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Particle Time of Flight: Reflections on Gas Flow Measurement in Hazardous Environments

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Abstract

The goal of this project was to create precise optical flow meters for the oil & gas industry optimized for measuring flare gas flow in explosive atmospheres. The flow meters had to incorporate enclosed electronics yet allow easy installation, accessibility and servicing. The overall approach was to design and develop an opto-mechanical probe and sophisticated software to accurately measure gas velocity and volumetric flow rates. Upon completion of the project, the goal of cost-effectively measuring high CO_2 gas flows as well as low pressure, high dynamic range conditions with measurements not affected by gas composition was achieved. This paper will include some examples of real applications.

Introduction to Optical Flow Metering

Optical techniques for measuring gas flow use the principles of optical velocimetry, which measures gas flow velocity. From this, we can obtain the volumetric flow rate. Within this model, there is both Laser Doppler Velocimeters (LDV) and optical transit time velocimeters. Within the latter, there is a further subdivision into laser-two-focus (L2F) and scintillation-based and absorption-based transit time velocimeters. This paper will address L2F.

Theory of Operation

The operating principle of Photon Control's Focus™ Optical Flow Meter (OFM) based on L2F velocimetry is explained in Figure 1. Small particles found in any natural or industrial gases pass through two laser beams focused in a pipe by illuminating optics. Laser light becomes scattered when a particle crosses the first beam. The detecting optics collect scattered light on a photodetector (P1), which then generates a pulse signal. When the same particle crosses a second beam, the detecting optics collect scattered light on a second photodetector (P2), which converts the incoming light into a second electrical pulse. By measuring the time interval between these pulses, τ, the gas velocity is calculated as:

$V = S/\tau$

where S is the distance between the laser beams.

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L2F Basics

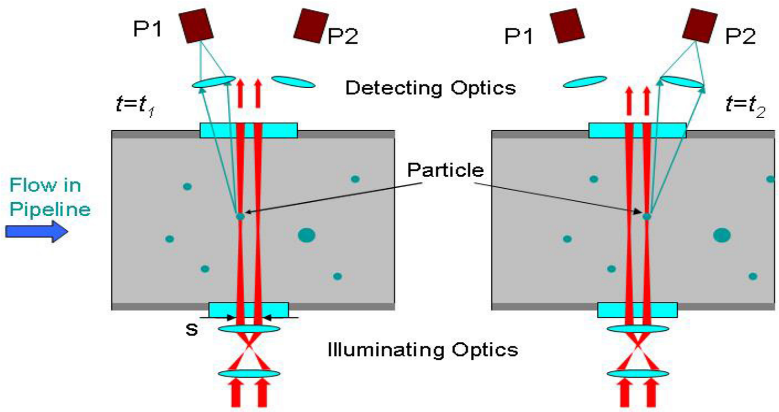

FIGURE 1: L2F Basics

With this L2F method, we can measure the linear gas velocity with high accuracy independent of pressure, temperature and gas composition. Photodetectors register individual photons, which allow them to use relatively low power lasers. The collecting optics collect the scattered light within as large a solid angle as possible while blocking all direct light. Light scattering efficiency is determined by the size of the particles and the laser wavelength. L2F velocimeters operating at near-IR (850nm) can measure the velocity of air with a minimum particle diameter of approximately 0.3 µm. Shortening the laser wavelength reduces this minimum detectable particle size to less than 0.1 µm. During the early development of the Focus™ OFM, particles found in a typical gas pipeline were shown to range from 1 to 10 µm.

The turn-down ratio is probably the most important parameter of any flare gas meter. The minimum velocity for Photon Control's Focus™ OFM is defined by the presence of particles – the dirtier the gas, the lower the possible minimum velocity. It has been shown that flow through the OFM can be measured down to Vmin =0.1 m/s. High Vmax has been tested up to Vmax=150 m/s, which is used to define the OFM turn-down ratio as 1500:1.

System Configuration

The Focus™ OFM consists of an optical head and a signal processing unit, which are connected by a fiber optic cable (see Figure 2). The basic Focus™ OFM probe (see Figure 3) developed by Photon Control is designed to fit into a standard ANSI flange. The signal processing unit (or opto-electronic converter) is designed on one electronic board, which fits into a normal NEMA or an explosion proof enclosure.

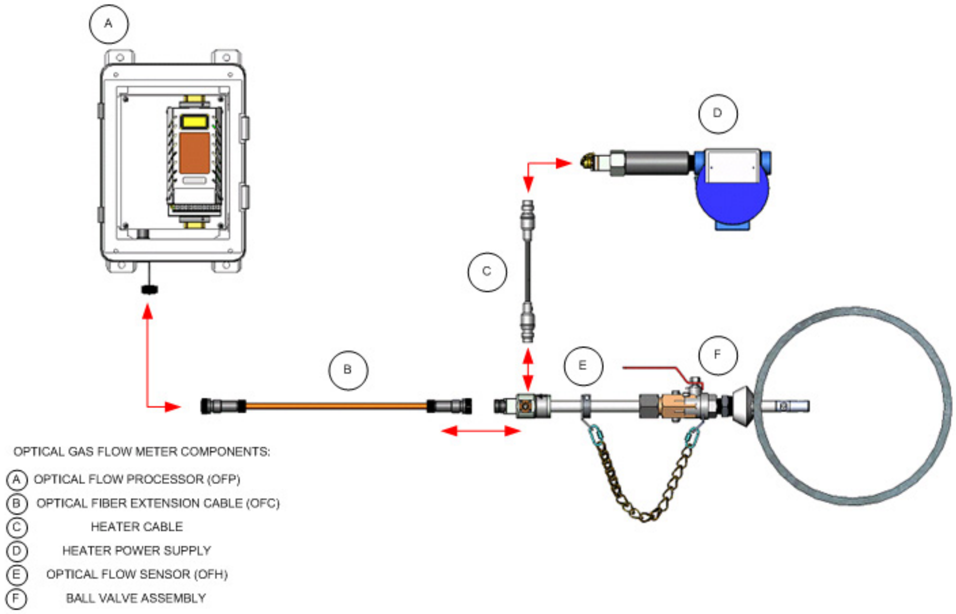

FIGURE 2: The Photon Control Focus™ Optical Flow Meter System

FIGURE 3: The Focus™ Optical Flow Meter Probe

The board incorporates a digital signal processing (DSP) chip with internal analog-to-digital conversion at sample rates up to 12 MHz. It has inputs for pressure and temperature transmitters, so that various flow calculations can be performed. The unit provides typical flow meter outputs: 4-20 mA, frequency and pulse, and RS-232 or RS-485 digital. The board is powered from 24 VDC; the average power consumption is 3 watts.

Signal pulses are collected over a fixed sampling interval, which is determined from the flow rate and number of particles in the gas. The raw flow velocity is calculated using a fast correlation technique (correlogram). The raw velocity data is then input to a post-processing calculation. The post processing filters average the output and remove spurious readings based on previously calculated data (see Figure 4). The flow profile correction is used to calculate the average flow velocity (bulk velocity) from the point velocity reading using a programmable look-up table specific to the piping and meter configuration.

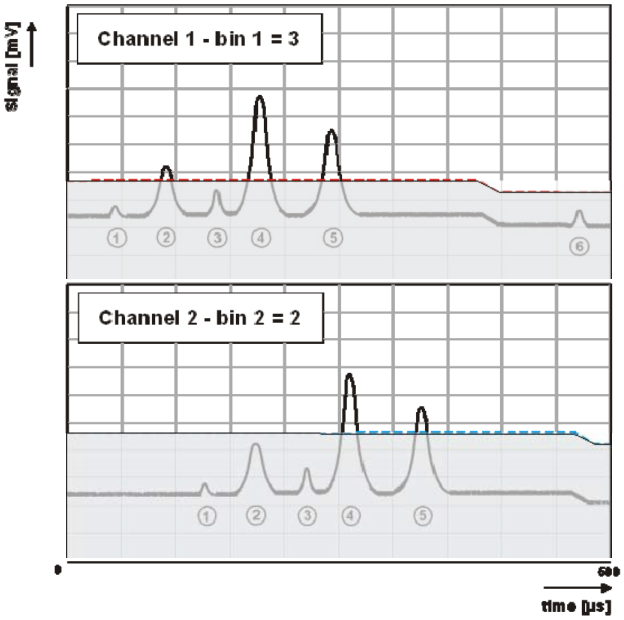

FIGURE 4: Photodetector Light Scatter Signals (after Threshold Filter)

The fiber optic cable accommodates a group of single-mode and multi-mode fibers protected by a flexible metal conduit and a waterproof indoor/outdoor PVC jacket. The standard length of the cable is 20 meters, but the power budget of the system allows extension of the cable length far beyond 100 meters.

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Applications

As with any technology, there are numerous practical issues that a user may encounter in real world installations.

Contamination of optical components is an inevitable concern when contemplating a flow measurement system using optics in a flare gas environment. This is especially so with flare gas, which generally has a variable composition and liquid content. We addressed this issue at the beginning of our Focus™ OFM probe development by implementing a shroud design. This solution dramatically improved the resistance of the device to concurrent liquid hydrocarbons, which are known to cause problems for other types of flare meters.

Another improvement aimed at the problem of liquids dropping out of the gas was the application of heated windows. In early commercial installations, it was discovered that many flare and biogas facilities deal with wet gas. Keeping the windows warmer than the ambient gas prevents laser light from scattering due to foggy or wet window surfaces. This has now become a standard feature for all OFMs produced by Photon Control.

Hundreds of Photon Control's laser-two-focus Focus™ OFMs have been supplied and installed in the field since commercialization began. Applications include flare gas and associated gas flow measurement in pipe sizes from 4 inches to 30 inches, fuel gas measurement in natural gas pipelines, and biogas flow metering.

Installation Planning

Feedback from the Focus™ OFM installers revealed that the four most important elements are:

(1) robust electronics,
(2) a protective shroud,
(3) a way of retrieving the probe without shutdown (retractable device), and
(4) a calibration curve to move to within an acceptable accuracy of +/- 5%.

The Focus™ OFM can be used in a pipe with a diameter between 4 and 30 inches. A key requirement is to only install the OFM after 20 diameters of straight upstream length and before 5 diameters of straight downstream length. This allows for the flow profile to be fully developed at the point of measurement (see Figure 5).

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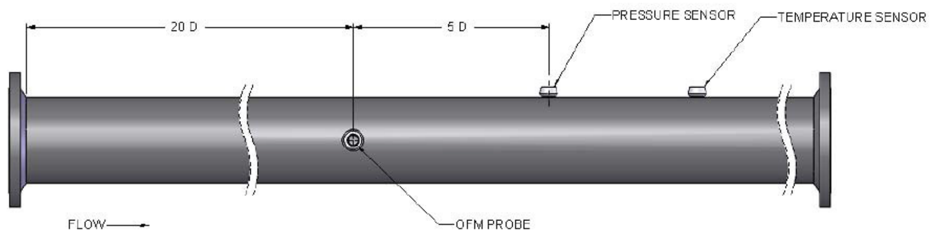

FIGURE 5: Correct Placement of the Focus™ Optical Flow Meter

The advantages of accurate flare metering include:

- meeting regulatory and environmental requirements,
- a better understanding of the facility process, and
- making decisions based on good data.

In many facilities, a large quantity of background gas goes up the stack unnoticed. Flare reduction is not just an environmental responsibility; it affects the facility's bottom line. Wasted gas is lost profit and, more important, an unnecessary environmental load.

Installation Examples

One of the most important factors when determining the ideal installation location is to follow the 20/5 rule: probe placement at least 20 diameters downstream and 5 diameters upstream. Without following that rule, there will be an unpredictable flow profile.

FIGURE 6: Installation Example: Not Ideal

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Note the image at Figure 6. This location is not ideal because the probe's location is less than 20 diameters downstream of a 90º elbow. Installing the device in this location will not allow the flow profile to fully develop.

FIGURE 7: Installation Example: Ideal

Note the image in Figure 7. This is an ideal location – the probe is installed at a 3 o'clock or 9 o'clock position, which minimizes the settling of dirt on the probe optics. There are more than 20 diameters of uninterrupted straight length upstream of the probe location, which allows the flow profile to fully develop. The pressure and temperature sensors are located downstream of the probe location, which prevents flow disturbance. The NEMA 4X enclosure and the heater power supply can be installed by a flare line support post. See Figure 8.

FIGURE 8: NEMA4X Enclosure and Heater Power Supply

Calculating Insertion Depth

Before installing the Focus™ OFM, it is necessary to calculate and mark the correct insertion depth on the probe. The actual sensing point for the probe is 1.65” (42mm) from the end of the probe. For 6” and larger pipe diameters, the sensing point should be positioned at the quarter radius point of the pipe for accurate readings. For a 4” diameter pipe, this measuring point should be positioned at the centre point of the pipe for accurate readings.

Pressure and Temperature Compensation

Pressure and temperature compensation is mandatory for gas volumetric flow rate correction since pressure and temperature differences will cause volume to vary as stated by ideal gas law.

The American Gas Association (AGA) publishes various reports describing how to measure the flow of natural gas, starting with AGA Report No. 1 issued in 1930, which described the measurement of natural gas through an orifice meter. By 1980, AGA Report No. 7 – Measurement of Fuel Gas by Turbine Meters – was published, detailing the measurement of natural gas through a turbine meter.

By applying the American Gas Association’s AGA-7 guidelines, we can recalculate actual conditions to base conditions.

Calibration Checks

Calibration is typically performed by comparing velocity measurement against a multi-path ultrasonic meter or sonic nozzles. Linearization coefficients based on a bulk to raw velocity ratio are collected then plotted against the reference meter’s Reynolds number. Full-range calibration can only be performed by a limited number of facilities, such as the Colorado Experiment Engineering Station Inc. (CEESI) due to the Focus™ OFM’s wide velocity range (0.1 to 150 m/s).

Conclusion

While the stated goal of the project was to create precise optical flow meters for the oil & gas industry optimized for measuring flare gas flow in explosive atmospheres, the flow meter that was developed is now being used by a myriad of customers outside of the oil & gas industry.

We exceeded our expectations with respect to ease of installation, accessibility and servicing. Furthermore, our measurement range, from 0.1 m/s to 150 m/s, surpassed our initial plans, giving us the desired turn-down ratio of 1500:1.

Ultimately, Photon Control was able to cost-effectively measure high CO_2 gas flows as well as low pressure, high dynamic range conditions with measurements not affected by gas composition.

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