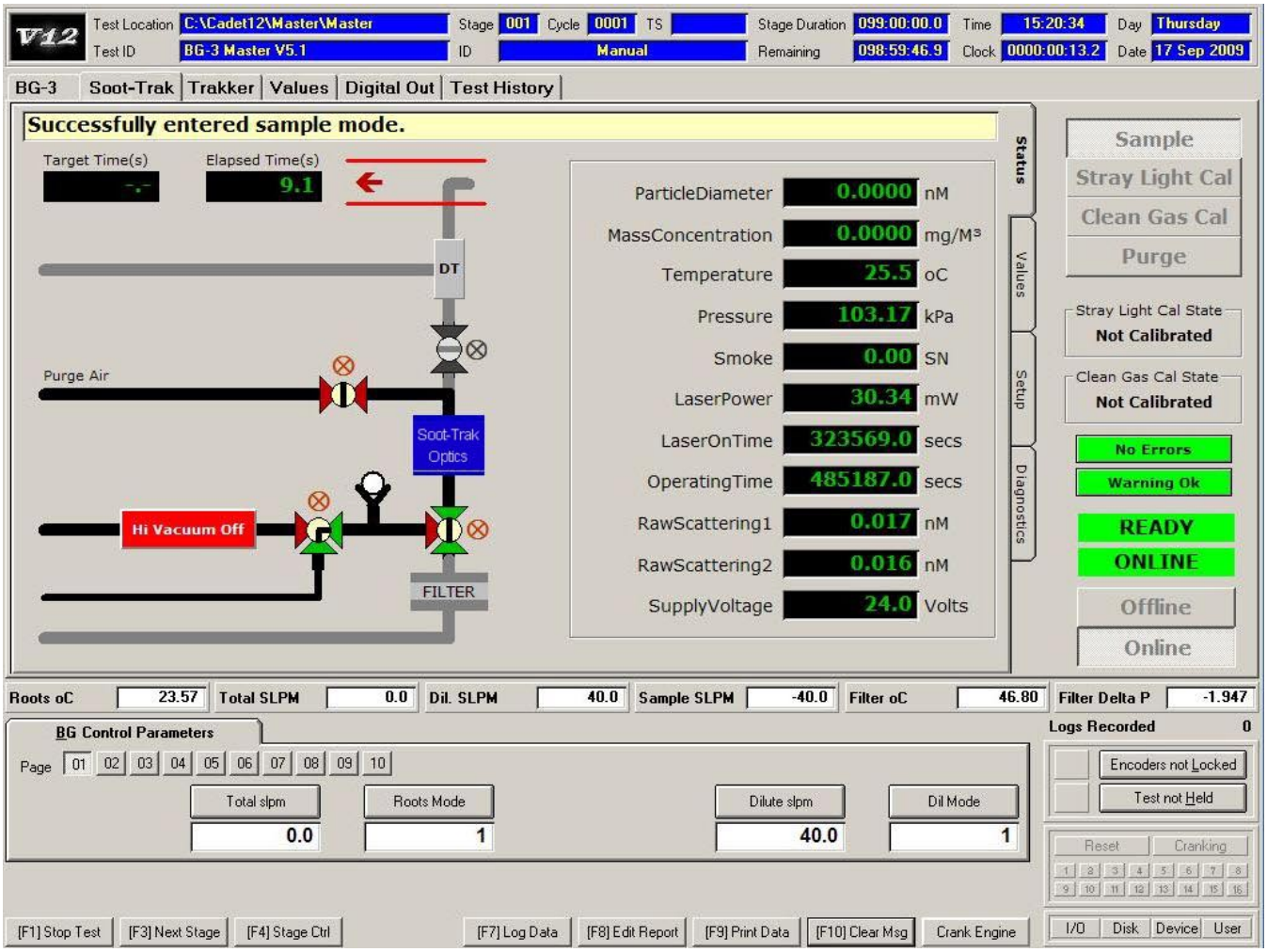
Flow Rate Through Laser: Controlled by BG-3

Software Interface

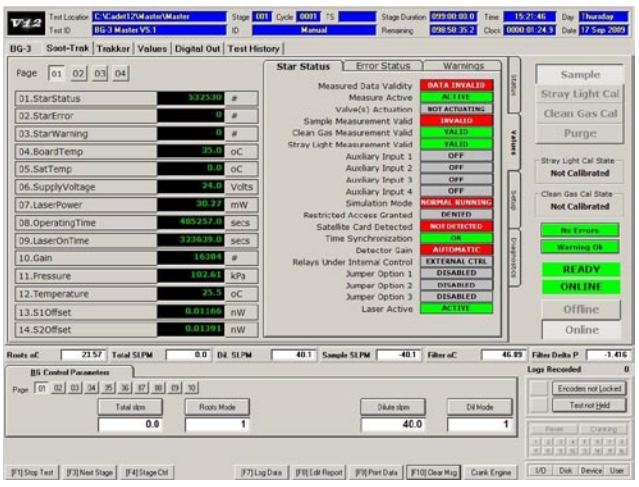


Main BG-3 & Soot-Trak Screen (above)

Software Interface (Continued)



Main Status/Control Screen (above)



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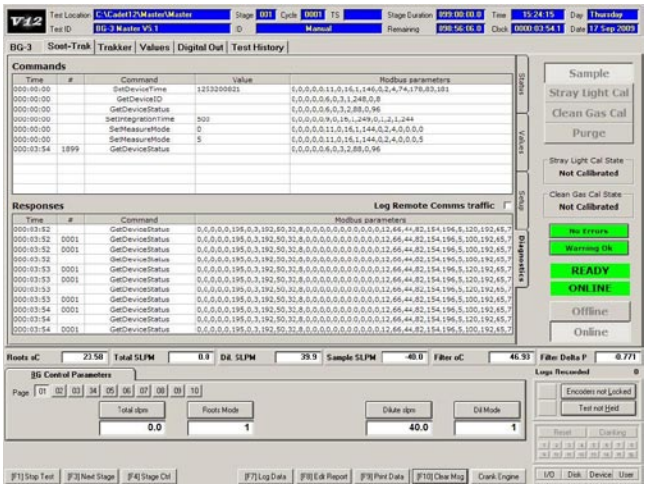
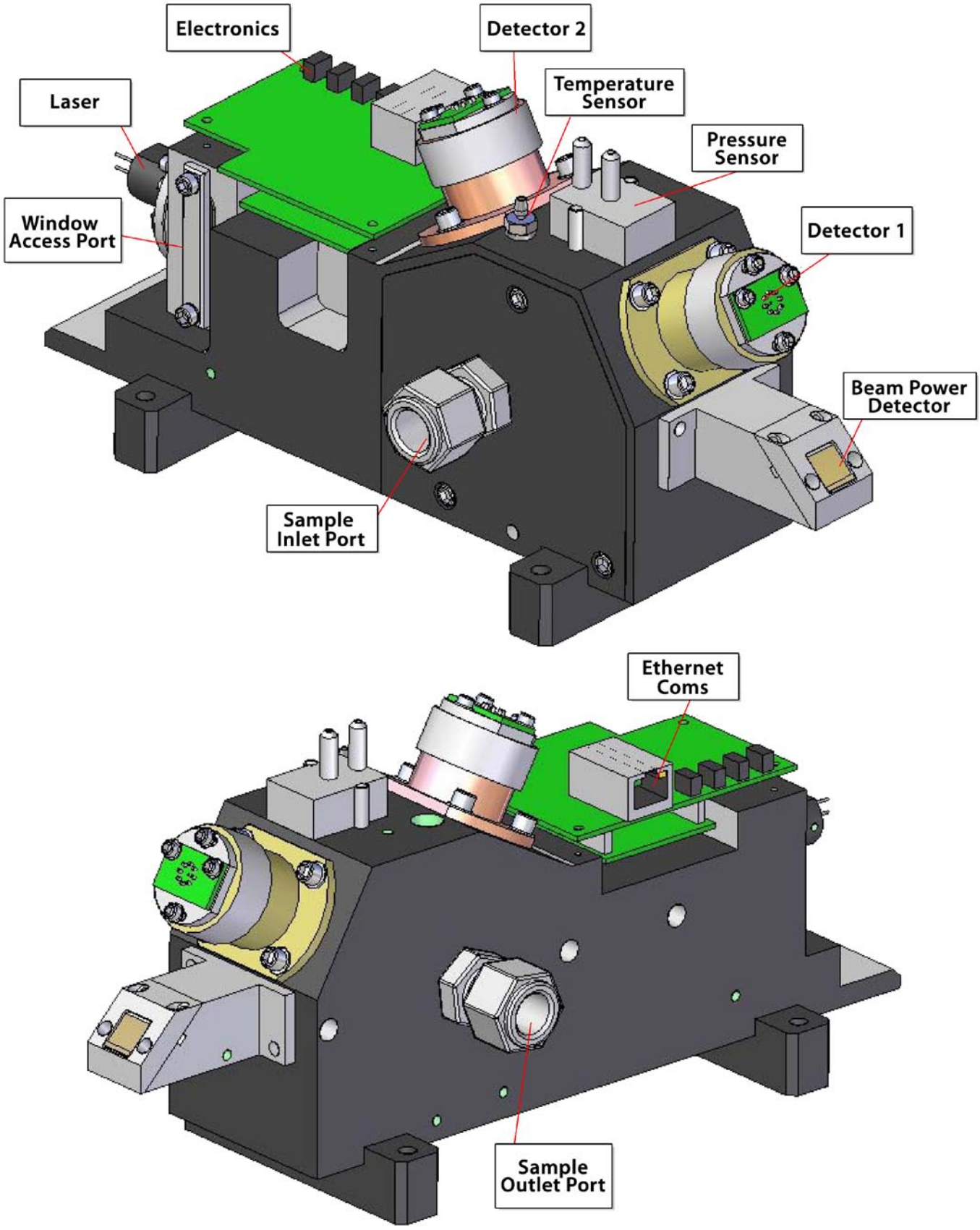


Diagnostics Tab (above)

Soot-Trak™ Component Description



Soot-Trak™ CFR Part 1065 and ISO 16283 Compliant Housing

SOOT-TRAK

REAL-TIME ENGINE SOOT MASS EMISSIONS

- **Real-Time Engine Soot Mass Emissions**
- **PM Filter Cross-Checking**
- **Soot Modeling & Soot Number Limits**
- **Plug & Play With BG®-3**

SIERRA'S GLOBAL LOCATIONS

USA

MAIN OFFICES:

- Monterey, CA
- Lansing, MI

SALES OFFICES:

- Golden, CO

EUROPE

MAIN OFFICE:

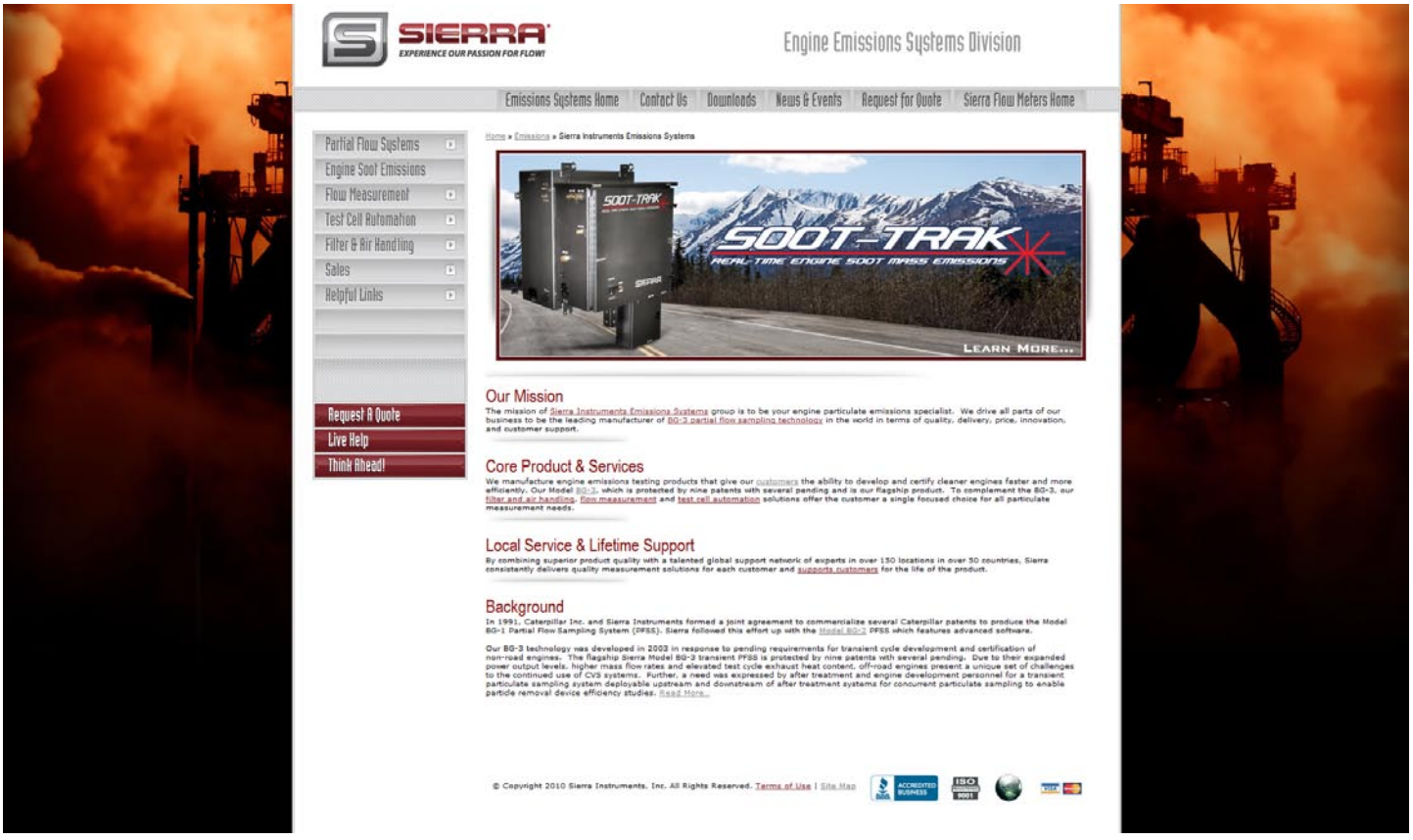
- Egmond, Netherlands
- Malvern, UK (CP ENGINEERING)

ASIA

MAIN OFFICE:

- Shanghai, China

YOUR ONLINE PM SAMPLING RESOURCE



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