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A novel optical telemetry system applied to flowmeter networks

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ABSTRACT

Recently developed transducers utilise the unique characteristics of Deformed Helix Ferroelectric Liquid Crystal (DHFLC) to linearly and passively transduce small voltage signals into the optical domain. These small optical transducers can be retrofitted to an existing flowmeter network where the true benefits of distributed sensing in the optical domain can be leveraged. Signals from multiple sensors can be multiplexed into a single optical fibre for measurement at a remote location. We demonstrate two methods of signal measurement based on a positive displacement oval gear flowmeter. Utilising a reed switch to produce short pulses, errorless flow rate transduction is possible across all flow rates including very low flows. Using a variable reluctance sensor, completely passive transduction of flow rates can be achieved. The same technique can be applied to any sensing network with an electrical signal output.

1. Introduction

Accurate measurement of flow rate is of great importance to a wide range of industries including oil and gas, chemical and textiles, food production and the pharmaceutical industry. In many cases, measurements are undertaken in hazardous and explosive environments where use of electrical signals is not desirable. Additionally, measurement of flowrates at multiple points in the network requires individual copper wiring from each flowmeter to an upstream control box or Programmable Logic Controller (PLC), or labour intensive measurement of each flow at the location of the flowmeter. Several alternative solutions for distributed flow sensing have been explored, the main being wireless and fibre optic telemetry systems. Wireless does not require any cabling, but it needs power at the sensor and it is prone to Electromagnetic Interference (EMI). Fiber optic systems, on the other hand, require cabling, but are immune to EMI and have large bandwidth. Typical fiber optic telemetry systems are designed either to use the fiber only to transmit data using standard telecommunications protocols, or to use the fiber itself as a flow sensor. Telemetry systems of the first type need power and some processing at the sensor location, while systems of the second type can be passive. For example, most of the fiber optic flowmeters use scattering effects inside fibres or bending losses due to increased flow around a fibre coil [1–3]. Spatial resolution can be very high using some methods and can be particularly useful in wellhead measurements in the petroleum industry, although flow profiles are inferred through acquisition of temperature data [4]. Additionally, methods employing tiny variations in acoustic or seismic environments around a fibre are also employed [5].

Here, we propose and develop a system allowing for the retrofitting of a point network of existing flowmeters with a low cost, novel optical transducer technology that brings with it a range of benefits. Recent innovation in the area of liquid crystal (LC) based optical sensors has seen the development of small passive transducers that indicate a wide variety of possible uses, including, but not limited to: flow measurement, hydrophone arrays, voltage measurement, pulsed lasers and biomedical applications [6–8]. The transducers utilise Deformed Helix Ferroelectric Liquid Crystal (DHFLC) to linearly transduce small voltages into optical signals. Through integrating the transducers with standard optical fibre technology, the unique benefits of using light can be realised. Multiple signals can be combined (multiplexed) onto a single optical fibre for measurement and analysis at a remote location, giving rise to simple, cost-effective distributed sensing of the flow network. Additionally, acquisition of flow rate signals from

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locations with flammable or explosive environments is intrinsically safe using optical methods.

Many different types of flowmeter are in use. In this paper, we demonstrate the transduction approach using positive displacement flowmeters of an oval gear type. These flowmeters are widely used due to their simplicity and also because of their durability, accuracy and suitability for use with more viscous liquids [9]. Rotation of the oval gears is measured indirectly through the production of a small voltage signal in a number of ways. We use two types to demonstrate the effectiveness of our technique: active flow measurement, using a magnetically activated reed-switch, and passive measurement (requiring no power), through the use of a variable reluctance sensor. Our approach could equally be applied to any other type of flowmeter that produces an electric signal as an output.

The structure of this paper includes Section 2, where the approach is outlined and we describe the individual components of the flow system and optical transduction network. We also provide a description of the signals that are produced by the flowmeters. In Section 3, we show the experimental results we obtained from laboratory tests of two flowmeters alongside a discussion of the results. Finally we provide our conclusions in Section 4.

2. Approach

Fig. 1 shows the proposed flow measurement system, consisting of four main parts. Firstly, the flow measurement network consists of pipes and channels with flowmeters attached at points of interest. Secondly, individual DHFLC transducers that attach to the existing flowmeters as part of the network. Thirdly, the optical network consisting of single mode optical fibre with add/drop filters; and lastly, the 'head end', containing optical source, amplifier, circulator and de-multiplexing module. Below, we provide descriptions and background to the system components listed above.

2.1. Flow measurement network

We assume that the flow measurement network consists of pipes and channels with integrated positive displacement flowmeters of an oval gear type. Rotation of the oval gears inside the flowmeter is measured using a range of methods, most commonly through use of a Reed switch, Hall Effect sensor or Variable Reluctance Sensor (VRS). Variable reluctance sensors use the irregular shape of a ferrous target feature rotating past the face of a magnet to measure the change in magnetic flux; the change in flux is registered as an induced voltage across a wire coil around the magnet. As the target passes close to the magnet the magnetic flux increases, thus proportionally increasing the voltage around the coil. As the target moves past the magnetic field collapses producing an opposite voltage. The resulting signal is an AC waveform. Although relatively cheap and completely passive, the magnitude of the alternating waveform produced by the sensor is proportional to the speed of the target, making low speed rotation measurement problematic due to a decreased signal to noise ratio at low rotation speeds [10]. Reed switches on the other hand, rely on small magnets embedded in the oval gear mechanism. They provide a mechanical alternative, as two electrodes are brought together (or forced apart) in the presence of a magnetic field. As the embedded magnet passes the switch, the powered circuit pulls the circuit between an arbitrarily high and low voltage.

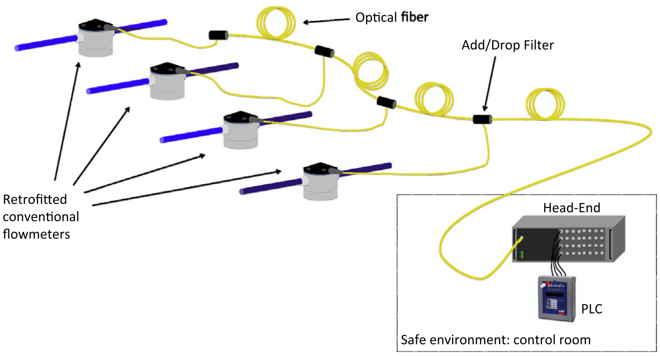

Fig. 1. Proposed flow measurement system showing flowmeters with integrated DHFLC sensors connected by a single mode fibre to the control module.

For our experiments a test rig was constructed using a 12 V DC water pump (DC50C-1240), a water tank and a selection of hoses. Two configurations of the "GPI 'Flomec' OM004 Oval Gear Flowmeter", with a documented output of 2800 pulses/litre, were then investigated. The setup allowed for testing of flow rates between 1.3 L/h and 26 L/h.

In one experimental setup the flowmeter was fitted with a reed switch and a DHFLC optical transducer, as shown in Fig. 2. An embedded magnet in one of the oval gears of the flowmeter outputs 2800 pulses per litre of fluid. Each pulse opens and closes the reed-switch producing a square wave. Crucially, the input for the optical transducer requires the average voltage to be zero in order to avoid degradation of the liquid crystal. For this reason a simple RC circuit was wired to the flowmeter as a differentiator such that each rising edge of the square wave produced a positive pulse and each falling edge produced a negative pulse about 0 V. In our experiment we used two batteries in series producing 6 V (2 × 3 V CR2032) and an RC circuit with a time constant of 0.1 ms, as shown in Fig. 3. Experimentally, this meant that every second pulse corresponded to a flowmeter magnet pulse.

In the second experimental configuration, the same flowmeter was retro-fitted with reluctance sensing coil (Motion Sensors Inc.) which has a centreline mounted magnet. The coil was then wired to our DHFLC optical transducer. This allowed for passive generation of an oscillating signal from the flowmeter from which the flow rate can be obtained.

Fig. 2. Oval gear flowmeter fitted with a DHFLC optical transducer. An optical fiber (in yellow) is used to read the electrical signal produced by the flowmeter. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)