Practical Application of Industrial Fiber Optic Sensing Systems

John W. Berthold and David B. Needham
Davidson Instruments, Inc. P.O. Box 130100, The Woodlands, TX 77393

ABSTRACT

In this presentation, we discuss an interferometric fiber optic pressure transducer used for making point measurements in an industrial application. We review the fiber optic sensing mechanism and the architecture of a fiber optic sensing system.

Fiber optic sensing systems are presently used in harsh industrial environments for the measurement of pressure, temperature, differential pressure, strain, position, vibration, and acceleration. The major technical advantages of fiber optic transducers include small size, inherent safety, immunity to EMI, and continuous use at temperatures up to 1000°F.

Fiber optic sensing systems can be configured as distributed sensing systems or point sensing systems. In this presentation, point sensing systems are discussed. Point sensors are suitable for plant operations where a variety of measurements are needed in thousands of locations. Fiber optic point sensing systems are extremely attractive for harsh industrial applications where conventional sensors cannot survive.

Fiber optic transducers look nearly identical to electronic transducers. The only outward difference is a fiber optic connector on the transducer or cable pigtail. On the inside, each fiber optic transducer contains a fiber optic sensor that replaces the strain gages or piezoelectric crystal sensors used in conventional transducers. The fiber optic sensors discussed in this presentation are identical – they all measure displacement, but the sensors are packaged into different transducers to measure, for example pressure, temperature, or strain. Since the interferometric fiber optic transducers (i.e. pressure, temperature, differential pressure, strain, and position) within a system have identical fiber optic sensors, the signal conditioners/transmitters used to convert the optical signals into electronic signals can also be identical. This feature along with immunity to electromagnetic interference (EMI) allows fiber optic systems to be configured with a variety of sensors and multiplexed with a single signal conditioner/transmitter. For example, one signal conditioner may be used to monitor an array of thirty-two transducers that measure temperature and pressure through a single access point in a fractionation column.

Significant benefits result from using such fiber optic sensing systems and these include increased system reliability, reduced installation and maintenance cost, and the ability to make measurements in harsh environments where conventional sensors simply cannot survive.

Keywords: Pressure, temperature

1. INTRODUCTION

Low power fiber optic process control instrumentation is ideal for use in refineries, chemical plants, power plants, oil production facilities, or in any hostile environment because the sensors are intrinsically safe. They pose no danger even in hazardous areas where explosive vapors may exist. The fiber optic systems described in this paper operate at less than 50% of the power level deemed intrinsically safe. Instrumentation installation and maintenance costs can be significantly reduced because low power fiber optic sensing systems do not require explosion-proof conduit and containment.

For many years, fiber optic sensors have been touted to be immune to electromagnetic interference and suitable for use near high voltage electrical systems. Because optical fibers cannot conduct current, fiber optic sensors eliminate problems associated with lightning and ground loops. They are tolerant of high concentrations of hydrogen and corrosive environments. The small size and lightweight characteristics of fiber optic sensors make the sensors ideal for most industrial applications.

The fiber optic sensors we have developed are Fabry-Perot type interferometric sensors. A basic Fabry-Perot sensor consists of two parallel reflective surfaces separated by a gap. We have designed and demonstrated Fabry-Perot fiber optic sensors in transducer packages that operate at temperatures from -55°F to 1000°F. This performance enables measurements in process conditions that are not possible with conventional electronic sensing technology. Use of fiber optic sensors results in significant cost savings in applications such as in severe cold where need for impulse lines, capillary tubes and the associated weatherization hardware can be eliminated. Significant process improvements and increased margins of safety can be achieved through the application of this enabling technology.

Fiber optic sensors can and have been used in industrial environments to measure temperature, pressure, vacuum, linear and rotary position, strain, vibration, and acceleration. Specific signal conditioners for optoelectronic conversion can be designed for high resolution, fast dynamic response, and/or for long transmission distances. The signal conditioners can communicate with any open
architecture ranging from digital RS-232 to 4-20mA and 0-5V analog. The signal conditioners can be dedicated to a single sensor for high-speed data acquisition or they can be multiplexed in large numbers to a variety of sensors to drive down the system cost.

Ruggedized cabling and multipoint connectors are used to interface and transmit optical signals from harsh environments to the signal conditioner in a non-hazardous location hundreds or even thousands of feet away. In the process control industry, fiber optic instrumentation is rapidly becoming recognized as safe, economical, and reliable.

2. OVERVIEW OF SENSOR TECHNOLOGY

The sensors described in this paper are based on Fabry-Perot displacement sensor technology.

For individual measurement parameters such as pressure and temperature, the transducer is designed to measure displacement that results from a change in that parameter. For example, the displacement transduction mechanism for a pressure sensor is the deflection of a diaphragm. The displacement transduction mechanism for a temperature sensor is based on the difference in the coefficient of thermal expansion between two materials. Temperature, pressure, vacuum, density, strain, acceleration, rotary and linear position, and vibration can all be measured by designing transducers that convert the measurement parameter to a change in displacement that can be measured by a Fabry-Perot displacement sensor. The full-scale design displacement of any sensor is less 12µm (< 0.0005 inch).

The resulting stress on transducer components is very small and the measured displacements are very repeatable. For example for pressure sensors, the deflection is so small enough that the maximum stress at design pressure is generally less than 25% of the elastic limit of the diaphragm. The optical interrogators inside the signal conditioners can resolve sub-nanometer displacements, which provides for large dynamic range and repeatability that is more than adequate for most industrial applications. A resolution of 1 nanometer over a displacement range of 12µm is equivalent to 1 part in 12,000.

In comparison, electronic sensors rely on a variety of technologies to perform a measurement. For example, thermocouples produce an electromotive force (EMF) and require a different signal conditioner than a strain gage that produces a change in resistance or a piezoelectric crystal that produces a change in dynamic voltage. Since each of the Fabry-Perot fiber optic sensor/transducers discussed in this paper contains the same basic Fabry-Perot displacement sensor, the same signal conditioner can be used for any sensor by simply defining the type of sensor along with the calibration constants. Thus, a variety of sensors may be multiplexed to share a single signal conditioner, which reduces overall cost and increases reliability. In addition, multiplexing facilitates thermal correction to be built into a pressure sensor to increase the effective range and resolution of the sensor.

The fiber optic signal conditioner uses interferometry to determine the displacement of each sensor. In all cases, changes in displacement are measured through a phase shift of the modulated light. The sensor detects the change in separation (gap) between two parallel mirrors (Fabry-Perot configuration) to perform displacement measurements, and the absolute measurement of the gap is converted into engineering units based on the calibration constants for a given sensor. Finally the signal is transmitted by the signal conditioner to a control system via a variety of standard communication protocols – digital or analog.

3. PRODUCTION PRESSURE SENSORS

Shown in Fig. 1 is a fiber optic pressure transducer with a ½ inch NPT fitting. The assembly contains two Fabry-Perot fiber optic sensors – one to measure the deflection of the diaphragm and the other to provide a temperature correction signal that corrects for thermal offset and temperature dependent change in Young's modulus of the diaphragm. The pressure diaphragm is shown on the left end and a fiber optic cable with two fibers exits the opposite end.

Fig.1 Photo of fiber optic pressure transducer assembly and cable.

Shown in Fig. 2 is an 8-channel signal conditioner. Fiber optic assemblies are located in the boxes at the bottom of the photo and the 8-channel printed circuit board with light sources is shown at the top of the photo.

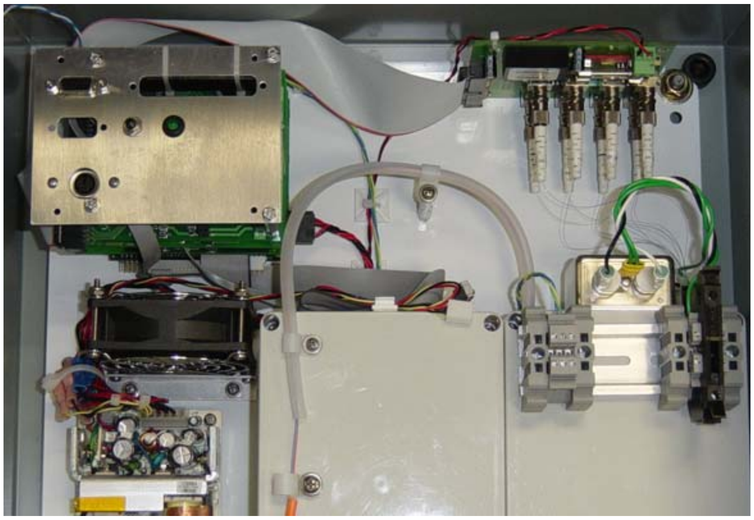

Fig.2 Photo of 8-channel signal conditioner.

Characterization data for two production pressure transducers with 800 psi range is shown in Fig. 3. The results indicate the repeatability of the manufacturing and production process. The sensitivities (slopes) of each transducer unit agree within 2.5%. The zero-pressure Fabry-Perot gaps agree to 4%. Pressure repeatability at constant temperature (150°F) is 0.05% of full scale.

Similar data for two Fabry-Perot fiber optic temperature sensors is shown in Fig. 4. The sensitivities each production unit agree within 0.2% and the offset gap between the two is 4%. Temperature repeatability is 0.6°F.

Fig. 5 is a plot of actual transducer calibration data. The data shows pressure response of the assembly (PT1004). The total error within 2σ limits is 1.75 psi (0.2% of full scale pressure).

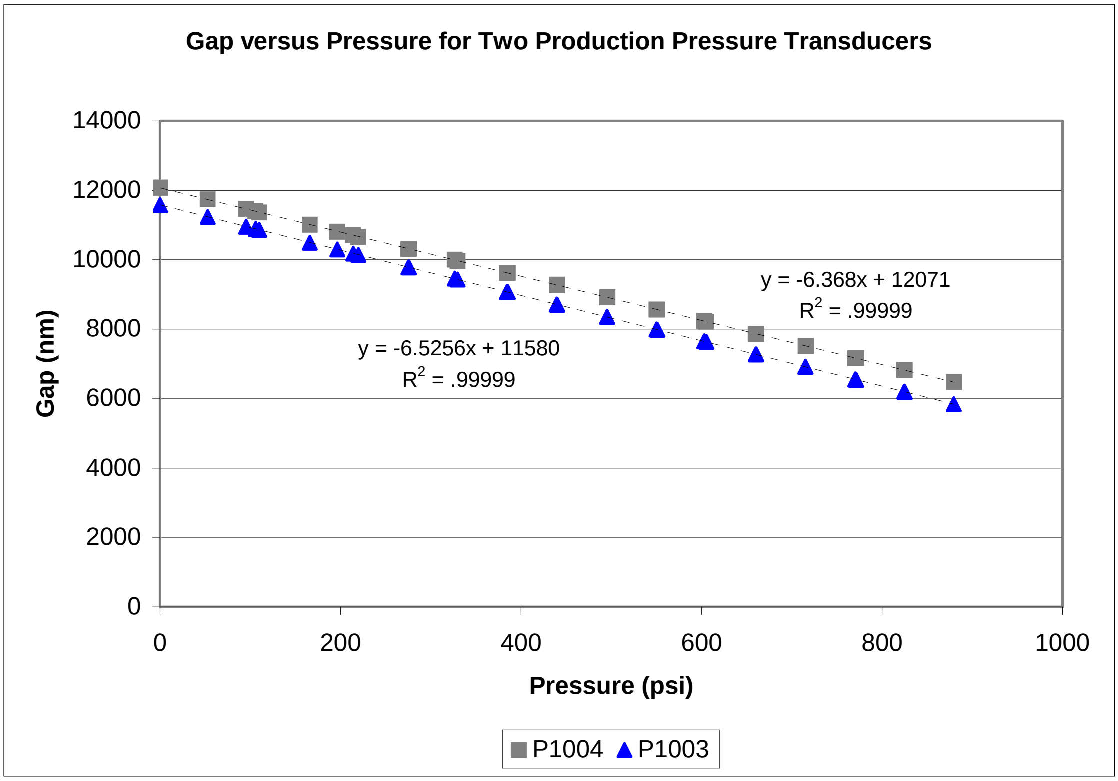

Fig. 3. Measured gap versus pressure for two production pressure sensors at 150°F.

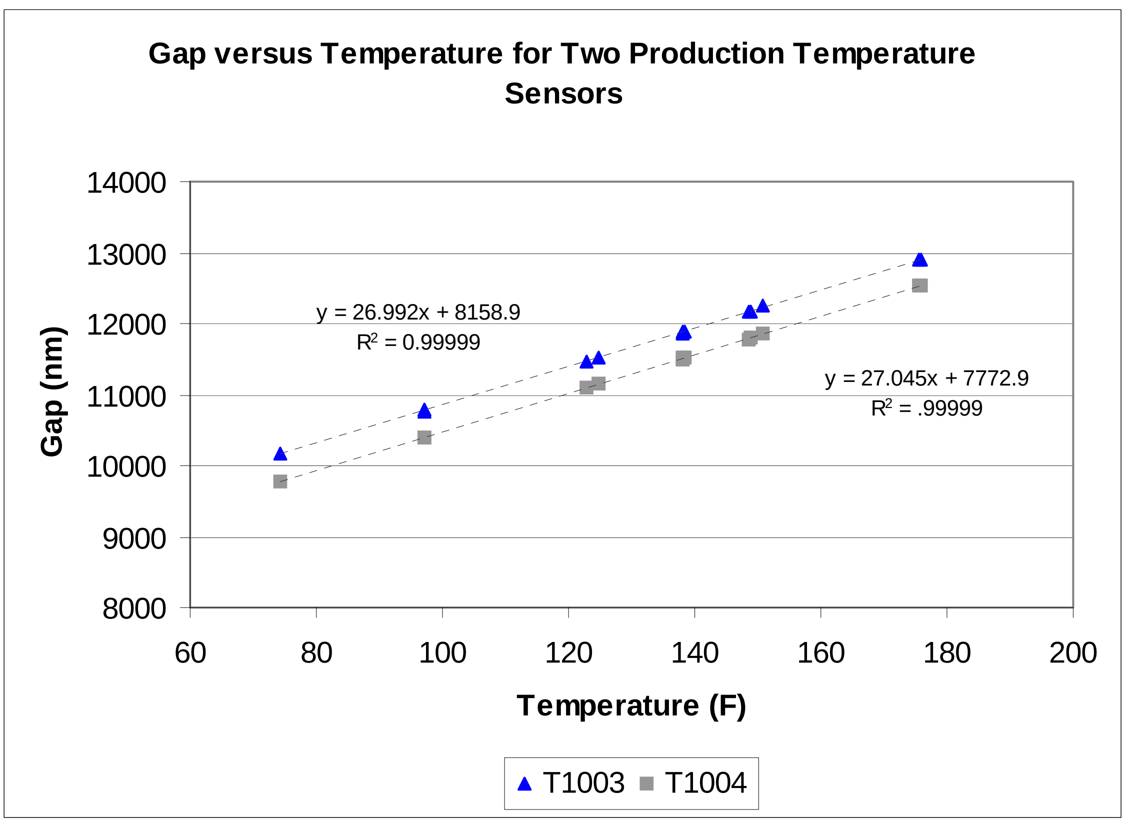

Fig. 4. Measured gap versus temperature for two production temperature sensors.

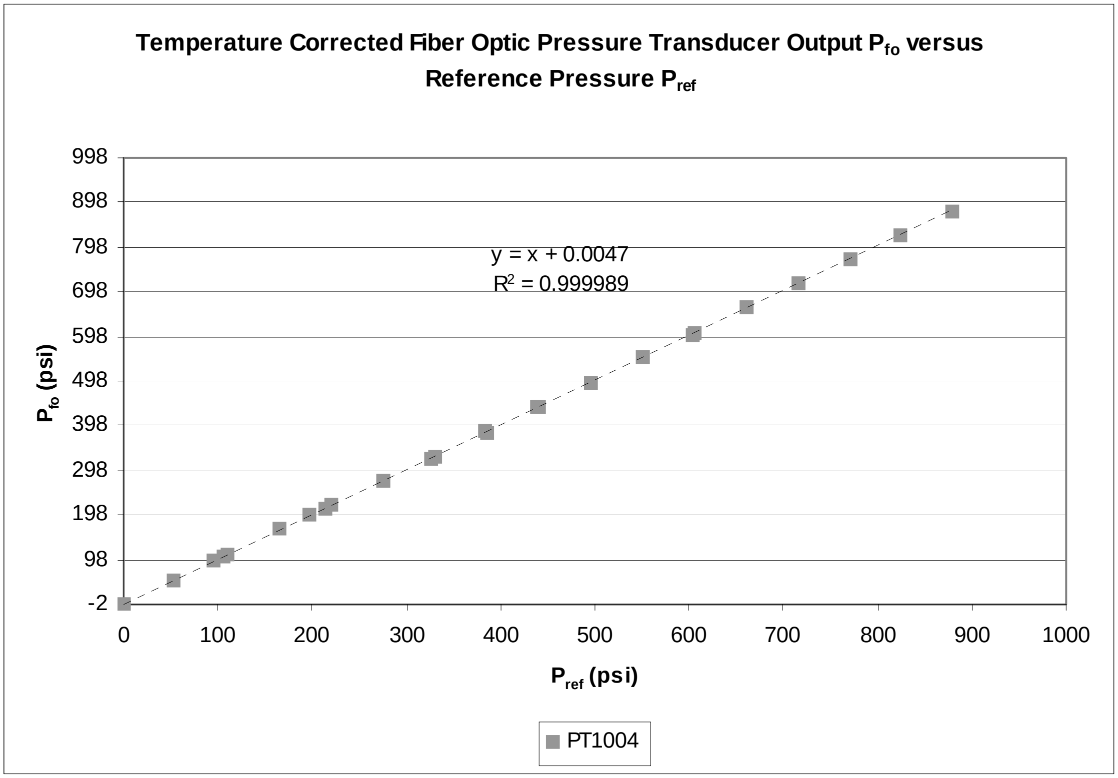

Fig. 5. Temperature-corrected fiber optic pressure versus pressure for manufactured pressure transducers. 2σ error = 1.75 psi (0.2% FS)

7. CONCLUSIONS

The advantages of fiber optics for industrial process control instrumentation are significant. The technology is mature; the infrastructure to support industrial fiber applications is in place; and the cost of fiber optic sensing systems continues to fall while technical performance improves.

Fiber optic sensing systems have been designed and are being packaged to address the harsh environments of industrial process control. Sensors and signal conditioners have been tested under field conditions and have demonstrated seamless interface with existing distributed control systems. Integrated families of fiber optic sensors and signal conditioners are available to measure most physical parameters and systems are being used in refineries, chemical plants, power plants, and in oil and gas production facilities.

8. REFERENCES

1. J. W. Berthold and R. L. Lopushansky, "Intrinsically-Safe Fiber Optic Sensors Reduce Cost and Improve Process Control," Proceedings of ISA EXPO 2003, Houston, Texas, 2003.