

Beta Gauge Particulate Monitoring - Theory and Practice

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Continuous particulate monitoring is becoming an issue in the electric utility industry. Title V permitting, compliance assurance monitoring, and credible evidence rules are forcing the utility industry to look critically at the question of particulate emissions. The industry has known for some time that changing the operating parameters of electrostatic precipitators can result in changes in particulate emissions. What has become evident recently to both utilities and regulators is that there are other factors that can significantly influence particulate emissions independent of precipitator operation, and these factors are not well documented. Unless these factors can be characterized properly or somehow related to full load stack tests, monitoring may become necessary.

Few electrostatic precipitators operate at full power all of the time. It is standard practice to vary precipitator power on the basis of external parameters such as load, opacity, spark rate, etc. and take for granted that the emissions remain in compliance with permit conditions. Even though particulate tests are normally only done at full load and under one set of operating conditions, it is assumed that precipitator operating parameters can be varied from full load test conditions and not affect emissions. Many utilities are beginning to question this assumption. What is really happening when precipitator operation is optimized using some other parameter than actual emissions? Are the emissions going up or going down?

The introduction of low NOX burners on an industry wide basis has complicated the problem. Poor efficiencies and higher loss on ignition have plagued many plants and resulted in numerous changes in firing procedures and precipitator operating parameters. Every change affected particulate emissions, but little if any data has been collected to document the effect of the changes.

The use of different coals and other opportunity fuels has had even more effect on particulate emissions. The change from a high sulfur eastern bituminous coal to a low sulfur western subbituminous coal has well known effects on the amount of ash generated and the amount of particulate emissions produced. What has been surprising is the growing body of evidence suggesting that changing coal within the same classification can also noticeably affect emissions. Changing from one bituminous coal to another bituminous coal may noticeably change particulate emissions. Those plants that are constantly changing or blending fuels will not be able to use periodic performance testing to determine particulate emissions unless all combinations of coals are tested.

Continuous verification of acceptable particulate emissions will become necessary when either regulators or utility risk managers become uncomfortable with undocumented operation. When this happens plants need options as to how to monitor particulates. While there is a concerted effort to see if modeling will work to address these problems, there will be significant difficulty in the application of this approach for those plants that require flexibility in operation. Continuous particulate emission monitors will likely be the instrument of choice for those facilities that cannot operate within very narrow and well defined ranges.

Historically there have been four types of particulate monitors:

Gravimetric (Reference method)

Triboelectric (Broken bag detectors)

Optical

Light Transmission (Opacity monitors)

Scintillation

Light Scatter

Back

Side

Forward

Beta Gauge

The gravimetric method has been used as the reference method with little or no application for continuous particulate monitoring. Recent refinements in the reference methods to measure lower concentrations have resulted in much more complicated procedures. This has only made it less likely that any continuous gravimetric instrument will ever be developed.

Triboelectric instruments have been used extensively as a cost effective method of monitoring catastrophic failures in fabric filters and baghouses. Although there are notable efforts in both England and Germany at this time to use these devices for compliance monitoring, the application in North American utilities is not expected to be that significant where the vast majority of particulate control is done by electrostatic precipitators.

Precipitators impart a charge to the entrained particles which is similar to the effect the triboelectric devices are measuring. This makes measurements very difficult if not impossible to characterize for most utility applications with this technology.

Light transmission devices or opacity monitors have been used extensively for visible emission compliance in the United States for over twenty years. The technology has worked well in the utility industry when opacity limits were in the 20% to 40% range. As permit limits come down, the correlation between mass concentration and light transmission becomes very difficult to measure with opacity monitors. The technology becomes unreliable and unable to accurately measure particulate concentrations below 50 mg/scm (.02 gr/scf). The EPA has expressed significant doubts that this technology will be acceptable for continuous particulate monitoring. As a result, opacity monitors have not been included in most of the official EPA tests and are not expected to have a significant presence in the particulate monitoring market.

There is another optical technology which uses the ability of particles to scatter light instead of obscure light to produce more accurate measurements. Light scattering instruments as a group have been used in Europe for almost the same amount of time as opacity monitors have been used in the United States. The results have been uniformly good at emission detection limits significantly below those presently seen with opacity monitors.

There are three variations of this technology; forward scatter, side scatter, and back scatter. All of the scatter technologies can work well under the right conditions and generally have the same limitations and restrictions as opacity monitors with one exception. Most scatter instruments do not measure across the stack, but measure a point a set distance in from the stack wall. This point is normally less than one foot from the stack wall which can be a problem for large utility stacks. The boundary layer effects that have been found and documented in recent flow studies by EPRI and the EPA will affect the distribution of particulates near the stack walls. Analyzing the sample at a more representative location farther from the stack wall will help ensure more accurate measurements.

Scatter instruments are very similar to opacity monitors in terms of operation and maintenance and will likely be the instrument of choice where they can be certified. They solve the lower detection limit problem of opacity monitors and only need one stack opening to be installed. With optical based scatter instruments apparently working well in other parts of the world, why is there a need for another method to monitor particulate?

Beta transmission technology was developed to address three very specific applications; wet stacks, changing stack conditions, and changing particle properties. Optical instruments cannot measure in wet stacks. Entrained moisture refracts, reflects, and diffracts light making it impossible for optical technology of any kind to work correctly. For years the opacity readings reported for wet scrubber stacks were taken before the scrubbers to circumvent this problem. While this may continue to be allowed, there is an incentive to move the particulate monitor to the stack to report more accurate data and take advantage of a scrubber's natural ability to remove particulate from the exhaust gas stream.

It is also well documented that changing stack conditions and changing particle properties make optical measurements unreliable. Figure 1 shows the problem associated with changing the particle size distribution in a stack. As the particle size varies, optical instruments will produce different readings even though the actual mass emission is not varying. Particle size variations occur commonly as the operating parameters on an electrostatic precipitator are varied.

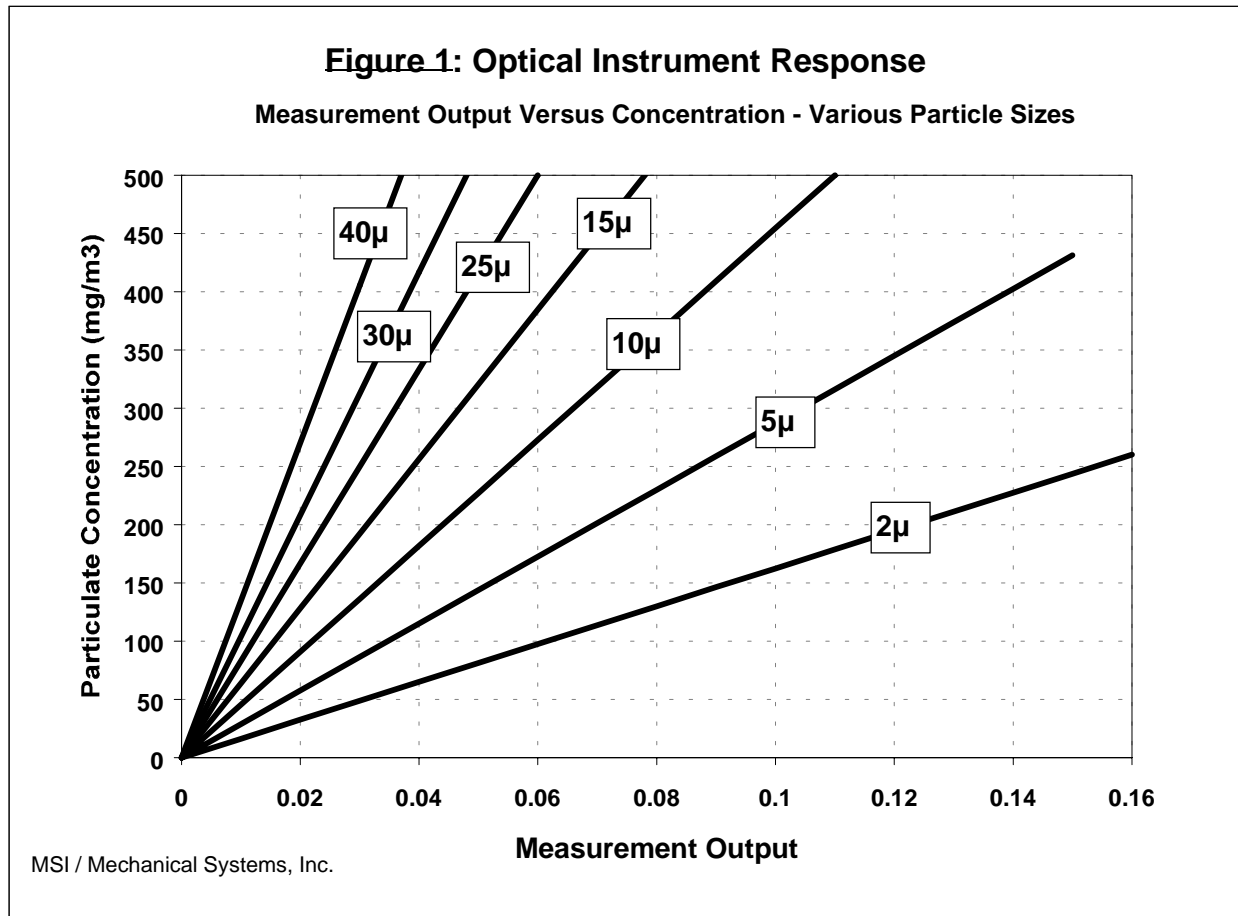
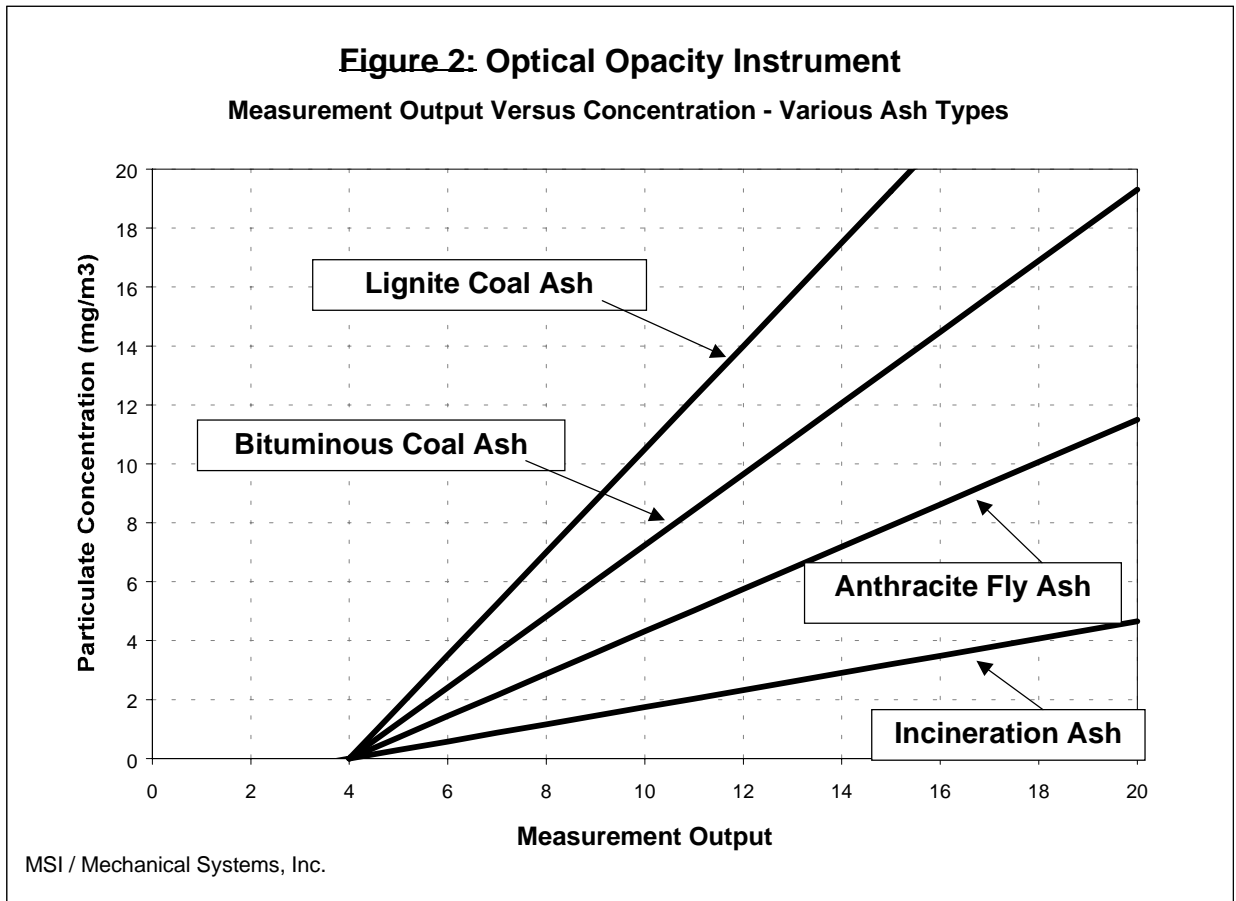


Figure 2 depicts a similar problem when the type of fuel changes. Here again optical instruments produce different outputs depending on the type of coal being burned and not on the amount of mass being emitted.

The difference in readings noted in Figure 2 are for several different types of coal but similar graphs can be produced for coals within the same classification. There are different optical responses between low sulfur and high sulfur eastern bituminous coal and between high sulfur West Virginia coal and high sulfur Illinois coal.



Different coals produce different outputs for the same mass emission in optical instruments for many different reasons. The average size distribution could be changing. The color or refractive index of the coal could be changing. The moisture in the coal could be changing. The average heat content/velocity in the stack could be changing. Optical instruments work well and are a cost effective solution when things don't change. For utilities with changing conditions or utilities who do not want to be limited to a one set of operating conditions, another technology had to be found.

The beta gauge particulate monitor is uniquely suited for documenting compliance of source particulate emissions and for optimizing precipitator and fabric filter operation. Beta gauge measurements are not affected by stack conditions or by particle characteristics.

Beta gauge measurements show no sensitivity to stack velocity, temperature, and moisture, or to particle size, shape, color, and refractive index. This non-optical technology can be installed in wet or dry stacks and will measure reliably even when the characteristics of the particulate emissions are constantly changing.

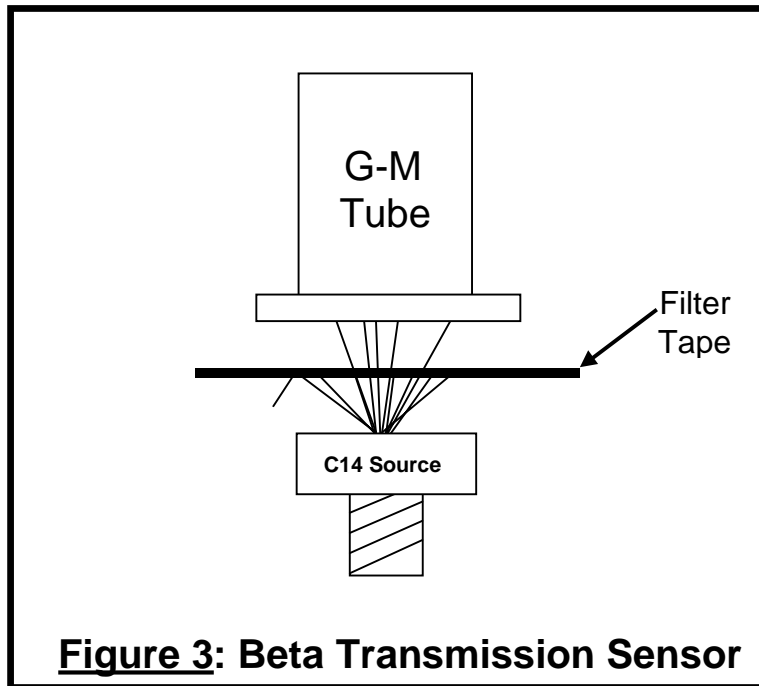


Figure 3 shows a typical beta gauge source and detector combination. A low energy Carbon-14 source furnishes a constant supply of beta electrons which are detected by a Geiger Mueller tube or photodiode array. A filter tape is interposed between the source and detector which produces an initial reduction in the number of beta electrons reaching the detector. The particulate measurement cycle begins by measuring a clean area (spot) on the tape for a fixed time period to determine a zero value. This clean spot is then moved under a collection apparatus for sample extraction

from the stack. A sample of stack gas is drawn through and deposits particulate on the filter tape. All particles above 0.1 microns are collected. Once a sufficient amount of sample is collected on the filter tape, the tape is moved back under the beta source and remeasured. The difference in beta emissions measured from the original clear spot to the collected sample is directly proportional to the mass on the tape.

Figure 4 shows a diagram of the complete beta gauge. The beta gauge extracts a sample isokinetically from the stack using a dilution probe to suppress moisture and increase sample flow. The sample is transported through a resistance heated line at high velocity to maintain particulate entrainment and prevent sample loss. The particulate is drawn through and deposited on a filter tape in a heated collection holder (Figure 5). The tape is held in place and sealed from the surrounding atmosphere by the heated holder. Heating the holder prevents condensables from dropping out of the sample during the collection process.

The sample is collected for a set period of time or until a maximum pressure differential through the tape is detected. The tape is then moved back under the beta source and re-analyzed for total mass. During the time mass is building up on the tape, the beta gauge is also measuring the sample volume extracted from the stack to produce that mass. Combining the mass collected with the sample drawn provides an output for mass concentration.

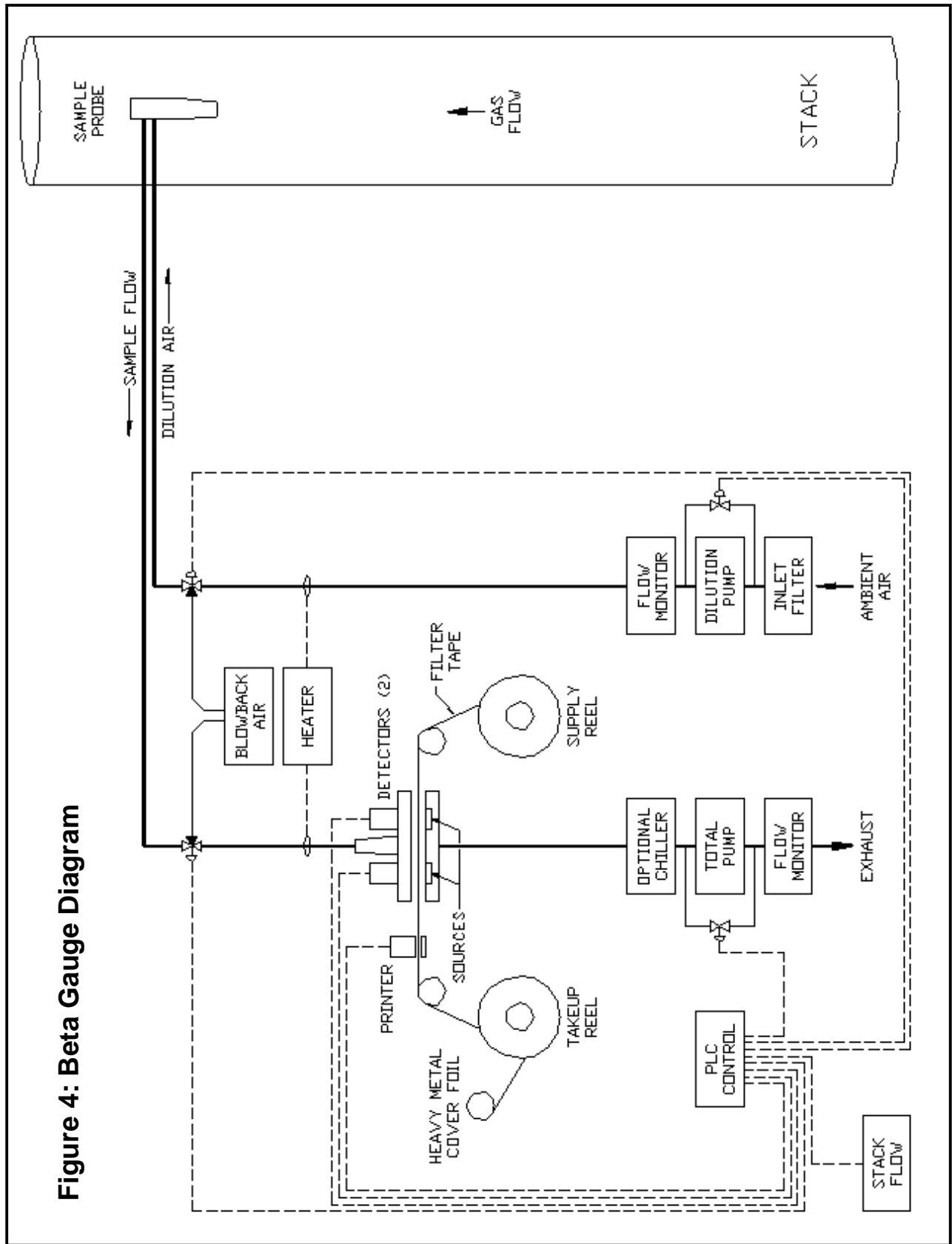


Figure 4: Beta Gauge Diagram

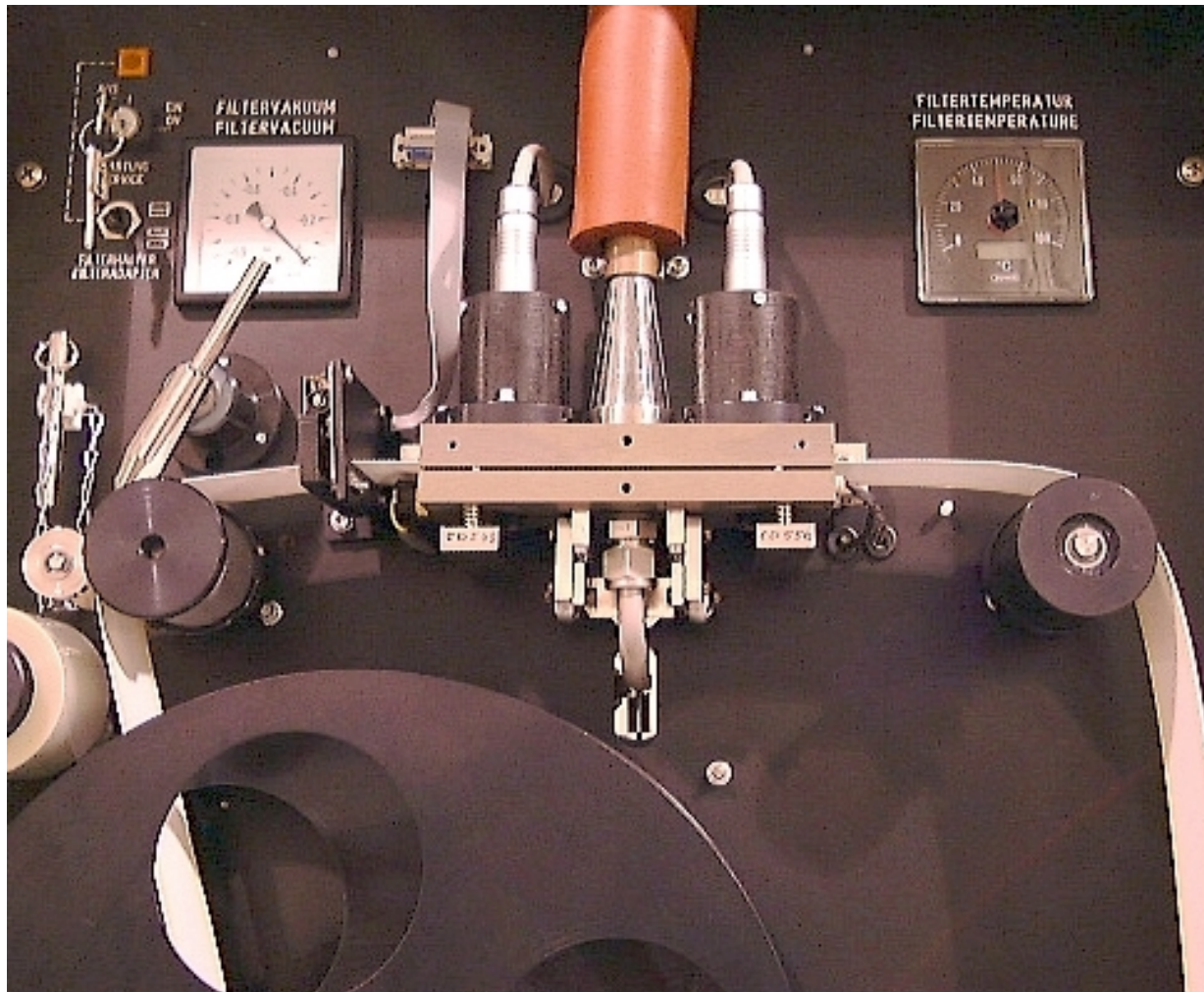


Figure 5: Beta Gauge Measuring Head

While relatively straightforward in concept, the actual sample extraction and measurement have proven much more difficult in practice. A great deal of time has been spent devising reliable methods for sample extraction and transport. Figure 6 shows the dilution probe used to extract the sample from the stack. As dilution technology addressed many of the sample conditioning problems with gas monitoring for the Acid Rain Program, dilution technology also addresses many of the sample conditioning problems with mass emission extraction.

Figure 7 shows the detail of the sample extraction nozzle at the end of the dilution extraction probe. Accurately measured dilution air is introduced into the probe at right angles to the extracted flow. The dilution air surrounds and envelopes the sample to minimize contact with the sampling system components. Rapid mixing of the dilution air and sample follows due to the turbulence produced in the mixing chamber.

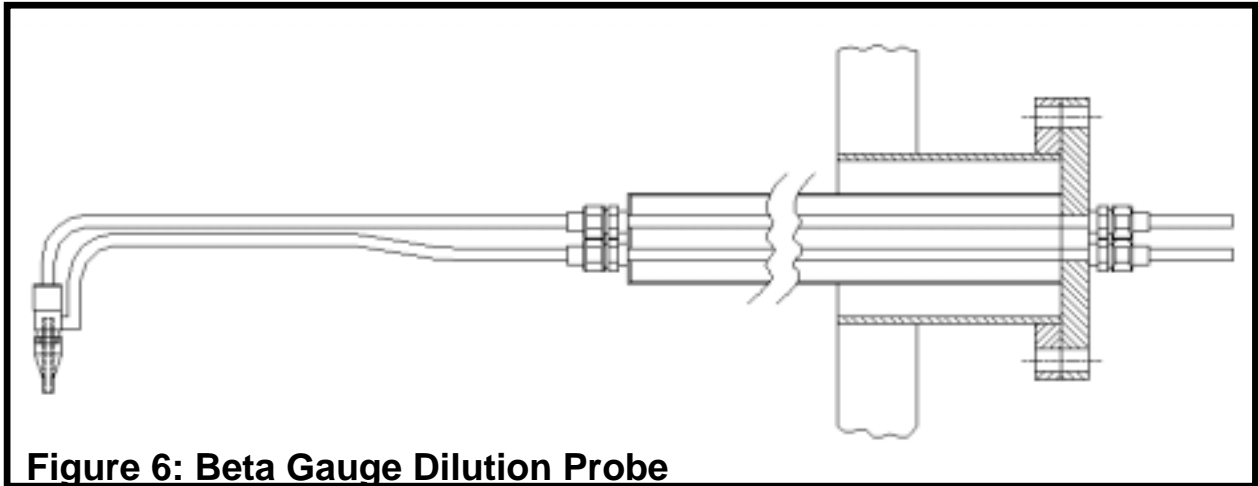


Figure 6: Beta Gauge Dilution Probe

This rapid mixing suppresses the moisture in the sample and eliminates the problem of condensation in the sample line. Moisture condensation trapping particulate in the sample line is one of the more difficult problem associated with particulate sample transport from saturated stacks. Without dilution the transport of the sample becomes progressively more unreliable as the moisture content of the sample increases.

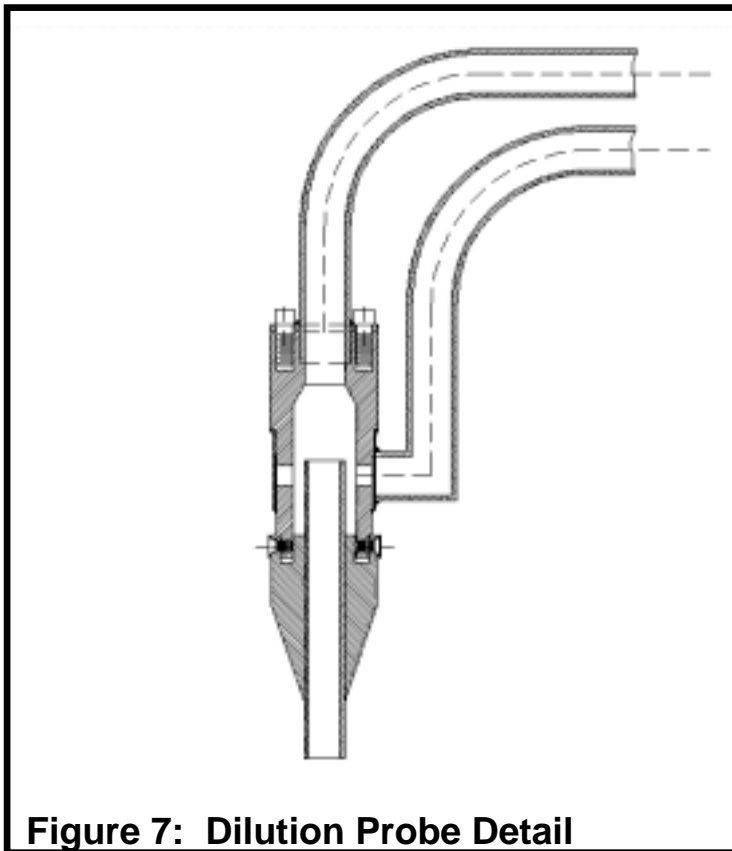


Figure 7: Dilution Probe Detail

Diluting the sample simplifies the transport of particulate samples from all types of stacks and allows wet scrubber stacks to be analyzed as accurately as dry stacks. Using dilution air also provides enough excess air so that there is more than enough flow to maintain a critical sample velocity. This is true even though the sample is extracted isokinetically from the stack and the amount of flow can change drastically from low load to high load operation. The total sample transported to the filter tape is maintained above critical sample velocity at all times by dilution air alone. The total sample flow is not dependent on the extracted sample flow to prevent sample loss during transport.

Maintaining a high sample velocity is absolutely critical to ensure that the sample is deposited on the tape and not in the sample tubing. At present sample tubing lengths up to fifty feet are possible under all stack conditions and could be longer on a case by case basis.

Flow monitors measure both the dilution air supplied to the probe and the total sample (dilution air plus extracted sample) drawn through the filter tape. The difference between the two measurements is the sample extracted from the stack. The sample extraction rate is controlled isokinetically by varying the dilution flow and maintaining constant the total sample drawn through the filter. This variation is based on an external flow measurement taken directly from the existing stack flow monitors or through the 40CFR75 data acquisition and handling system.

The beta gauge has a resistance heated sample line which is maintained at a constant temperature of 120° Celsius for Method 5/5i testing or allowed to vary slightly above stack temperature for Method 17 testing. Keeping the sample temperature slightly above stack temperature for Method 17 testing provides a more accurate measurement of front half particulate by ensuring that condensables are neither formed nor destroyed during sample transport. The resistance heated sample line is driven by low voltage AC transformers that operate at either 6 Vac or 12 Vac depending on the length of sample line. The heating circuit is formed by passing a current through the sample line, probe,

and dilution line. The probe and connected sample and dilution lines are electrically insulated from the probe holder to allow the probe inside the stack to be heated.

The sample line is 0.50" diameter by 0.035" wall Type 316 seamless stainless steel tubing. The interior surface of the tubing is specially cleaned and polished to minimize particle entrapment. The fittings and valves in the sample line likewise are specially prepared to minimize turbulence and eddies that might allow particulate to fall out of the sample stream during transport to the filter tape.

The beta gauge is controlled by an Allen-Bradley SLC 500 programmable logic controller (Figure 8). The PLC controls the filter tape movement, pump operation, measurement cycles, and all aspects of instrument operation.



Figure 8: Allen-Bradley SLC500 PLC

The PLC also calculates the concentration and mass emissions and outputs this information in analog (4-20 mA) or serial form (RS-232/485). Digital contact closures indicating system operations including calibrations, blowbacks, and alarms are also available. The PLC can accept digital inputs to control calibration or blowback cycles.

Other advantages of the beta gauge worth noting are:

1. The EPA calibration correlation between mass emissions and output is linear with a beta gauge. All optical instruments show decidedly non-linear operation which makes initial calibration and set up of the instruments for particulate monitoring difficult.
2. The collected samples can be protected for latter analysis by other techniques such as x-ray diffraction for heavy metals. A polyester cover foil dispenser used to protect the sample, and a dot matrix printer used to mark the filter tape with date and time and collected mass.
3. Automatic blowback of the sample lines during filter tape transport is standard to ensure the sample probe tip does not become plugged. Additional timed or manual blowbacks can also be initiated as required.
4. Quarterly audits using NIST traceable standards are possible.
5. Dual measurement heads minimize the amount of sample time lost to the batch process. Should a Geiger Mueller tube fail, the instrument automatically goes into single head sampling mode.
6. Multiple spot resampling extends the life of the filter tape. The measured amount of mass of one cycle becomes the zero of the next cycle.
7. An optional high capacity chiller is furnished for dry basis measurements. This chiller is rated at over 50 lpm and comes complete with integral temperature control and water carryover alarm.

Particulate concentration is rather unique in being one of the few Title V permit parameters that is not directly measured by utilities. It is not reasonable to assume that this situation will go on too much longer given the significant contribution utilities make to controllable particulate emissions in ambient air. The reference methods are being revised, and the performance specifications are being finalized at this time for particulate monitors. The process has been anything but easy or well controlled and is being driven by an industry, hazardous waste incinerators, that could not be more different in approach or application than the electric utility industry. Many utilities now face the installation of significant new capital equipment for controlling nitrogen oxides which will only make particulate monitoring more difficult for all instruments except beta gauges.

Beta gauge measurements can be used not only to monitor but also to control electrostatic precipitators and fabric filters. Performance of exhaust gas cleanup equipment in the future will likely be optimized based on actual emissions and not on other easier to measure, but less reliable and less accurate parameters. It is surprising this is not being done now and even more surprising that little attention is being given to this problem by the utility industry. The impact on the utility industry could be significant and deserves to be addressed in a more involved manner.

The technology is there to do the job. Beta gauges and other mass emission monitoring technologies have been in use for years. Beta gauge and scatter technologies in particular need to be applied and tested now by the utility industry to confirm applicability and long term viability. We suggest it is time for this process to begin before some unexpected event forces the issue on an unprepared industry.