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Study on temperature and current sensors based on optical driving optical fiber transmission

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ABSTRACT

A sensing measurement scheme based on the optical fiber coupling optical driving converting probe is proposed. Using the optical feedback stabilized 5 mW LD as illuminant, the optical driving distance is 100 m. The power of designed low-consumption temperature-sensitive sensor probe is small to 2.2 mW. The design idea of this new sensor and the key technology of realizing optical driving are introduced in this paper. Experimental results show that the temperature sensor with high resolution can resist high-voltage and electromagnetic interference, and has high sensitivity and precision with 1000 Hz/°C.

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1. Introduction

Optical driving photoelectrical current sensor for high pressure adopts fiber isolation on high-voltage probe and signal processing apparatus, which has the electric technology with high precision, high resolution, optical sensing and strong electromagnetic anti-interference ability. It is a practical optical fiber sensing technology.

The photoelectrical sensor connects the probe and signal processing unit with fiber, which is competent in the various types of measurement in the special circumstances. (1) Converting probe or system is supplied by light transmission with low- consumption probe circuit. The parameter measurement is safe under the flammable and explosive conditions, which is applied to online measurement of petroleum, chemical industry, gas, liquid, and other parameters. (2) The converting probe of measurement and signal processing are connected by long optical fibers. Because the fiber has high insulation, sensors can fit the online measurement of super high-voltage power system's operating parameters such as current, voltage and temperature of the switch cabinet. (3) In certain pathological examination, chemotherapy and biological status measurement, characteristics such as micro-electric field and micro-power consumption of sensors supplied by optical fibers can avoid effecting measurement and bio-electric field effect [1–3].

Light-powered system suits for resistance, capacitor and can measure parameters including temperature, pressure, flow, velocity, vibration and micro-displacement. The sensing system is mainly composed of three parts: power which is the light power channel of coupled-fiber, parameter measurement of the probe and transform of photoelectrical signals, fiber transmission and the processing part of measurement signals. The structure composition is shown in Fig. 1.

2. The converting probe's light-powered driving channel settings and photoelectric conversion

The power of photoelectric conversion is the guarantee for the temperature probe and high voltage circuit of current transformer. Power must meet the following requirements: first, stability for a long time with no interruption, and meet the power requirements of electronic circuits; second, strong anti-interference ability for the harsh working environment. Laser power has simple structure, good insulation properties, high reliability, strong anti-interference and other advantages, which has an increasingly broad application in recent years. Excitation light transmits through optical fiber to probe ends, and photoelectric diodes convert light power into electric energy for related functional circuits.

Based on PPM-2W, a laser-powered system is shown in Fig. 2. The laser-powered system includes two closed-loop control system of PPM power and temperature control, which can monitor real time and ensure constant PPM power output and temperature stability. Through the sampling of the laser powered module's output power, battery status can be monitored and the output power of the laser can be adjusted to get the stable power output. PPM's 11 pin can be used as power monitoring interface module, which is measured to get PPM's power. The 11 pin's voltage collected by

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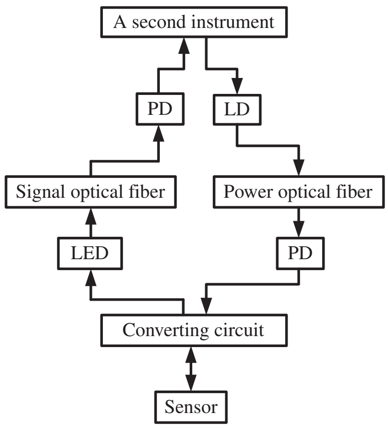

Fig. 1. Structure of the light-powered sensors.

single-chip determines the controlling direction of PPM's power, and will fed back the results to 1 pin and 3 pin.

The operating temperature of the laser will directly affect the output wavelength of the laser, thus give fluctuation to PPM's output power and give the adverse impact on the power stability. PPM's temperature control needs temperature monitoring and controlling devices, so the thermistor and cooler can be used. Thermistor feds back temperature change of PPM to the single-chip, which can determine parameters for temperature control through calculation, ultimately, adjust the operating temperature of laser's modules [3–5].

3. Optical drive temperature sensors

Quartz resonator's vibration frequency depends on the temperature. Special cutting direction can make this change to strong, linear or nearly linear control and can make a high-sensitivity temperature sensor. Considering the impedance matching and bandwidth of quartz resonator, the optical cable with whole wavelength accesses to the system. The instrument has a vibration and temperature compensation circuit to carry T/F transformation. Because output frequency is high, after the counter divides the frequency, the frequency can be measured by reasonable gate time. The frequency which is converted to temperature for the temperature displaying and printing is calculated by the overflow and count of the gate time. Optical driving sensors use Semiconductor Laser Diode (LD) with large core diameter, large numerical aperture and low-loss optical fiber to drive sensors for long-distance optical signals [6]. The system of the optical driving temperature sensor is shown in Fig. 3. It is composed of three parts: instrument controlling port, optical driving temperature sensing end and fiber-coupling between the two units which form a self-feedback closed-loop system. Oscillation frequency depends on the quartz crystal resonator frequency in the temperature-sensitive probe. The phase-locked-loop tracking outputs the measured temperature related to the oscillation frequency [7–10]. The system is essentially a temperature-frequency converter.

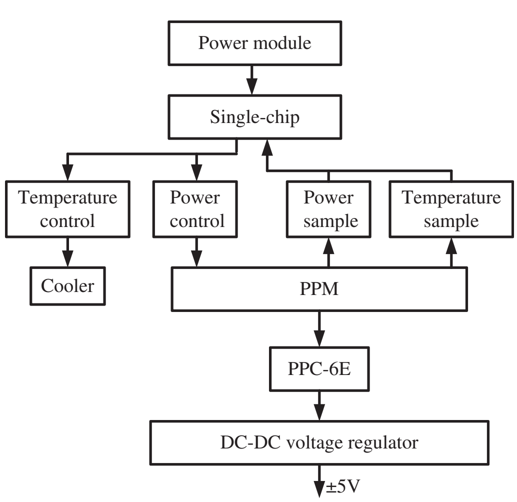

Fig. 2. Laser-powered system.

The instrument controlling and processing unit is composed of three parts: the optical-feedback power stability LD driver, V/I converter and frequency phase-locked loop. PLL's output frequency tracks system's oscillation frequency whose frequency acquisition range should meet requirements. LD has optical feedback circuits, which is coupled into the optical fiber. One-tenth of light power from the optical fiber divider is the feedback light with a negative feedback polarity, which compares with phase-locked-loop's output signal through the I/V converter, then added to the LD driving circuit.

3.1. Quartz resonators

Experiments show that between −200 °C and +200 °C, quartz resonators' frequency–temperature characteristics can be expressed as a third-order polynomial.

$$f(T) = f_0\left[1 + F_T^{(1)}(T - T_0) + F_T^{(2)}(T - T_0)^2 + F_T^{(3)}(T - T_0)^3\right] \quad (1)$$

f_0 is the resonator frequency at the temperature of T_0, MHz; $F_T^{(1)}$, $F_T^{(2)}$, $F_T^{(3)}$ are temperature coefficients, 10^{-6}/°C, 10^{-9}/(°C)^2, 10^{-12}/(°C)^3, which are related to the orientation and vibration of the piezoelectric element.

Temperature–frequency characteristics can make the temperature sensor with high thermal sensitivity. For high sensitivity and better linear temperature-frequency conversion, $F_T^{(2)} = F_T^{(3)} = 0$, that is $\phi = 8°44'$, $\theta = 13°$, the crystal's average temperature-frequency coefficient is $F_{r1}(T) > 60 \times 10^{-6}/°C$.

3.2. The temperature measuring probe

Quartz crystal temperature sensor has high-resistance performance, low-consumption, high Q resonant circuits, whose resonant frequency is the function of the temperature. Due to its very high input and output signal impedance, the power consumption is negligible. LD optical power through long-distance optical fibers transports into the probe's (Photo Diode, PD), whose load is transformers TP [11,12]. When PD conducts by the light, PD's optical power produces 2 V voltage in the TP, which is rectified for probe circuits.

When PD cuts off with no light, due to no sudden changing current of the TP, both ends on the secondary have sensing pulsed voltage of ±20 V to motivate quartz crystal. We can see that the system oscillation waveforms are pulsed light with 10% proportion, 63 s glowing time, 70 s cut-off time. The optical power and voltage waveform is shown in Fig. 4. The low voltage is in the light of the PD, which has very low source impedance and is suitable for low resistance circuits. The high voltage in the cut-off time of the PD whose output power is very small because of short duration, but it can drive the load of quartz crystals.

Electronic circuits in the probe are composed of amplifiers and light-emitting diodes (LEDs) drive circuit [13], which has the small static and dynamic power. The static power is determined by the amplifier. While the micro-power programmable amplifier's least

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