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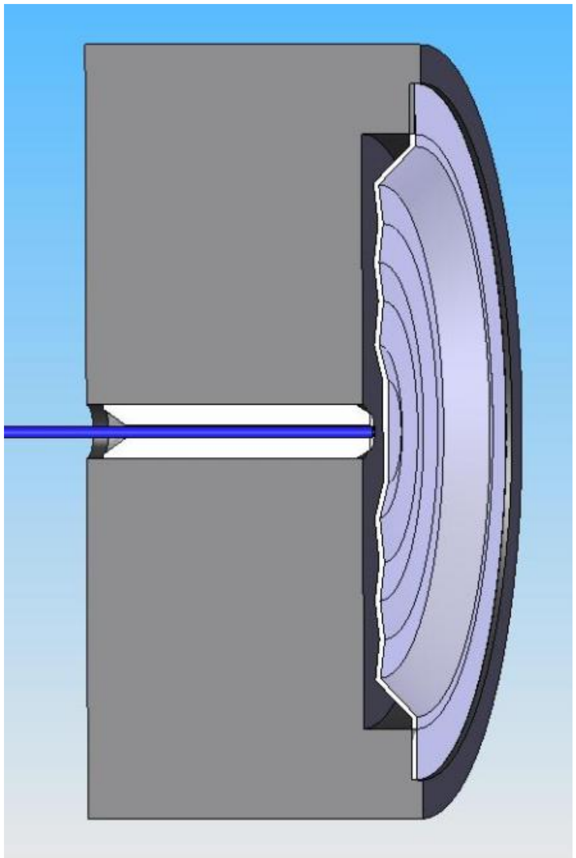
DavidsonSensors™

Fiber Optic Sensing Basics



Davidson Fiber Optic Sensing System

- DavidsonSensors™ Measure Temperature, Pressure, Vacuum, Flow, Level, and Vibration
- DavidsonSensors™ Transmit Intrinsically Safe Signals to Passive Fiber Optic Transducers
- DavidsonSensors™ are Immune to Lightning Damage and Grounding Problems
- DavidsonSensors™ are Immune to Electromagnetic and Radio Frequency Interference (EMI/RFI)
- DavidsonSensors™ Operate at 1000°F
- DavidsonSensors™ are Easy to Install and Require Very Low Maintenance

Fiber Optic Sensing Basics

1. Introduction

Fiber optic sensing technology offers a number of advantages for measurement in harsh industrial environments. Fiber optic transducers are tolerant to high temperatures, intrinsically safe, and immune to electromagnetic interference. Since many fiber optic transducers can be multiplexed with a single signal conditioner, significant cost savings can be achieved. To realize the full potential of this technology, it is helpful for the user to understand some of the basics of fiber optic sensing.

This guide is intended to help the new user understand the basics of DavidsonSensors™ fiber optic sensing systems. For more advanced information to help with the planning of a fiber optic sensing system, see the Davidson Guide to Configuring a Fiber Optic Sensing System which is available at www.davidson-instruments.com. For more detailed technical information about fiber optic sensing systems, see Davidson technical publications at www.davidson-instruments.com/techpubs.html.

2. Safety

Davidson has designed its systems for industrial applications. The systems are eye-safe and intrinsically-safe. DavidsonSensors™ use broadband white light from tungsten lamps and narrow-band LEDs as the light sources. The amount of light energy transmitted into an optical fiber is not sufficient to cause damage to the eye and is not sufficient for ignition. The maximum energy transmitted in a fiber is below the standards set by ANSI/ISA-TR12.21.01-2004, Use of Fiber Optic Systems in Class I Hazardous (Classified) Locations.

3. Optical Fiber

Fiber optic sensors use optical fiber and light to make useful measurements of temperature, pressure, and other physical parameters. Optical fibers are strands of glass that transmit light over long distances and are the equivalent of wire in electronic systems. The glass optical fibers are 0.005 inch in diameter and are protected from damage by acrylate, polyimide, plastic, or metal coatings. Once properly protected, the delicate glass fibers operate maintenance free for years.

4. Sensing Theory

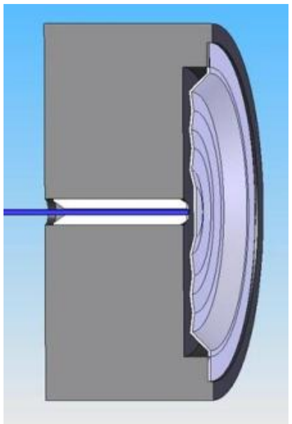
Davidson fiber optic sensing systems are based on white light interferometric sensing technology using extrinsic Fabry-Pérot sensors. The same Fabry-Pérot sensing technique is used regardless of whether the parameter being measured is temperature, pressure, vacuum, flow, level, density, vibration, or acceleration.

The sensor consists of two partially reflective and parallel surfaces that are placed in close proximity to one another and coupled to an optical fiber that transmits the light. One of the reflective surfaces is held in a fixed position while the other reflective surface moves (transduces) in response to an environmental stimulus such as temperature or pressure. The light reflected from the sensor experiences a phase modulation that is caused by the interference of the reflections at these two surfaces. The characteristics of the modulation are defined by the reflectivity of the two surfaces in the sensor, the wavelength of light transmitted to the sensor, and by the length of the sensor gap. Two scientists, Charles Fabry and Alfred Pérot, first documented this phase modulation in 1899 and the equation that defines the modulation is called the Fabry-Pérot equation.

$$I(\lambda, d) = \frac{F \sin^2\left(\frac{2\pi d}{\lambda}\right)}{1 + F \sin^2\left(\frac{2\pi d}{\lambda}\right)}$$

5. Practical Transducers

In practical pressure measurement applications, the second reflector is attached to a metal diaphragm and process pressure deflects the metal diaphragm. At full scale pressure, for example 3000 psi, the diaphragm deflects approximately 0.0005 inch or 12,700 nanometers (for reference consider that a dollar bill is 100,000 nm thick). Since the signal conditioner can resolve changes of less than a nanometer, the system is able to make precise measurements of the pressure. Temperature sensors are made by using two materials with slightly different coefficients of thermal expansion. As the temperature changes, the difference in the expansion rates of the two materials causes the gap to increase or decrease. As in the pressure sensor, the full range of displacement is only 0.0005 inch. A temperature sensor may be inserted into the pressure transducer and used to make corrections of the pressure output based on the actual temperature of the transducer. In this manner, the accuracy of the pressure measurement is improved.



5. Cabling and Connector Considerations

The fiber optic cabling and connectors used for telecommunications systems may not be appropriate for fiber optic sensing systems. Unlike telecommunication systems which use a very narrow band of light and share many signals on a single fiber, Davidson's discrete fiber optic sensing systems require a dedicated fiber for each sensor. The characteristics of the optical transmission fibers in the cable must match the characteristics of the optical fiber used in the transducer and signal conditioner or severe degradation will occur. The standards of acceptable quality of the connectors and terminations for fiber optic sensing systems exceed the standards for telecommunication systems.

6. Signal Conditioning

A fiber optic signal conditioner is the equivalent of a transmitter in conventional electronic sensing systems. During operation, the signal conditioner sends a pulse of light in sequence to each of the interferometric transducers. The light signal received from each transducer is focused through a lens and transmitted through a Fizeau interferometer (optical wedge) and onto a CCD array. The Fizeau interferometer acts as an optical cross-correlator and instantly converts the modulated light into a cross-correlated signal that is projected onto a linear CCD with thousands of pixels. The effect of the cross-correlation is that the peak of the signal occurs at that location on the CCD where the optical length of the interferometric gap in the sensor matches precisely with the optical length of the interferometric gap in the Fizeau interferometer. Each pixel in the CCD is calibrated to a precise optical thickness in the Fizeau interferometer.

The CCD converts the light signal into an electronic signal that is processed by a microprocessor. The microprocessor in the signal conditioner converts the peak signal into a known length of gap. Through rigorous calibration done at the factory, the calibration constants are known for each transducer and loaded into the microprocessor. The microprocessor converts the known gap into the proper engineering units, (i.e. psig, inches of water, °F), for the transducer.

Since all of Davidson fiber optic sensors are based on the same interferometric sensing technology, different measurands can be multiplexed and processed by a single signal conditioner. Multiplexing a variety of sensors with a single signal conditioner allows multivariate signal processing, error correction, etc. The result is unprecedented measurement accuracy in harsh industrial environments. Once the measurement is corrected and converted into the appropriate engineering units, the signal conditioner then transmits the measured result to the process control system based on the specified analog or digital protocol, i.e. 4-20mA analog or RS-485 Modbus digital protocol. Ideally, a multi-channel signal conditioner is located in a control room environment and interrogates multiple transducers. The signal conditioner can be packaged in a 19" rackmount, NEMA enclosure, or explosion-proof container.