



# Using New Electrodynamic Cross-Correlation Technology for Flow Measurement in Stacks

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## Abstract

Continuous 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. Results from an ECSC (European Coal & Steel Commission) development project test comparing the accuracy of such an instrument against standard pitot methods will be reported. The paper concludes with performance data taken from the operation of the instrument in industrial applications.

## 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 ( $\text{mg}/\text{m}^3$ ), but also in terms of mass flow emissions (eg  $\text{g}/\text{hour}$ ). 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 ( $\text{g}/\text{hour}$ )  
C = Mass Concentration ( $\text{mg}/\text{m}^3$ )  
V = Average Stack Velocity ( $\text{m}/\text{s}$ )  
A = Stack Cross Sectional Area ( $\text{m}^2$ )

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  $45^{\circ}$  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:

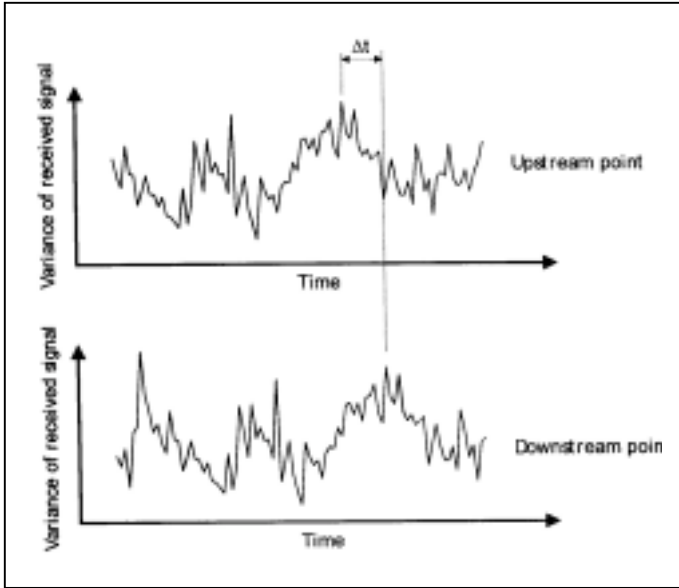
- Smaller stacks with vibration making it difficult to mount ultrasonic
- High temperature applications
- High particle concentrations
- Cost-effective initial purchase price and cost of ownership
- Little recourse to perform additional instrument servicing
- Need for rugged, practical on-line measurement

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**

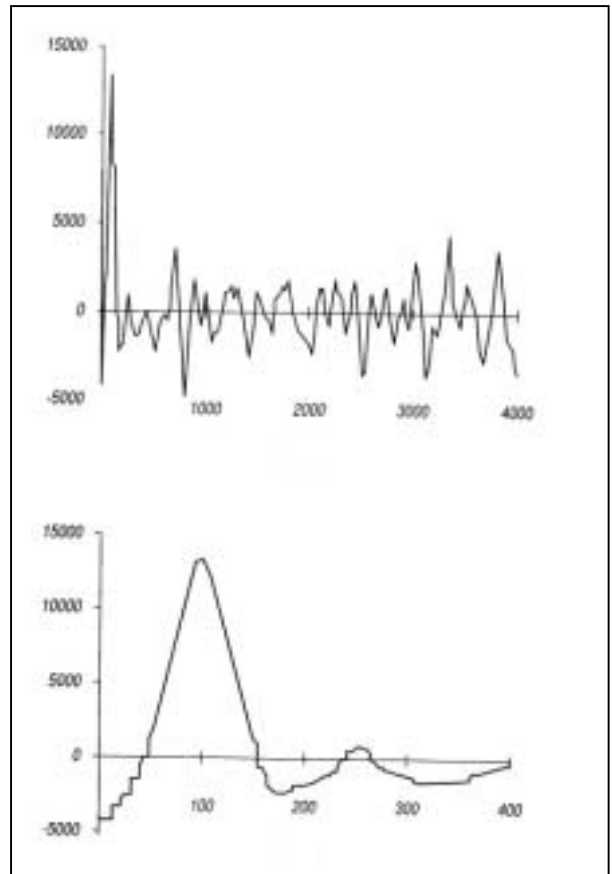
The principle of Electrodynamic cross-correlation is to derive the stack velocity from measuring the transit time of particles between two grounded sensor rods inserted in the stack. All particles carry

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  $5\text{mg/m}^3$  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 new Electrodynamic velocity instrument (the Stackflow 2000) 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.

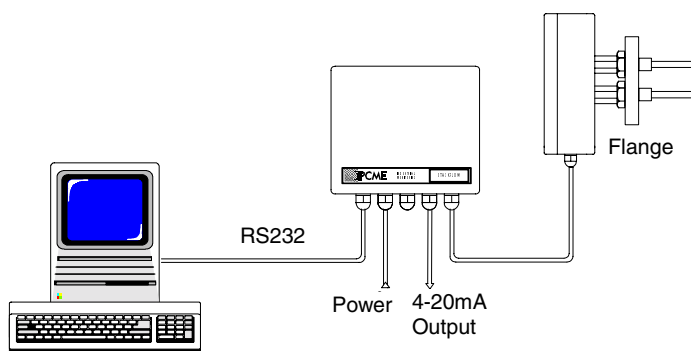


Diagram showing Instrument Construction

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°C
Stack/duct size	150mm – 3m (max probe 1m)
Velocity range	5 – 50m/s
Minimum dust conc	$5\text{mg/m}^3$
Moisture	Dry, humid, condensing

Table showing Instrument Application Limits

Evaluation of the instrument's performance is an ongoing project, however, initial results in laboratory and field applications confirm that the instrument is capable of measuring velocity in a particle laden stream and that this velocity is very representative of the average stack gas velocity. The system also is turning out to be immune to particle build up.

Testing in the stack after a coal burner at CRE has shown a relatively good correlation between air velocity determined by pitot and the instrument output. Further testing is currently underway to provide a full statistical analysis.

Test	Pitot (m/s)	Stackflow (geometric m/s)
1	10.4	10.35
2	11.2	11.25
3	13	13.3
4	15.1	15
5	15.1	14.83
6	9.5	9.28

*Table from CRE comparing Air and Stackflow Velocity*

Testing performed by Powergen as part of the coal measurement project has confirmed the instrument can still operate reliably when continuously exposed to high levels of particulate. The instrument was installed in the pipes where pulverised coal is pneumatically conveyed to the burner head and in spite of the heavy particle loading provided a continuous sensible signal of particle velocity of the 3-month field test. Signs of wear were noticed on the rods, however, a subsequent change in rod shape has stopped this issue causing any error in measurement.



*Graph from Powergen Trial of 3 Instruments*

***Graph from Greenwich/PCME Test Results***

Testing performed by the University of Greenwich on PCME's own test rig has confirmed a linear and repeatable response between instrument output and average velocity.

Testing has just started to investigate the effects of changing particle size (which might effect particle slip) and rod length (which might effect the accuracy of measurement).

**Future test work**

Further testing is planned over the next six months in industrial applications including combustion, steel, smelting and mineral applications. Interestingly the instrument has just been installed both after and before pollution arrestment plant at a sinter plant which will provide useful feedback on performance in very dirty applications and at low dust concentrations.

Current testing is also centred around a new fully integrated instrument in which the velocity measurement is combined with a dust concentration monitor. The sensor rods used for velocity measurement can also double as an Electrodynamic concentration measurement, meaning that velocity, concentration and mass flow can be measured by the same instrument.

The results of any new development arising from this ongoing test work will also be presented at the Conference.