# Ratio error of all fiber optical current transformer caused by mean wavelength's fluctuation

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**Abstract:** Substandard ratio error under full temperature (-40-60 ℃) is one of the factors that restrains the practical application of domestic All Fiber Optical Current Transformer(FOCT). The Verdet constant of the sensing fiber changes with the fluctuation of mean wavelength when the light goes through. Then the output ratio is influenced which decreases the accuracy of the system. The relation between the fluctuation of mean wavelength and system ratio error was analyzed thoroughly and validated experimentally. Also, influence on the mean wavelength caused by the entire optical components was theoretically analyzed, and the degree of influence and the variation trend were experimentally measured. A method was put forward to make the polarizer and the fiber delay line have a temperature self-compensation on the variation of mean wavelength, and thus the change of mean wavelength was reduced. While the 0.2 s class accuracy requirement is guaranteed, the impact can be lowered as much as possible.

**Key words:** all fiber optic current transformer; mean wavelength; Verdet constant; ratio error; optimization design

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# 光纤电流互感器平均波长漂移变比误差

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**摘 要:** 全温条件下(-40~60 ℃)测量精度误差较大是影响光纤电流互感器实用化进程的主要原因之一。传感光纤的维尔德常数随光纤内光波平均波长变化,导致系统输出变比漂移,从而降低系统的测量精度。理论分析了光谱平均波长与系统输出变比之间的关系,并通过实验验证了关系式的准确性。分别对光纤电流互感器光路各组成器件对通过光平均波长的影响进行了分析,实验测量了变温条件下平均波长变化的趋势以及程度。提出了起偏器与延迟光纤在变温条件下对平均波长影响的自补偿方案,有效的减小了传感光纤中平均波长的漂移程度。保证光纤电流互感器在变温条件下到达 0.2 s 级精度要求。同时为适应更高测量精度应用场合提供了参考。

**关键词:** 光纤电流互感器; 平均波长; 维尔德常数; 变比误差; 优化设计

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## 0 Introduction

All fiber optical current transformer (FOCT) is the key equipment of the intelligent substation with lots of advantages such as wide measure range, high measure precision, good insulation, et al[1-2]. However, the test result of the performance on the electronic transformer released by the electric power research institute of state grid shows that, unsatisfactory full temperature performance is one of the factors that restrains the practical application of domestic FOCT. Nowadays, researches on improving the full temperature performance are focused on the temperature compensation of the wave plate [3]; the restraint of the temperature error caused by the linear birefringence in the sensor coil [4]; analysis and suppression technique for polarization errors[5].

Of all the researches on the influence on the FOCT caused by the mean wavelength's fluctuation, there is only research on the SLD [6-7], no reports on the whole optical structure. The Verdet changes with the mean wavelength of the light going through the sensing fiber, and then brings about the ratio error. The mean wavelength's fluctuation of the SLD's output is only one of the reasons making the mean wavelength of the light going through the sensing fiber change, which can't entirely reflect the ratio error caused by the mean wavelength's fluctuation.

In this paper, the relation between the fluctuation of mean wavelength and system ratio error was analyzed thoroughly and validated experimentally; changes of the mean wavelength caused by the entire optical components were theoretically analyzed further; the degree of influence and the variation trend were experimentally measured; concrete method for reducing the mean wavelength's changes was put forward to make the polarizer and the fiber delay line have a temperature self-compensation on the mean wavelength's variation. While the 0.2 s class accuracy requirement is guaranteed, the impact was lowered as much as possible.

## 1 Mechanism of the influence

### 1.1 Principle of FOCT

As Fig.1 shows, the light path of the FOCT is: the light comes out of SLD, goes through the circulator and then the light becomes polarized light by the polarizer. The polarized light goes into the polarization maintaining optical fiber which is the tail fiber of the modulator at a 45° angle. So it is divided into two equal portions and spreads separately and orthogonally in the $X$ axis and $Y$ axis of the fiber. The two polarized lights are modulated by the modulator and then transferred by the fiber delay line. At last, they both go through a quarter-wave plate, respectively becoming left-hand rotation and right-hand rotation circular polarized lights, and get into the sensing fiber coil.

In ideal conditions, the output expression is[1]:

$$\frac{S_{out}}{I}=-\frac{2NV}{\pi}2^{N_1} \tag{1}$$

Where $S_{out}$ stands for the transformer's digital output, $I$ represents the current magnitude, $N$ stands for the number of the sensor fiber coil turns, $V$ is Verdet, and $N_1$ represents the digit of D/A. So it is clear that the output of the FOCT is related with Verdet.

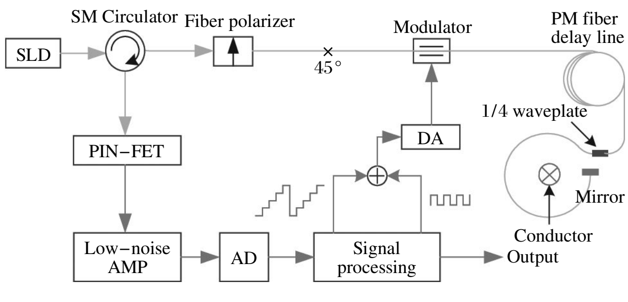



Fig.1 Schematic diagram of FOCT

### 1.2 Influence on the ratio error caused by the mean wavelength's fluctuation

The sensing fiber is a key sensing device of FOCT which is magnetic sensitive, and also a kind of magneto-optical crystal. When polarized light goes through magneto-optical crystal in a magnetic field, by the theory of dispersion, the Verdet constant at room temperature can be expressed as[8]:

$$V(\omega)=C\cdot\frac{\omega^2}{n}\cdot\frac{1}{(\omega_0^2-\omega^2)^2} \tag{2}$$

Where $C$ is a constant related to the magnetic field, $\omega$ stands for the primary frequency of the incident light, $n$ represents the fiber's refractive index, and $\omega_0$ stands for inherent frequency of the fiber.

According to the Sellmeir dispersion equation[8]:

$$n^2=1+C'\cdot\frac{1}{\omega_0^2-\omega^2} \tag{3}$$

Where $C'$ is a constant. Combining Eq. (2) and Eq. (3), there gets:

$$V(\lambda)=C''\cdot\frac{(n^2-1)^2}{n}\cdot\frac{1}{\lambda^2} \tag{4}$$

Where $C''$ is a constant related to $C$ and $C'$, $\lambda$ stands for the mean wavelength of the incident light. It shows that the $V(\lambda)$ varies with $n$ and $\lambda$. And changing of $n$ with temperature is the major reason which causes the variation of $V(\lambda)$ with temperature, lots of researches have been done, and the normal relational expression is:

$$\frac{1}{V_0}\frac{\mathrm{d}V}{\mathrm{d}t}=0.7\times10^{-4}\,℃^{-1} \tag{5}$$

So, without regard to $n$, $V(\lambda)$ is in direct proportion to $\frac{1}{\lambda^2}$. Furthermore, according to the differential, Eq. (5) can be described as:

$$\Delta V(\lambda)=C''\cdot\frac{(n^2-1)^2}{n}\cdot\frac{-2}{\lambda^3}\cdot\Delta\lambda \tag{6}$$

Combine Eq. (4) and Eq. (6):

$$\frac{\Delta V(\lambda)}{V(\lambda)}=-2\frac{\Delta\lambda}{\lambda} \tag{7}$$

Also can be described as:

$$\frac{\Delta V(\lambda)}{V(\lambda)}=-2\frac{V(\lambda)}{\lambda} \tag{8}$$

From Eq. (7), we can see when $\lambda$ changes a little, the relative change amount of $V$ is in direct proportion to the relative change amount of $\lambda$. So does the system output ratio error. For example, the mean wavelength of the passing light is 1 310 nm at room temperature, 1 nm change of the mean wavelength will bring a 0.153% relative ratio error.

As we know, working on different drive currents, SLD's output has different mean wavelengths [6-7]. First, connect the fiber delay line's tail with a spectrograph, and take a record of the mean wavelengths with different drive currents. And then take the ratio error of the recorded drive current before, which measured by a calibration down. Figure 2 shows the experimental data and the line ar. It is observed that the variation of the ratio is in direct proportion to the variation of λ, the slope of the line is negative and the linearity is 0.997 2, matching the Eq. (8) very much.

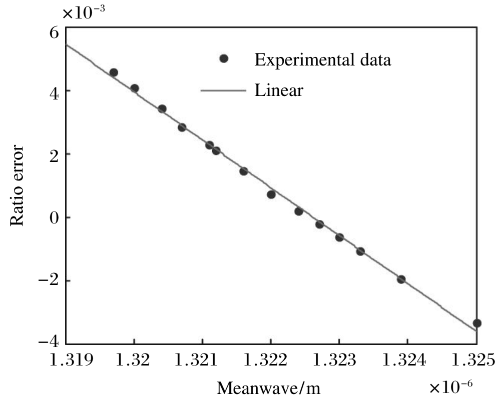



Fig.2 Ratio error versus mean wavelength

## 2 Analyzing and optimizing on light structure

### 2.1 Optical elements

(a) SLD

The mean wavelength of SLD light source is affected by the drive current and the tube core temperature [6-7]. Lots of researches have been done. In this paper SLD from ACCELINK was used for experiments and the type of the light source drive was JGTC−0501C. Under the condition of 80 mA drive current and a variable temperature from −40 ℃ to 60 ℃, fluctuations of the output wavelength was 0.4 nm.

(b) Circulator/ Coupler

Circulator takes the advantage of small optical power loss, but the principle is more complex, the components of PBS, Faraday rotation and fiber optic wave plate are affected by temperature a lot.

Coupler's principle is simpler, it is made by fused biconical taper of two optical fibers, when the temperature changes, the coupling between two optical fibers will change, and then the spectra of the transmission light in the straight arm and coupling light in the coupling arm will change[9]. But the light power loss is larger.

Full temperature tests have been done on both the circulator and coupler. As shown in Tab.1, the mean wavelength of the coupler's transmission light changes in the minimum, within 0.1 nm. And on 80 mA drive current, the light power loss of a coupler will not affect the system output precision, so the output of the coupler's straight arm will be a good choice to steady the mean wavelength.

**Tab.1 Mean wavelength ranges of circulator/ coupler**

| | Max meanwave/nm | Min meanwave/nm | Range/nm |
|---|---|---|---|
| Output of circulator | 1 311.8 | 1 311.2 | 0.6 |
| Transmission light of coupler | 1 312.4 | 1 312.3 | 0.1 |
| Coupling light of couple | 1 313.7 | 1 313.2 | 0.5 |

(c) Polarizer

Polarized or partially polarized light after polarization-maintaining optical fiber and polarizer, the output from the polarizer will be the interference of the main wave and the coupled wave along the optical transmission axis, there will be periodical functions added to the output spectrum[10-11]. The cycle of periodic function associated with the polarization-maintaining optical fiber length, and the amplitude size with shaft angles between optical fiber and optical fiber and between optical fiber and polarizer. In FOCT, coupler made of single-mode fiber, decoherence happened between the two light waves through the coupler front tail polarization-maintaining optical fiber by extending the tail fiber long, and then the superposition periodic function impact on the spectrum can be weakened. Experimental measurements have been done severally with a 6.3 m and a 1.9 m long tail fiber under a full temperature test. As shown in Tab.2, a long front tail fiber of a polarizer can reduce the mean wavelength range.

**Tab.2 Mean wavelength ranges of different input tail lengths of polarizer**

| Front tail length of polarizer/m | Max meanwave /nm | Min meanwave /nm | Range /nm |
|---|---|---|---|
| 1.9 | 1 313 | 1 312.4 | 0.6 |
| 6.3 | 1 311.6 | 1 311.3 | 0.3 |

(d) Polarization-maintaining optical fiber/modulator

The front tail fiber of the straight waveguide and the end tail fiber of the polarizer were welding at 45°, so the linear polarized light was divided into two polarization modes which transferred respectively along the fast and the slow axis of the polarization-maintaining optical fiber. Straight waveguide is optical devices made of integrated lithium niobate, which can be treated as an special polarization-maintaining optical fiber (crystal) [12].

The coupling way that the integrated optical phase modulator tail fiber usually adopt polarization-maintaining fiber and the chip surface direct bonding. When the environment temperature changes, the heat capacity of the coupling point of different materials, thermal expansion coefficient, elastic modulus and Poisson's ratio and other parameters will change as well, especially the coupling rubber on the tail fiber, will lead to a lot of stress on the coupling point, which makes changes in partial birefringence of polarization-maintaining fiber optic main axis[5], and then the phase modulator fiber tail polarization crosstalk changes.

There are many polarization coupling points in polarization-maintaining fiber delay line, main wave train through the coupling point will produce parasitic times waves with smaller amplitude, the parasitic times wave may also be coupled again. As the change of temperature, polarization-maintaining fiber delay crosstalk changes[5].

Polarization crosstalk will produce interference phenomenon, so the changes of the crosstalk with temperature will affect the stability of the transmission spectroscopy, in turn, affect the mean wavelength. By improving the axis aligning accuracy between the fiber tail and the chip surface, improving the winding way of the fiber delay line, and reducing adhesive use, the polarization crosstalk is decreased. The mean wavelength range of different crosstalk is shown as Tab.3.

**Tab.3 Mean wavelength ranges of different crosstalk**

| Crosstalk range | Max meanwave /nm | Min meanwave /nm | Range /nm |
|---|---|---|---|
| Higher | 1 310.5 | 1 310 | 0.5 |
| Lower | 1 312.5 | 1 312.8 | 0.3 |

## 2.2 Entire light structure

Found in the experiments, the output mean wavelength of the polarization-maintaining fiber delay has approximately the same change trend with the change of temperature, and the change trend of the polarizer output mean wavelength was in contrast to the temperature. Shown as Fig.3, the curve polarizer output mean wavelength versus temperature was based on experimental tests of a 1.9 m long front fiber tail polarizer, and the curve fiber delay line output mean wavelength versus temperature was based on experiments with higher polarization crosstalk. They both have an obvious change strand versus temperature, and it can be seen that the change of the average range is 0.4 nm, better than that of either a single output. Figure 4 shows that when the polarizer is chosen a 6.3 m long fiber tail one, and polarization crosstalk is lower, even the trend is not obvious, the average range is still reduced, it is only 0.2 nm, compensated for the same. So if the output mean wavelength of the polarizer and the fiber delay line has a same range, the wavelength's fluctuation through the light path will get compensated better.

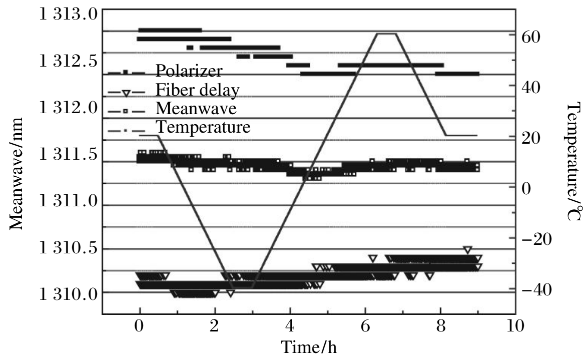
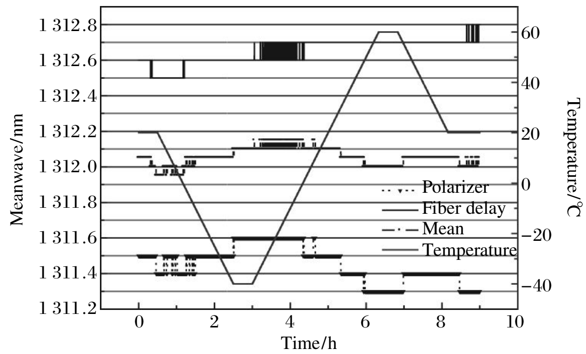



Fig.3 Obvious experimental data compensation result

In summary, set up an entire light structure of FOCT with the coupler, whose straight arm is the output end, the polarizer with 6.3 m front fiber tail, and the straight waveguide and fiber delay line with lower polarization crosstalk. Test the output mean wavelength range of the system under a full temperature test. Shown as Fig.5, the mean wavelength has a fluctuation in 0.6 nm, which leads to 0.091% ratio error to the FOCT according to Chapter.2, meeting the 0.2 s class accuracy requirement.




Fit.4 Improved experimental data compensation result

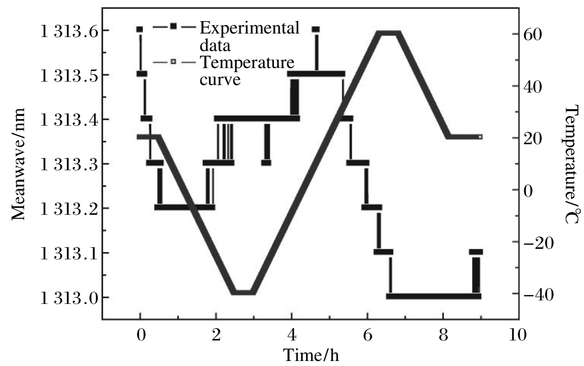



Fig.5 Range of output mean wavelength of optimized light structure versus temperature

# 3 Conclusion

In this paper, the mechanism that how the mean wavelength change affects the FOCT output ratio error was analyzed, and experiment was conducted to prove that the output ratio is in direct proportion to one in square of the mean wavelength. Furthermore, the relative ratio error is in direct proportion to the relative change amount of $\lambda$. Through analysis of each optical device which constitutes the FOCT, ways for each device to reduce the mean wavelength fluctuation under full temperature test were put forward. Compensation between polarizer and optical delay line was analyzed, which reduced the mean wavelength fluctuation in the sensing optical fiber further. It is of great significance to the temperature stability of the

FOCT. And the next step is to make the compensation between the polarizer and the optical fiber delay more accurate.

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