Using Electrodynamic Cross-Correlation Technology for Mass Emission & Flow Rate Monitoring in Stacks

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Abstract

Continuous velocity and volume flow measurement is often performed in industrial stacks to enable emissions to be converted from units of concentration to units of total mass over a given period. This requirement has increasing importance with the advent of emission inventories which industry and regulators are starting to maintain.

The traditional flow measurement techniques for stacks are averaging pitot, ultrasonic transit time and thermal mass, however, all can be rendered unreliable by the presence of high levels of particulate or moisture. In a new technique described as Electrodynamic cross-correlation, the measurement is unaffected by moisture or particles. In fact, the technique responds positively to particles, since it is the electrical signature of particles interacting with an Electrodynamic sensor which is cross-correlated with the signature of a second down stream sensor to determine the transit time of the particles.

This paper describes the operating principle of Electrodynamic-correlation instruments, including details of the signal processing. The sensor can also be combined with particle concentration measurement determined using an electrodynamic dust algorithm on the signal on one of the rods – hence permitting an integrated mass measurement to be made.

Flow Monitoring Requirements

Continuous flow measurement of emissions from industrial processes is a subject of growing interest to both the Environmental Regulator and Process Operator.

For the Regulator there is a move to express emission limits not just simply in terms of concentration (mg/m^3), but also in terms of mass flow emissions (eg g/hour). This reflects that the environmental goal is to control the total amount of pollution being emitted to atmosphere and that a large, high velocity stack has for the same mass concentration a higher environmental impact than a smaller lower velocity one. This change in regulator approach also reflects the European IPPC (Integrated Pollution Prevention & Control) directive which places increased requirements on member states to maintain an emission inventory of total emissions. This again increases the need to measure mass emissions in addition to mass concentrations.

In processes with constant emission velocity, the mass flow is simply proportional to the emission concentration and may be calculated by the simple relationship with a fixed value of velocity:

$$M = C \times V \times A \times 3.6$$

Where: M = Mass Flow (g/hour)
C = Mass Concentration (mg/m^3)
V = Average Stack Velocity (m/s)
A = Stack Cross Sectional Area (m^2)

In emission sources with varying exit velocity the same equation may be used, however, there is the need to use the actual velocity on an ongoing basis to ensure a realistic measurement of mass flow. A choice of implementation exists between regular ‘spot measurement and calculation’ or continuous measurement. The recent trend is for concentration and velocity to be measured continuously, and then the mass flow can be calculated and reported on an up-to-date basis.

From the process operators perspective, stack velocity is also of growing interest for a number of reasons:

1. Mass emissions can be calculated for the process to provide a better monitor of environmental impact than emission concentrations.

2. For drying and product collection processes, (eg milk powder spray drying) the mass emission better reflects product lost from the process and a control parameter to minimise losses.

3. For processes operating pollution arrestment plant close to design capacity, better measurement and control of the gas velocity entering into arrestment plant can have a significant effect on reducing overall emissions from a plant.

Limitations of current flow measurement approaches

Historically, the major regulatory need for stack velocity instruments has been to continuously measure the velocity in large combustion stacks at Power Stations. This has led to the development of a number of measurement technologies which can be used satisfactorily for this application. The major techniques used are:

1. Averaging Pitot: in which a bar with multiple pitots is mounted across the stack so that a representative measurement of the stack velocity is measured. The velocity is calculated from the average dynamic pressure. Important practical issues are:
- minimising pitot blockage caused by dust by the use of air purges.
- calculation errors arising from the dynamic pressure being proportional to velocity squared and, therefore, meaning the average pitot reading does not reflect the average velocity.

2. Ultrasonic: in which the transit time of a sound pulse travelling with the flow is compared with the time against the flow. In practice transmitters and receivers are mounted on opposite sides of the stack and offset so that the sound pulse travels at 45^0 across the stack. Practical problems are:
- installation costs due to mounting arrangements for transmitter and receiver.
- keeping the transmitter and receiver clean.
- maximum temperature limits.

3. Thermal Mass: in which the power to maintain a heated element at a fixed temperature is related to the cooling effect, and hence velocity of the air stream. In practice a number of separate sensor elements are positioned along a probe mounted across the stack to obtain representative measurement and again sensor cleanliness is an important operational issue.

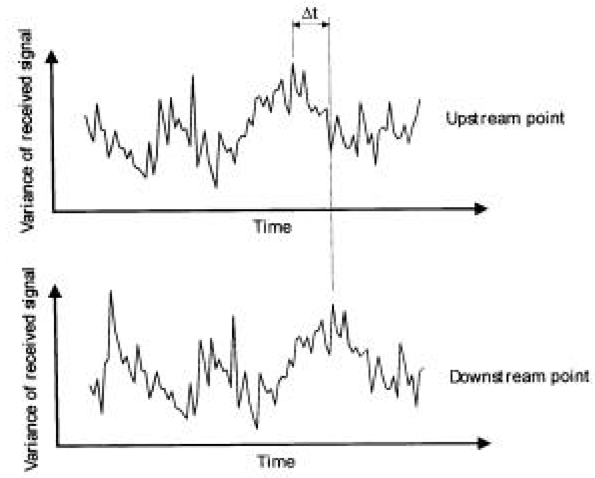
As discussed, each of these techniques can be rendered unreliable by the presence of high levels of particulate and moisture, especially if regular instrument maintenance is not performed and, therefore, there has always been the need for more rugged measurement techniques. For processes outside the Power Generation sector there can be additional application constraints such as:

- Smaller stacks with vibration making it difficult to mount ultrasonic
- High temperature applications
- High particle concentrations
- Cost-effective initial purchase price and cost of ownership
- Little recourse to perform additional instrument servicing
- Need for rugged, practical on-line measurement

It is with many of these constraints in mind that the new Electrodynamic velocity technology has been developed. It has the potential to provide a practical alternative to solve the limitations of existing techniques in particle laden applications and processes not limited to the Power Generation Industry.

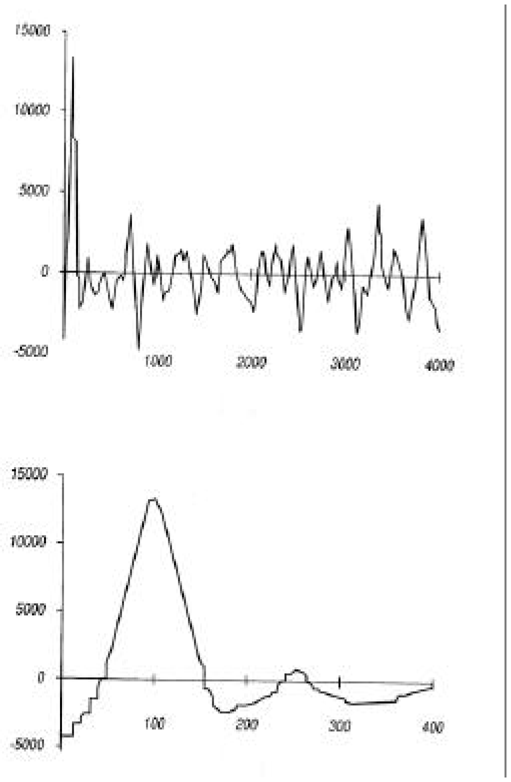
Principle of Electrodynamic Velocity Measurement

The principle of Electrodynamic cross-correlation is to derive the stack velocity from measuring the transit time of particles between two grounded sensor rods inserted in the stack. All particles carry a small amount of charge and, therefore, as the particles pass the rods they induce an electrical signature related to the charge distribution pattern. Provided the second sensor is not separated too far downstream from the first, the charge distribution pattern will be similar and a similar electrical signature will be induced on the second sensor. However, this pattern will be shifted in time in relation to the first pattern by the transit time of the particles.



Graphs showing Signal produced at Upstream and Downstream Sensors

Cross-correlation is a signal processing procedure to determine the time lag between the two signals. The cross-correlation algorithm involves digitising the two signals to obtain the signal value at a number of different times. (4000 points are used in the PCME cross–correlator) Each of the digitised values is then multiplied against the corresponding value of the second signal and the results summed to derive one point on the correlation function. This procedure is repeated, but instead of multiplying the first signal points by corresponding point of the second signal, the first signal points are multiplied by the points of the second signal shifted by one position. This derives the second correlation point. The complete correlation function is calculated by multiplying the signals against each other, but each time the signal is shifted by another increment. The peak of the correlation algorithm occurs for a total time increment equal to the time shift between the two signals.



Graphs showing typical Signal and Correlation Result

The velocity of the particles is simply derived from:

$$V = S/T$$

Where V = Stack particle velocity (m/s)
S = Sensor separation (m)
T = Transit time of particles derived from correlation algorithm (s)

The signal processing required to perform a proper cross-correlation involves literally millions of multiplications and additions and, therefore, it has only been possible in the last few years with the availability of high speed electronic hardware to perform this task on a real time basis.

Characteristics of Electrodynamic Velocity Instruments

One of the most interesting characteristics of Electrodynamic instruments is that unlike other velocity instruments they respond positively to particulate and moisture which both carry a charge signature. This makes them inherently suitable for dirty flue applications. They also have no moving parts and have no orifices to block which means from a maintenance perspective they have many advantages.

However there are certain limitations inherent in the technique:

- It is particle velocity that is measured rather than air velocity, so if assumptions of zero slip between particles and rod are not true there will be errors in measurement. One expects the amount of slip to be a function of particle loading and particle size. Of course the benefit of measuring particle velocity is that in some cases it is exactly this parameter that is required.
- It is necessary to have dust present to make a measurement. A minimum concentration of 5mg/m^3 is necessary, however, if the dust level is this low it may well be possible to use a standard averaging pitot without reliability problems in these applications any way.
- The Electrodynamic signal is derived from particles across the rod length meaning that the calculated velocity is an 'Electrodynamic' average rather than necessarily the true average.
- The particles are disturbed by the intrusion of the first sensor rod meaning that the second signal does not exactly replicate the first one. This can flatten the peak in the correlation function reducing resolution. However provided rolling averages are used, resolution of better than 0.1% fullscale is still possible.
- The apparent separation of the sensor rods as far as the particles are concerned may not be exactly the same as the physical spacing. It is, therefore, always better to calibrate the instrument in-situ to increase accuracy.

As in all process measurements the key is to balance the shortcomings of a technique for its benefits in a specific application. In the case of Electrodynamic instruments the key advantage is reliability and ruggedness. The limitation is that accuracy may fall to 95% in some applications although in many it is within the 3% error specified in the international standard for continuous flow measurement (ISO-14164).

Results from Electrodynamic Correlator

PCME's Electrodynamic velocity instrument (Stackflow II) was developed in 1997 as a part of an ongoing European Steel & Commission (ECSC) development project involving CRE, PCME and British Steel. The instrument is designed for continuously monitoring flow in a stack.

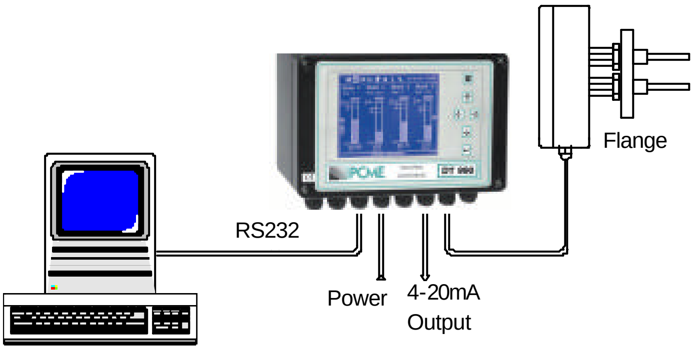


Diagram showing Instrument Construction

The sensor comprises two 10mm flat rods separated by 50mm. The complete sensor assembly fits to the stack by means of a 4" flange. The Electrodynamic signals are digitised at 1khz in the sensor head and the signal processing is performed in a separate hardware correlator and control unit with a 16Mhz processor and optimised correlation algorithm. The complete processing time for a 2000 point cross-correlation is less than a second providing a sufficient response time for practical on-line measurement. The application range of the instrument is currently as follows:

Temperature	0 – 250^{0}C
Stack/duct size	150mm – 6m (max probe 1m)
Velocity range	3 – 50m/s
Minimum dust conc	5mg/m^3
Moisture	Dry, Humid

Table showing Instrument Application Limits

Testing performed by the University of Greenwich has confirmed a linear and repeatable response between instrument output and average velocity.

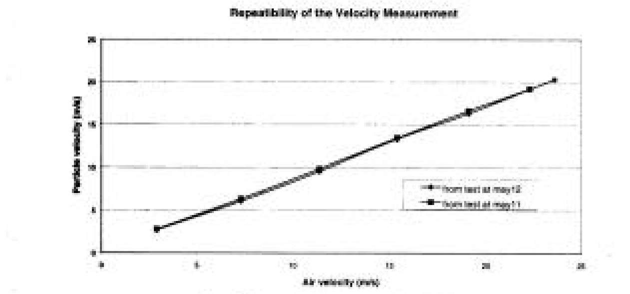


Fig. 3 Repeatability test of velocity measurement

Graph from Greenwich/PCME Test Results

Integrated Mass Velocity & Concentration Measurement

The Electrodynamic signal produced at the upstream sensor rod can also be analysed using a classic 'dust' concentration algorithm to enable dust concentration to be measured in with the same sensor.

PCME's StackMasster II uses this approach to provide dust concentration, (mg/m^3), velocity (m/s) and flow rate (m^3/s) as well as calculated Mass discharge (mg/hr)

This instrument is already used in cement, incinerator and power generation facilities to enable users to meet regulatory requirements for dust concentration measurement (mg/m^3) as well as calculate total mass discharge for corporate and regulatory reporting.

StackMasster II Installation at Power Generation facility

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