Nonlinearity test and compensation of the passive AFOCT's scale factor

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***Abstract*—In order to compensate the nonlinear error of passive all-fiber optic current transformers (AFOCT) in the case of large current input, a new method based on the inverse function correction is presented. Taking the feature of the AFOCT's nonlinear response into account, a high-order signal is produced by an analog circuit, thus the scale factor of the AFOCT could be compensated quickly and accurately. Experimental test shows that when the phase difference between the two interference light paths is within the range of 0~20°, the output of the AFOCT could be compensated to maintain the GB/T 20840.8 0.2 accuracy class.**

Keywords-All-fiber optic current transformer; nonlinear compensation; analog multiplier

I. INTRODUCTION

Smart Grid is an electrical grid that uses the sensor technology, embedded information processing technology and communication technology to gather the network information to the electric power companies and thus improve the efficiency and safety of the power system [1-2]. The accuracy and compatibility of the current transformers are very important to the development of the smart grid. All-fiber optic current transformers (AFOCTs), which offer the advantages of high immunity to electro-magnetic interference, high isolation from HV lines and high accuracy, are a kind of strong contender of the next generation of current transformers [3-5].

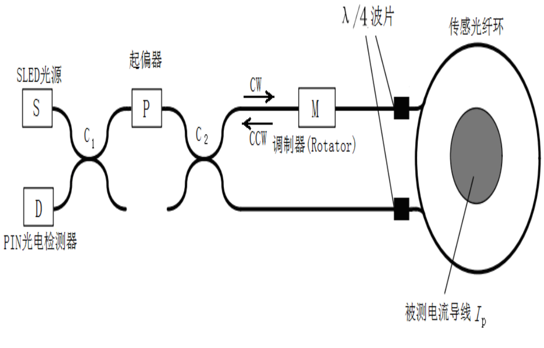

Figure 1. Schematic of the passive AFOCT.

Passive AFOCTs are simple and lower cost. However, the nonlinearity of the scale factor seriously limits the accuracy the passive AFOCT, especially when the primary current is large. In this paper, a method based on the inverse function correction is provided to compensate the nonlinearity of the AFOCT's scale factor. Experimental test shows that when the phase difference between the two interference light paths is within the range of 0~20°, the output of the AFOCT could be compensated to maintain the GB/T 20840.8 0.2 accuracy class.

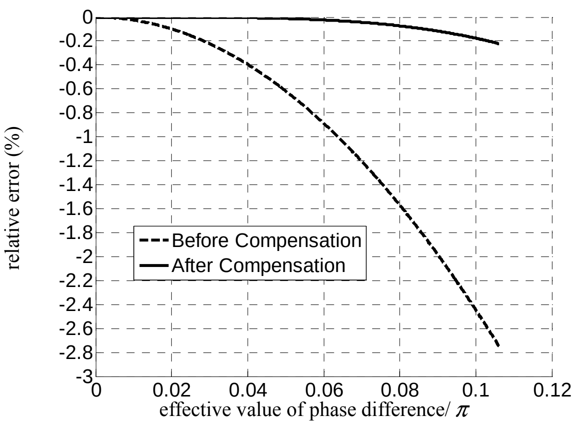

Fig ure 2 Relative error analysis f the passive AFOCT

II. NONLINEARITY ERROR AND COMPENSATION OF PASSIVE AFOCTS

The schematic of the passive AFOCT is shown in Fig. 1. Light from a 1.55μm SLD is directed through a coupler C_1 to a fiber polarizer P. The polarized light is split into the two optical paths, going in two opposite directions. Due to the Faraday effect, the phase shift between the two interfering beams is proportional to the primary current in the busbar. Thus the output AC signal of the photo detector is:

$$\begin{aligned} V_{ac}(t) &= KI_0 \sin\left[2VNI_p(t)\right] \\ &= A\sin\left[\Phi_{\max}\sin(2\pi ft)\right] \end{aligned} \tag{1}$$

Where K is the circuit gain, I_0 is the intensity of light detected by the photo detector, and $\Phi_{\max}$ is the maximum phase shift caused by the Faraday effect, $\Phi_{\max} = 2VNI_{p\max}$. V is the verdet constant of the sensing fiber [6], N is the turns of the fiber coil, I_{pmax} is the amplitude of the primary current and f is the frequency. If we define the scale factor SF as the ratio of the effective values of the output AC signal V_{ac} and the primary current I_p:

$$SF = \frac{rms(V_{ac})}{rms(I_p)} \tag{2}$$

It is obvious that the scale factor of the passive AFOCT is nonlinear from (1). Commonly used methods to compensate the nonlinearity are the table lookup method [7] and the polynomial fitting method [8]. However, since the response of the AFOCT is an explicit function, the most accurate compensate method is to apply an inverse function correction, that is:

$$V_{ac\_com}^{ideal} = A \times \arcsin\{\sin[\Phi_{\max}\sin(2\pi ft)]\} \tag{3}$$

The ideal arcsine function is difficult to realize either by an analog circuit or by an intelligent chip. However, the polynomial approximation of the arcsine function also can reduce the nonlinearity error within a certain range of angle. If a 3rd-order approximation is used, that is:

$$V_{ac\_com}^{real} = A\left\{\sin[\Phi_{\max}\sin(2\pi ft)] + \frac{\sin^3[\Phi_{\max}\sin(2\pi ft)]}{6}\right\} \tag{4}$$

It is illustrated in Fig. 2 that the angle range of the 0.2 accuracy limit could be expanded to 20° after compensation, about three times of that before compensation.

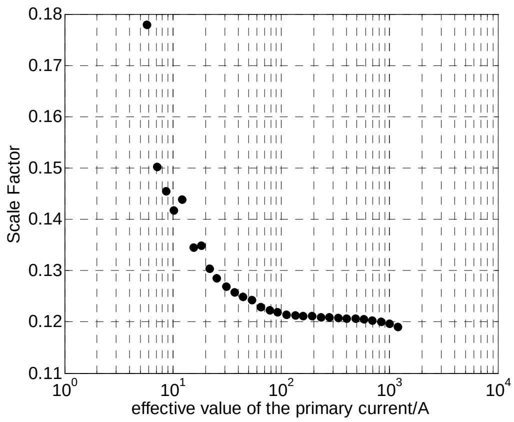

Figure 4 Scale factors of different primary current

III. SCALE FACTOR TEST

The experimental setup to test the scale factor is shown in Fig. 3. The output optical signal is processed by the opto-electronic unit, and is sent to the PC by a NI data acquisition card, noted as V_{ac}. The reference signal obtained from the standard resistance is also sent to the PC, noted as V_{cal}. When different primary current is applied, the effective values of V_{ac} and V_{cal} are calculated and the scale factor is obtained, as shown in Fig. 4. It is shown that the scale factor decreases when the applied current increases, which coincides with the theoretical analysis.

IV. COMPENSATION CIRCUIT DESIGN AND EXPERIMENTAL RESULTS

Compensation according to Eq. (4) could be realized by analog circuits or by digital circuits, such as the DSP. The analog circuit is low cost and easy to realize, and does not take up the processing time of the DSP. The designed circuit is as shown in Fig. 5. The AD633 is a low cost four quadrant multiplexer. The input ports X and Y, with high resistance, make signal source loading negligible. The transfer function of AD633 is:

$$W = Z + \frac{(X_1 - X_2)(Y_1 - Y_2)}{10} \tag{5}$$

The outputs of the two AD633s are W_1 and W_2, respectively.

$$W_1 = \frac{R_1 + R_2}{10R_1}V_{in}^2 \tag{6}$$

$$W_2 = V_{out} = V_{in} + \frac{R_4(R_1 + R_2)}{100R_1(R_3 + R_4)}V_{in}^3 \tag{7}$$

It is easy to get that:

$$V_{out} = A\left\{\sin[\Phi_{\max}\sin(2\pi ft)] + \frac{\sin^3[\Phi_{\max}\sin(2\pi ft)]}{6}\right\} \tag{8}$$

When $K = \frac{R_4(R_1 + R_2)}{100R_1(R_3 + R_4)}A^2 = \frac{1}{6}$.

Thus the 3rd-order approximation of the arcsine function could be realized by the designed circuit. Since the real values of resistances have certain errors to their nominal values, two variable resistances, R_2 and R_4, are used to adjust the value of K.

The experimental setup shown in Fig. 3 is used again to test the compensation circuit, just adding a compensated signal V_{ac_com}. The signals V_{cal} and V_{ac} are compared firstly and the constant A in (1) is got by data-fitting. The values of variable resistances R_2 and R_4 are then justed and the signals V_{cal} and V_{ac_com} are compared. The test results are shown in Fig. 6. It is shown that the closer the value of K *is* to 1/6, the better compensation result could be got. The best output of the AFOCT could be compensated to maintain the GB/T 20840.8 0.2 accuracy class when the effective values of the primary current are within the range of 0~3000A (the phase difference is about 0~20° between the two interfering beams).

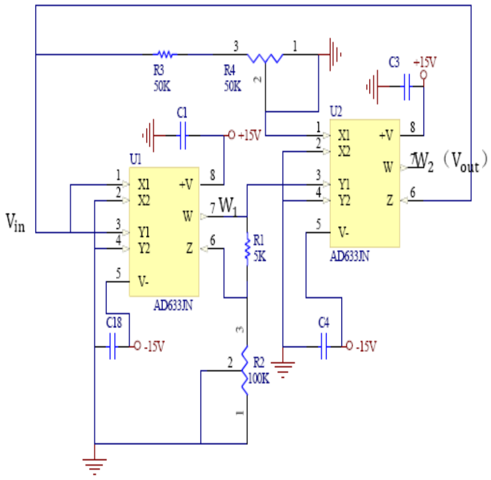

Figure 5 Schematic of the compensate circuit

V. CONCLUSIONS

A new method based on the inverse function correction is presented to compensate the nonlinear error of the passive AFOCT. The scale factor of the AFOCT is measured and compensated by the designed analog circuit. Experimental test shows that when the phase difference between the two interference light paths is within the range of 0~20°, the output of the AFOCT could maintain the GB/T 20840.8 0.2 accuracy class.

ACKNOWLEDGMENT

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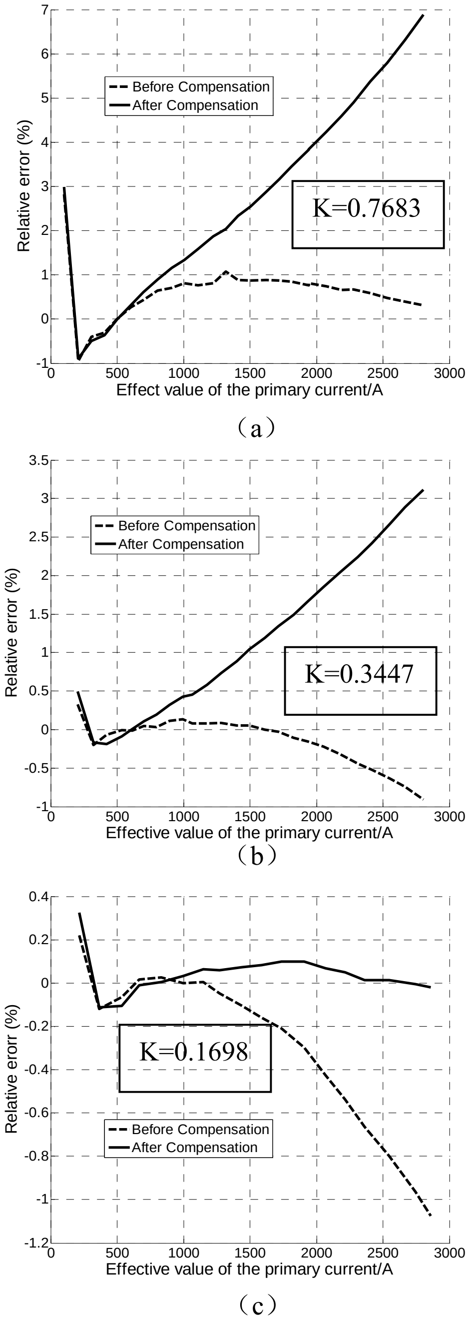

Figure 6 Relative error before and after compensation when K takes different values: (a) K=0.7683; (b) K=0.3447; (c) K=0.1698

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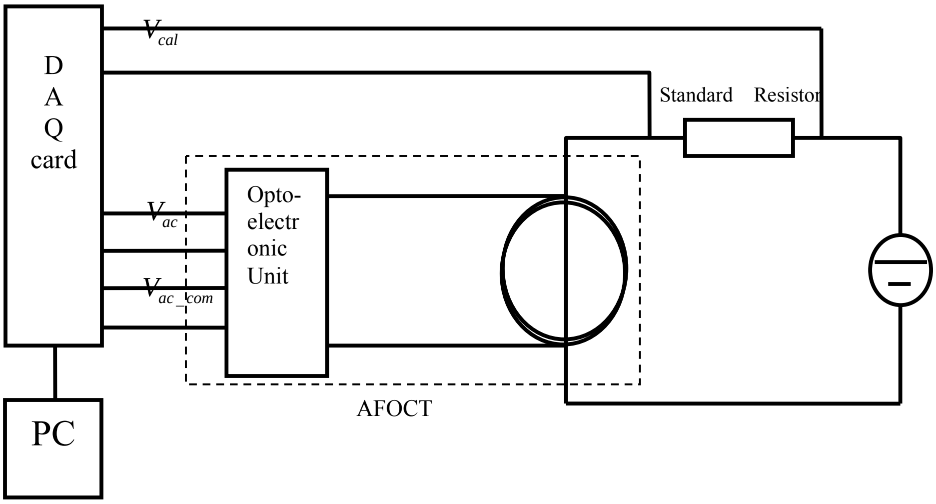

Figure 3 Experimental setup to test the scale factor