Optical Flow Sensor Low Speed Performance

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I. Introduction

Airflow sensing in an industrial process control environment such as a duct is a difficult challenge. Existing technologies like ultrasonic and Pitot tubes require significant maintenance and have installation limitations. Both can suffer from nonrepresentativeness leading to a misreporting of flow rate. For example, Pitot tube devices only measure at one point and may under or over report the true flow. Ultrasonic devices must be installed at two cross sections along the duct, which may not be available for a short run of the duct. In addition, both ultrasonic and Pitot devices are intrusive to the media and may affect the flow rate and lead to degraded system performance.

II. OFS vs Pitot Tube and Ultrasonic Sensor

The Optical Flow Sensor (OFS) using a non-intrusive atmospheric scintillation technology was designed to solve these problems. The OFS is installed at one cross section and measures through glass windows across the duct. The configuration is perpendicular to the flow across the duct on the same cross-sectional plane. The user simply places the transmitter and receiver on flanges on opposite sides of the duct. The path-averaged result of the OFS provides a more representative reading of the flow characteristics in a duct. The sensor makes a true cross-duct measurement of the velocity along the entire path. The instrument does not require straighteners or additional ductwork like Pitot tubes often do in more challenging flow environments. Another advantage to the user is that fewer sensors are required to measure complex flow fields. One optical flow sensor could replace an entire Pitot tube array. True representativeness of the data is assured due to the path-averaged nature of the measurement. Unlike the Pitot tube and ultrasonic techniques, this velocity measurement is completely independent of temperature, pressure, humidity, and opacity.

The optical technology allows the sensor to sit behind windows “looking” through the duct. No part of the instrument is exposed to the direct flow of the duct. Therefore the OFS does not affect the flow field because of its non-intrusive nature. The OFS can be utilized in very extreme conditions such as explosive and high heat application. The sensor can be installed behind protective windows or flange extensions if needed. Avoiding direct exposure to duct effluent helps reduce maintenance and increase durability. Pitot tubes must be located directly in the duct environment where aggressive conditions (such as excessive heat, acidic gases, particulate, etc.) can degrade performance or damage the unit irreparably. Ultrasonic sensors whose transducers are exposed to the direct flow as well face the same problem.

III. Optical Scintillation Technology


Figure 1 – Effect of Scintillation on an optical beam after traveling through the atmosphere.

The optical flow sensor uses optical scintillation as the detection method. Scintillation is a general term, which describes changes in the apparent position or brightness of an object when viewed through the atmosphere. Starlight twinkling is a common example of scintillation. Scintillation effects are caused by optical refraction occurring in small parcels of air whose temperature and density differ from their surroundings. Figure 1 shows the effect of scintillation or optical turbulence on an optical beam after traveling through the atmosphere. If there is no atmosphere, the beam pattern should be a uniform circular disc. The atmospheric turbulence produced the intensity fluctuations as shown. The receiver detects this beam and reconverts it to an electronic signal. Intensity variations of the detected signals caused by the scintillating air parcels provide the basis of the turbulence measurement. The twin modules in the receiver furnish the capability of measuring cross wind by detecting the temporal correlation between the two signals as the air parcels move across the beam path (covariance). The movement of the scintillation from one receiver to the next is related to the flow rate.

Optical scintillation technology has a proven track record and history. It has been used for nearly 30 years to measure crosswind outdoors. This same technology is used for industrial airflow monitoring in the aluminum industry. The OSi LOA (Long-baseline Optical Anemometer) measures the air velocity along a smelting pot room roof vent typically 500-700 m long. The EPA approved the LOA for Method 14 (as an equivalent method in air monitoring compliance rules for the aluminum industry.) The LOA is widely used in the aluminum industry for air velocity monitoring to comply with EPA regulations. Most of the aluminum smelters in the US and Canada rely on this technology to provide air velocity measurements.

The optical flow sensor uses the same technology as the LOA. The major difference is that the OFS uses smaller optics to measure the flow over shorter path lengths (stack and duct diameters). The OFS has been certified for Part 75 airflow measurement in stacks and ducts. The optical flow sensor affords the user a distinct combination of advantages which the other methods do not offer. In addition, the optical technology is proven and tested. It is patented, approved by the EPA for airflow monitoring (Method 14 equivalent), NIST (National Institute of Standards and Technology) wind tunnel calibrated, relied on for almost 30 years to make atmospheric and environmental measurements, and has virtually no drift. No other flow sensor currently available in the environmental monitoring industry meets these conditions. Many OFS' have been installed on stacks, passed RATA tests and have been continuously measuring the flow rate for years.

IV. OFS Low Speed Performance

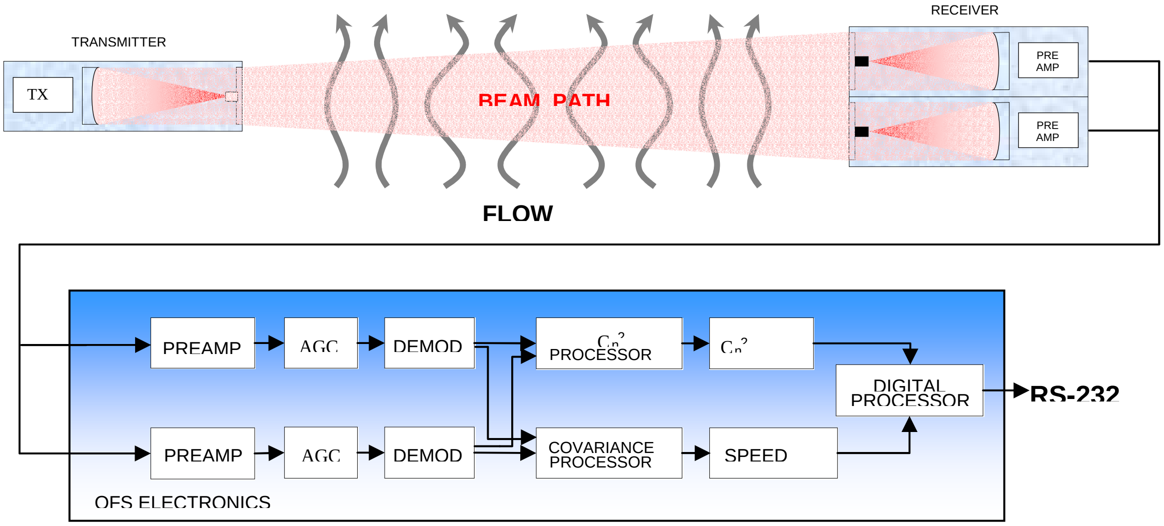

Figure 2. OFS Schematic Diagram.

A block diagram of the OFS is shown in Figure 2. A light source is transmitting a beam to the two receiver detectors through a turbulent flow. Along the path, the optical beam is modulated by the flow turbulence as shown in Figure 1. The two photodetectors detect the flow induced optical scintillations. Using a stochastic correlation technique, the flight time (**t**) of the signal detected by the two detectors can be measured. For a known separation (**d**) between the two detectors, the flow speed (**v**) can simply be obtained as **v = d / t**. The Digital-Signal-Processor (DSP) in the electronics box in Figure 2 performs all the necessary calculations to obtain the flow speed.

The ultrasonic technique has to compare the media flow rate to the speed of sound. It is known that when the flow speed is high compared to the speed of sound, nonlinear shock wave effects will severely degrade the accuracy of the measurement. At the other end, for extremely slow flow, at only a small fraction of the speed of sound, the measurement accuracy is jeopardized. For Pitot tubes, the slow flow only gives a very small pressure difference that are usually difficult to measure accurately. Therefore for both ultrasonic and Pitot tube techniques, the accuracy of slow flow rate is at best questionable.

Unlike the ultrasonic technique, the optical scintillation technique does not need to compare the flow speed to any reference speed such as the speed of sound or the speed of light. The flow speed measured by OFS is independent of temperature, pressure, humidity, and opacity. As long as the flight time of the signals detected by the two detectors can be accurately measured, the flow speed can be accurately measured. Therefore, the flow rate measured by OFS has no lower limit. No matter how slow is the flow, it can always be measured accurately. In the NIST wind tunnel test, at low speed, there were indications that the OFS measurement accuracy may even be better than the NIST standard that was based on Pitot tube measurements. The OSi OFS clearly offers the best flow measurement performance from high to extremely low flow speed that no other flow sensor can match.