SIcon/02 – Sensors for Industry Conference
Houston, Texas, USA, 19-21 November, 2002

Fiber Optic Sensors for the Refinery of the Future

J. W. Berthold, L. A. Jeffers, and R. L. Lopushansky
Davidson Instruments, Inc.
4800 Research Forest Drive
The Woodlands, TX 77381

Abstract* - We are manufacturing fiber optic sensors/transducers for the measurement of temperature, pressure, differential pressure, strain, vibration, acceleration and acoustic emission. The major technical advantages of our instrumentation are the small size, the inherent safety, immunity to EMI, and tolerance to high temperatures. Each transducer unit contains the same fundamental fiber optic sensor – a Fabry-Perot displacement sensor. For each individual measurement parameter such as temperature or pressure, the transducer is designed and packaged such that the transduction mechanism results in a displacement that is measured by the fiber optic sensor. The packages look similar to commercial transducers that use electronic sensors such as strain gages or piezoelectric crystals. Since our transducers all contain the same type of sensor, the signal conditioners are identical and as a result, we achieve significant benefits including increased reliability, reduced cost and capability to provide a single multiplexed system that can accept inputs from any type of transducer. In this paper, we discuss the Fabry-Perot sensing mechanism and the operation of the optical signal conditioner and readout electronics. We describe the results of an extensive characterization program performed on temperature and pressure transducers. We also discuss the multiplexing approach and communications options. Finally, we discuss other refinery measurement needs and transducers we are developing to make the measurements.

I. INTRODUCTION

We have developed and are commercializing fiber optic sensors in a suite of transducers for the measurement of temperature, pressure, differential pressure, strain, vibration, acceleration and acoustic emission. The major technical advantages of our instrumentation are the small size, the inherent safety, immunity to EMI, and tolerance to high temperatures. For each individual measurement parameter such as temperature or pressure, the transducer is designed and packaged such that the transduction mechanism results in a displacement that is measured by the fiber optic sensor. Each transducer unit contains the same fundamental fiber optic sensor – a Fabry-Perot displacement sensor.

II. BACKGROUND

Our transducer packages look similar to commercial transducers that use electronic sensors such as strain gages or piezoelectric crystals. However, our sensor signal conditioning instrumentation differs considerably from electronic sensors. For example, thermocouples that produce a thermal emf 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 our transducers all contain the same type of sensor, the signal conditioners are identical and as a result, we achieve significant benefits including increased reliability, reduced cost and capability to provide a single, universal multiplexed system that can accept inputs from any type of sensor in the suite.

III. SENSING METHOD

The Fabry-Perot displacement sensor is the fundamental sensor in our various transducers. Figure 1 is a schematic view of the entire sensing system with a light signal processor used in conjunction with the sensor. The Fabry-Perot sensor consists of two reflective surfaces spaced apart from each other. In a pressure transducer, the gap is defined by a reflective diaphragm and the reflective end of an optical fiber. When pressure changes, the diaphragm deflects and the thickness of the gap decreases. In a temperature sensor, the gap is defined by the reflective ends of two optical fibers fixed to the ID of tube. When the temperature changes, the tube expands or contracts and the gap thickness changes accordingly. When light reflected from the gap is plotted versus wavelength, the result is a series of interference fringes shown in Figure 2. When the thickness of the gap changes, the fringe pattern shifts along the wavelength axis. Precise measurement of the shifts in the fringe pattern enables precise measurement of temperature or pressure with changes in the Fabry-Perot gap.

An optical fiber delivers broadband light to the Fabry-Perot sensor as shown in Figure 1. Light reflected from the sensor gap reenters the same fiber and returns to a fiber power splitter, which delivers a portion of the light to a mirror. The mirror reflects the light to a wedge-type optical interference filter. Exiting the wedge is a spatially spread light signal indicative of the spectral characteristics of the light reflected from the Fabry-Perot gap. The light signal is converted to an electronic signal with a CCD detector. The thickness of the gap is determined by measurement and analysis of the spectrum of the spatially spread light signal.

IV. TEMPERATURE TRANSDUCER TESTS

We have performed extensive tests on our fiber optic temperature transducers. Initial tests were performed on 15 transducers mounted in a thermal mass with reference thermocouples. The thermal mass was placed inside a furnace, which was cycled three times between ambient and 500^{o}F. Typical results are shown in Figure 3 for one of the transducers tested. The combined test results for all 15 transducers demonstrated a 95% confidence repeatability of +/- 3^o F over a 500^o F temperature range. The repeatability of the best transducer was +/- 1.2^{o}F and the worst was +/- 4.4^{o}F.

Presently, we are completing the construction of a 32-channel temperature measurement system. The system layout is shown in Figure 4. Each temperature transducer performs a separate point measurement. Thus we have 32 optical fiber leads from the multiplexer to the transducers. Multiplexing is performed by sequentially lighting 32 sources. All 32 light signals from the transducers deliver light to the mirror shown in Figure 1 and each signal is read by the CCD when the light source for each sensor is turned on.

V. OTHER FIBER OPTIC TRANSDUCERS

In addition to temperature measurement, a host of different pressure measurements are performed in a refinery. We have manufactured and are presently testing both gage and absolute pressure transducers to cover the measurement ranges 100 psi, 500 psi, 1000 psi, and 3000 psi. In addition, we are manufacturing and testing a differential pressure transducer with a range of 400 inches of H2O and a vacuum transducer with a range of 0 to 10 Torr.

In addition, we have manufactured and are testing proximity sensors, vibration sensors and accelerometers that have acoustic frequency response of 20 kHz and 200kHz.

VI. CONCLUSION

We have demonstrated a dynamic range of 10,000 for our Fabry-Perot displacement sensors. The results of an extensive characterization program performed on 15 temperature transducers demonstrate a repeatability of +/- 3^o F over a 500^o F temperature range. Presently, we are completing the construction of a 32-channel temperature measurement system, and are testing other transducers to measure pressure, differential pressure, vacuum pressure, vibration and acceleration.

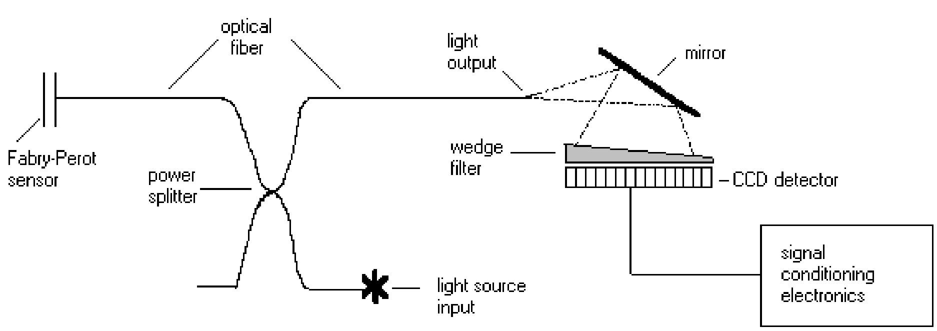

Fig. 1. Schematic diagram of fiber optic sensing system.

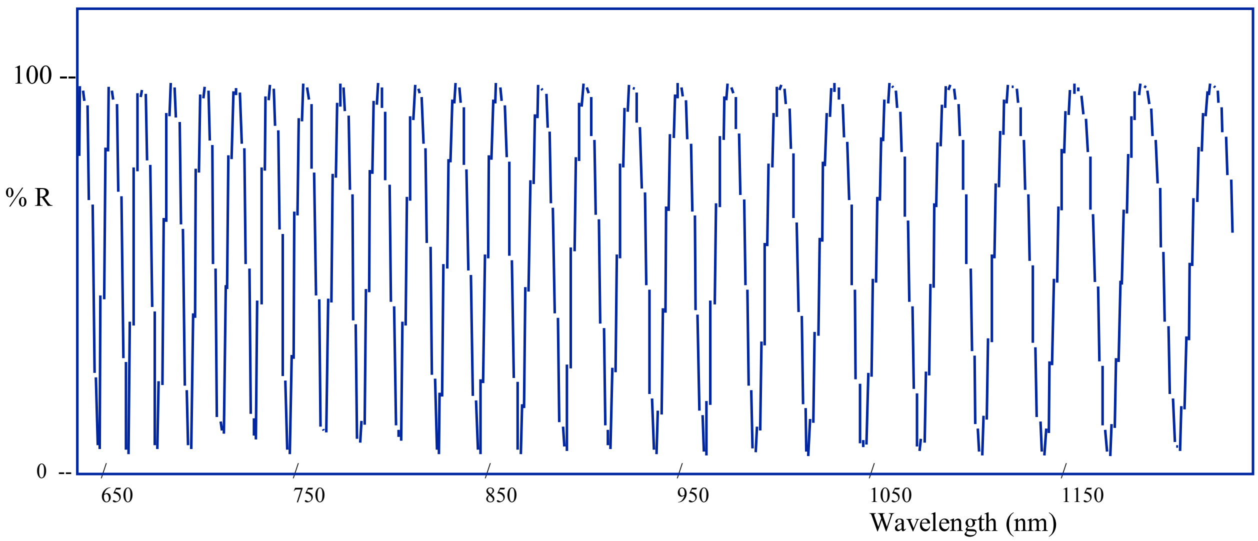

Fig. 2. Percent of light R versus wavelength reflected from Fabry-Perot gap.

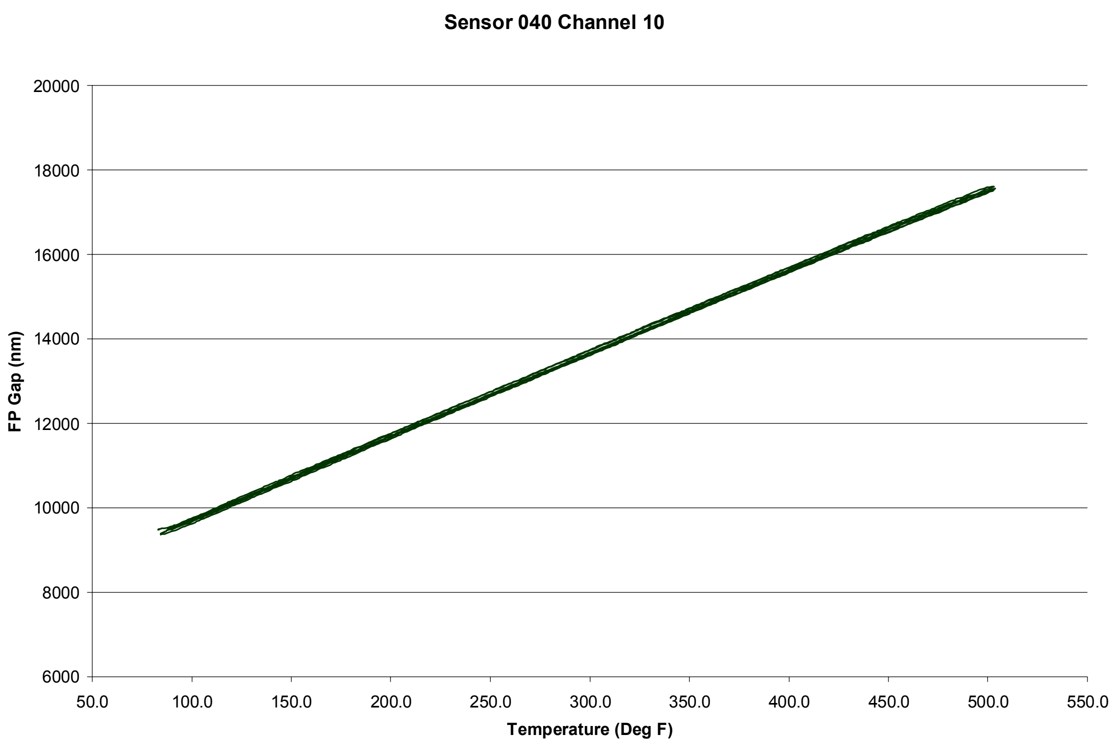

Fig. 3. Fabry-Perot gap versus temperature for one of fifteen sensors tested.

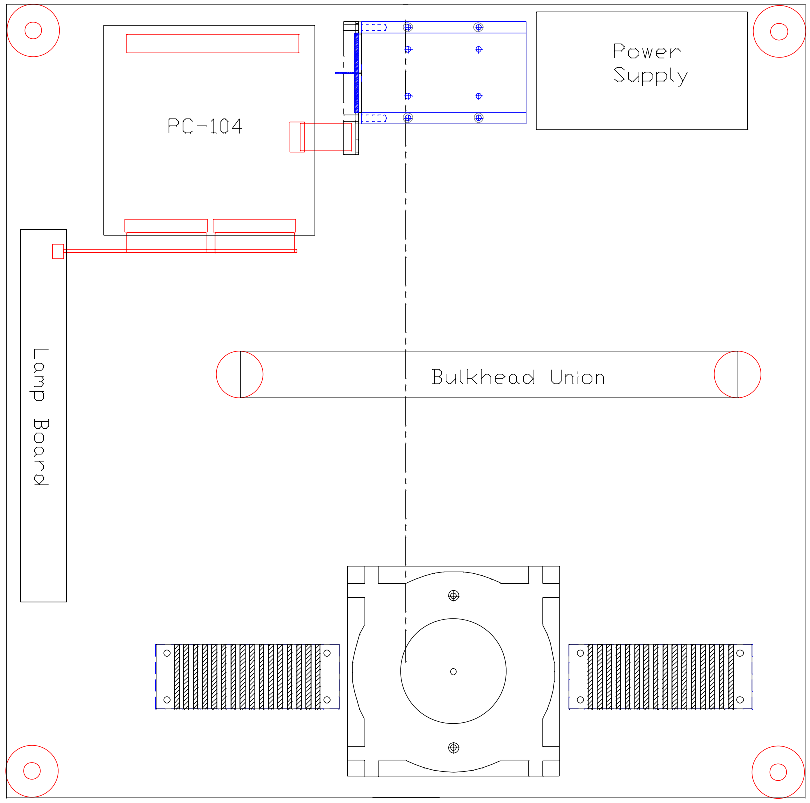

Fig. 4. Layout of 32 channel measurement system.