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A novel fibre grating gas flow sensor

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Abstract

This paper studies an optical fibre grating flow sensor through research and extension of "King's law" to make full use of the advantages of optical fibre sensing and to improve the shortcomings of a traditional gas flow sensor. Using the constant-current source as a heat source for this sensor and using an optical fibre grating temperature sensor for a temperature survey in the auxiliary pipe and the air pump, the pipeline's gas flow is determined though King's law. The experimental results indicate that the temperature sensor can respond quickly to the gas temperature; in addition, via conversion into a flow measurement, the results indicate that the novel natural gas flow sensor is stable and effective.

Keywords: FBG; King's law; Flow sensor

Introduction

Natural gas is a very important source of clean energy and has become one of the raw essential materials and energy sources for industry, city, traffic, electric power and other fields. Natural gas is flammable and explosive, so gas security is particularly important. The transport and supply of gas rely on pipelines. Flow measurement in the pipeline is very important for the management of gas. Traditional flow sensors based on electronic devices are restricted by factors such as explosion in flammable and explosive situations; because there are many unsafe situations that can occur during a measurement using electronic devices, a new type of sensor with good explosion-proof performance and high accuracy is required.

A fibre grating sensor has practical value, exhibiting high precision, high stability, and high reliability; being safe to operate, not susceptible to electromagnetic interference, corrosion resistant and lightning resistant; and possessing other unique advantages [1–4]. As a result, it can be used in flammable, explosive and other adverse conditions and can be used to form a sensor network. When using a general flow sensor for gas detection, if people are not careful, a serious accident can occur; thus, we use optical equipment to measure the flow of gas because such equipment is safe to operate and stable and has high sensitivity and high measuring accuracy.

Research for "King's law"

The thermal gas flowmeter is based on the principle that a measured fluid flowing through the solid medium

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can undergo a heat exchange process. Thus, real-time detection of the temperature sensor and the use of thermal balance theory can be used to derive the fluid's flow. The measured results of the thermal flow sensor conform to “King's law”. Using “King's law”, we can derive the functional relationship between temperature and flow [5,6]. The formula is:

$$H/L = \Delta T[\lambda + 2(\pi \lambda c_\upsilon U d)^{1/2}] \quad (1)$$

H/L: the heat dissipation rate in per unit length; ΔT: the average temperature difference of the heating resistance and the measured fluid; λ: the thermal conductivity of the fluid; c_υ: volume specific heat; ρ: density; U: the velocity of the fluid; d: the diameter of the wire.

By placing two Pt thermistors in the pipeline, one Pt thermistor measures the temperature of the gas, which is called T_f, and the other Pt thermistor measures the temperature of the heating unit, which is called T_w; T_w is larger than the temperature of the fluid. T_w reaches a climax when no air flows past, but as the flow in the pipe increases, the gas can take away more heat from the heating unit, thereby causing the temperature difference $\Delta T = T_W - T_f$. When the system reaches thermal equilibrium, the following equation describes relationship between the power consumption (P) and the heat dissipation (W): $W = fPL$ (L: wire length, f: constant). Substituting the numerical value into formula (1) results in formula (2):

$$f\mathrm{PL} = \Delta T[\lambda + 2(\pi \lambda c_\upsilon U d)^{1/2}]L \quad (2)$$

Next, the relationship between P and ΔT is shown in formula (3)

$$P = \Delta T[\lambda + 2(\pi \lambda c_\upsilon U d)^{1/2}]/f \quad (3)$$

From the above-mentioned formulae, we can calculate the flow of fluid through the temperature difference (ΔT) when the power of Pt thermistors is constant.

FBG and fibre grating temperature sensor

Producing a fibre grating involves the use of photosensitive fibre (the incident photon from outside is absorbed by the germanium ions in the core, inducing a permanent refractive index change) to form the spatial phase grating in the core that acts as a narrow-band filter or reflector (projection or reflection) for light propagating in the core (Fig. 1).

An optical fibre grating temperature sensor is a form of optical fibre sensor that is based on the characteristics that the Prague wavelength is sensitive to temperature. According to the thermal expansion effect and thermo-optic effect of the fibre, when the temperature outside changes, the period and refractive index of the fibre grating will change accordingly so that the centre wavelength changes. Conversely, the wavelength change can be used to measure the temperature. The formula is:

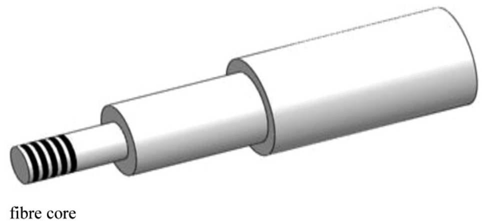

Fig. 1. Fibre Bragg grating sensor.

$$\lambda_B = 2n_{\mathrm{eff}}\Lambda \quad (4)$$

λ_B: Prague centre wavelength; n_{eff}: the effective refractive index of grating; Λ: the period of the grating.

A fibre grating not only has the advantages of being easily connected to the fibre, low loss, good spectral characteristics and high reliability, but its wavelength parameters will also not be affected by the fluctuation of the light source power and the connection or coupling loss.

Making and calibrating the fibre grating temperature sensor

A fibre grating is brittle and fragile, so it must be encapsulated before it can be used in engineering applications; in this paper, a metal tube is used to encapsulate the FBG temperature sensor. Because the temperature sensor is in contact with the fluid, we must ensure that the optical fibre grating temperature sensor is in an unstressed state to avoid the disturbance of the fluid during measurements.

Rubbing alcohol was used to remove the oil pollution and dust on the metal pipes to avoid any effect on the package quality of the temperature sensor. The optical fibre is laid in the metal pipe, and then the fibre is affixed using silica gel in the metal's nozzle; the silica gel solidifies 30 min after application. The other end of the optical fibre is connected to another optical fibre via a joint, thereby making it easy to connect the fibre to an instrument.

The calibration system includes an optical fibre grating temperature sensor, the optical fibre grating demodulator, a water thermostat, and an electronic temperature sensor.