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The application rule of simple symmetrical wave signal magneto-optical modulation in spatial azimuth measurement

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ABSTRACT

The purpose of the study is to summarize the application rule of sine wave and other simple symmetrical wave signal magneto-optical modulation in azimuth measurement, and acquire the limit on modulation signal when establishing azimuth measurement model. Firstly, we analyze the principle of traditional azimuth measurement system based on sine wave signal magneto-optical modulation, and establish the error free measurement model based on trigonometric function, after that we present the measurement models based on mixed signal with tangent, cosine and sine function, respectively. Secondly, we discuss the application feasibility of rectangle wave, triangle wave and sawtooth wave signal magneto-optical modulation in azimuth measurement respectively, and establish the azimuth measurement models based on rectangle wave and triangle wave signal modulation respectively, and analyze the reason why the sawtooth wave signal modulation cannot be applied in the azimuth measurement. Finally, we summarize the four simple signal magneto-optical modulation and acquire the requirements on modulation signal when establishing the azimuth measurement model based on simple wave single magneto-optical modulation. The study has an important guiding significance on the application of simple symmetrical wave magneto-optical modulation in azimuth measurement.

1. Introduction

The spatial azimuth measurement technology based on magneto-optical modulation, refers to measure the azimuth between instruments in different horizontal plane and without mechanical connection, with polarized light and Faraday effect [1]. As a new type of non-contact optical azimuth measurement method, it has been gradually applied in industrial, medical, biological, chemical detection and other fields, and it also has a broad application prospects in spacecraft docking and military fields.

According to the waveform of modulation signal, only sine wave and rectangle wave signal magneto-optical modulation are used in azimuth measurement system currently.

The study on the sine wave signal magneto-optical modulation is the research hotspot now, and it focuses on the following two points: (1) the study on the relationship among the modulation signal, magnetic field intensity and Faraday rotation angle, and calculate the Faraday rotation angle or the magnetic field intensity, such as P. Mihailovi verified the relationship with experiment, and calculated the magnetic field intensity with the extinction phenomenon [2]; O. Brevet-Philibert acquired the Faraday rotation angle with the modulated signal, and discussed the measurement error [3]; Jia Ouyang calculated the Faraday rotation angle with magneto-optical modulation, and found that the rotation angle is larger with the modulation signal intensity increases, and less with the modulation signal frequency increases [4]. (2) The effect of frequency and waveform of modulation signal on modulated signal, Bernhard M. Schmidt studied the change of modulated signal when the frequency of modulation signal is low and high, respectively with experiment [5]. Only M. Abe [6] and Kazuya Yonekura [7] and Dong Xiaona [1] studied the application of sine wave signal magneto-optical modulation in azimuth measurement, established the azimuth measurement model respectively, but they all spreaded the modulated signal with the first Bessel function, which brings measurement error, and the system measurement scope is narrow.

The study on rectangular wave signal magneto-optical modulation is few, Koji KIKUSHIMA studied the amplitude and frequency characteristics of modulated signal [8], but he did not study its application in measurement; Li Xiaojun simulated the rectangular wave signal magneto-optical modulation with computer, studied the relationship between modulation signal and modulated signal with Lissajou figure, and pointed out that the precision of the rectangular wave signal magneto-optical modulation may be higher [9], but he did not analyze the magneto-optical modulation mechanism and its application in the azimuth measurement; only Shiguang Li introduced the rectangular wave signal magneto-optical modulation into azimuth measurement, and measured

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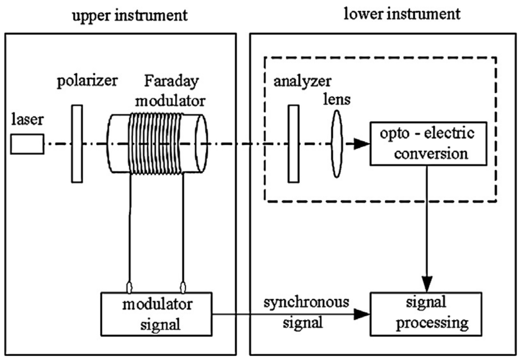

Fig. 1. Principle of azimuth measurement system based on magneto-optical modulation.

azimuth in ±30° [10], but his azimuth measurement model is not accurate.

We study the application of sine wave, rectangular wave, triangle wave and sawtooth wave signal magneto-optical modulation in azimuth measurement. We analyze the characteristics of AC signal and mixed signal from modulator respectively, discuss the feasibility of establishing azimuth measurement model under different modulation signal, summarize the application rule and acquire the requirements on modulation signal when establishing the azimuth measurement model based on simple wave signal magneto-optical modulation.

2. Theoretical foundation

Fig. 1 shows the principle of azimuth measurement system based on magneto-optical modulation. The linear polarized light from the polarizer passes through the magnetic rotation glass in modulator, its optical polarization plane will turn some angle. The modulated signal received by analyzer is processed with focus, photoelectric conversion, amplification and certain arithmetic, after that he azimuth information is acquired.

2.1. The application of sine wave magneto-optical modulation in azimuth measurement

2.1.1. The azimuth measurement model based on the AC signal from modulator

The sine wave modulation signal is

$$f(t) = \sin(wt) \tag{1}$$

where w is the angle frequency of the modulation signal and t is the variable of time and θ is the rotation angle of optical polarization plane.

$$\theta = \frac{1}{2} m_f f(t) \tag{2}$$

where m_f is the modulation degree.

According to Faraday effect, Malous law and the principle of system, the modulated signal from the modulator is processed by photoelectric conversion and amplification, then we get

$$u = ku_0 \sin^2(\alpha + \theta) \tag{3}$$

where k is the amplification rate of circuit, $u_0 = \eta \cdot I_0$, I_0 is the light intensity of laser signal from the polarizer, η is the quantum efficiency and α is the azimuth between different instruments.

Substituting Eq. (2) into Eq. (3)

$$u = \frac{ku_0}{2} \{1 - \cos[m_f \sin(wt)] \cos(2\alpha) + \sin[m_f \sin(wt)] \sin(2\alpha)\} \tag{4}$$

Spreading $\cos[m_f \sin(wt)]$ and $\sin[m_f \sin(wt)]$ with the first Bessel function, and omitting the high terms in the expansion

$$\cos[m_f \sin(wt)] = J_0(m_f) + 2J_2(m_f) \cos 2wt \tag{5}$$

$$\sin[m_f \sin(wt)] = 2J_1(m_f) \sin wt \tag{6}$$

Substituting Eqs. (5) and (6) into Eq. (4), and acquiring the DC signal u_D and AC signal u_A from modulator

$$u_D = \frac{ku_0}{2} [1 - J_0(m_f) \cos 2\alpha] \tag{7}$$

$$u_A = ku_0 [J_1(m_f) \sin(wt) \sin 2\alpha - J_2(m_f) \cos(2wt) \cos 2\alpha] \tag{8}$$

When the azimuth changes, there are always two extreme points u_{A1}, u_{A2} in the AC signal, whose abscissas are constant.

$$u_{A1} = ku_0 [J_1(m_f) \sin 2\alpha + J_2(m_f) \cos 2\alpha] \tag{9}$$

$$u_{A2} = ku_0 [-J_1(m_f) \sin 2\alpha + J_2(m_f) \cos 2\alpha] \tag{10}$$

Collecting the two extreme points with acquisition circuit

$$\frac{u_{A1} - u_{A2}}{u_{A1} + u_{A2}} = \frac{J_1(m_f) \sin 2\alpha}{J_2(m_f) \cos 2\alpha} \tag{11}$$

Then we can get the azimuth measurement model

$$\alpha = \frac{1}{2} \arctan \left[\frac{u_{A1} - u_{A2}}{u_{A1} + u_{A2}} \cdot \frac{J_2(m_f)}{J_1(m_f)} \right] \tag{12}$$

In the principle, the omitted high terms in the first Bessel function expansion must result in measurement error. The coefficient $J_0(m_f)$ is infinite, so u_D is no longer the true DC signal from modulator. According to the above analysis, there must be theory error in the principle.

In order to avoid all the theory error in the principle, a new azimuth measurement model based on trigonometric function is established [11].Outspreading Eq. (3)

$$u = ku_0 (\sin^2 \theta \cos^2 \alpha + \cos^2 \theta \sin^2 \alpha + 2 \sin \theta \cos \theta \sin \alpha \cos \alpha) \tag{13}$$

Substituting $\cos^2 \theta = 1 - \sin^2 \theta$ into Eq. (13)

$$u = ku_0 \left\{ \sin^2 \alpha + \sin^2 \left[\frac{1}{2} m_f f(t) \right] \cos 2\alpha + \sin \left[\frac{1}{2} m_f f(t) \right] \cos \left[\frac{1}{2} m_f f(t) \right] \sin 2\alpha \right\} \tag{14}$$

According to the expansion of $\cos[(1/2)m_f \sin(wt)]$ and $\sin[(1/2)m_f \sin(wt)]$ with the first Bessel function, we can see that only $\sin[(1/2)m_f \sin(wt)]$ is the function of wt. When the azimuth is a constant and wt changes, only $ku_0 \sin^2 \alpha$ is a constant, so the DC signal from modulator is

$$u_d = ku_0 \sin^2 \alpha = \frac{ku_0}{2} (1 - \cos 2\alpha) \tag{15}$$

and the AC signal is

$$u_a = u - u_d = \frac{ku_0}{2} \{\cos 2\alpha - \cos 2\alpha \cdot \cos[m_f f(t)] + \sin 2\alpha \cdot \sin[m_f f(t)]\} \tag{16}$$

We find that there is always two extreme points u_{a1}, u_{a2} in the AC signal, whose abscissas are constant in one cycle, and another extreme point u_{aa} whose abscissa changes with the azimuth changes. Taking $m_f = 1$ rad, $k = 10$, $u_0 = 1$ V and $T = 0.01$ s for example, Fig. 2 shows the AC signal from modulator when the azimuth is 1°