정현파 엔코더를 이용한 서보전동기 초정밀 위치 제어에 관한 연구

김주찬*, 김장목*, 김철우*, 최철**, 조한익**
*부산대학교, **OTIS-LG

A Study on Ultra Precise Position Control of Servomotor using Analog Quadrature Encoder

Ju-Chan Kim*, Jang-Mok Kim*, Cheul-U Kim*, Cheol Choi**, Han-IK Cho**
*Pusan National University, **OTIS-LG

ABSTRACT

This paper describes the ultra precise position estimation of a servomotor using sinusoidal encoder based on Arcsine Interpolation Method. The amplitude and offset errors of the sinusoidal encoder output signals are effectively compensated and on-line tuned by utilizing a low cost programmable differential amp without any special expensive equipments. To theoretically evaluate the practical resolution of this system, the relationship between the amplitude of A/D converter input signal errors and the anticipated resolution is briefly dealt with. The performance of the proposed method is verified by the experiments, by comparing it with position and speed control characteristics of the servomotor driving system using a digital incremental 50,000ppr encoder.

1. Introduction

In order to achieve high accurate servomotor control, it is essential to secure appropriate accurate position feedback in the related system, and this is considered to be one of the most important criterions to guarantee reliance of the system[1,2,3]. However, the price of a digital incremental encoder is overwhelmingly increased according to its resolution, and it has the problem of bandwidth limitation. Although servomotor control using sinusoidal encoder has been researched with these reasons, there are few precedents to apply for the servomotor control system.

For the total cost reduction of highly accurate servomotor position or speed estimating system, this paper describes servomotor control using sinusoidal encoder based on Arcsine Interpolation Method[4], which is optimized to the cost of signal processing circuits. The performance of the proposed method is verified by the experiments. The test results show that, with much cheaper sinusoidal encoder, the proposed method exhibits better performance both in both position and adjustable speed control characteristics than the 50,000ppr optical encoder.

2. Signal Processing Principles of Analog Quadrature Signals

Analog rotor position is determined by output signals of sinusoidal encoder, while digital rotor position can be acquired by counting comparator output signals of them. Fig.1 is the schematic diagram of typical decoding circuitry of a sinusoidal encoder quadrature decoding and phase interpolation.

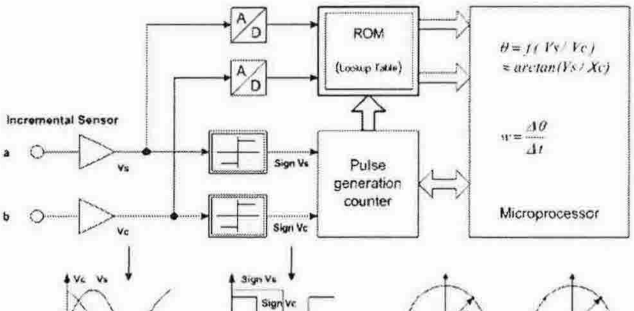

Fig. 1 Schematic diagram of typical decoding circuitry of a sinusoidal encoder incorporating quadrature decoding and phase interpolation

The total period number of analog incremental signals V_s and V_c per a revolution of mechanical rotor angle are different according to sinusoidal encoder models.

Putting it to 'M', resolution of rotor angle guaranteed by digital rotor position is expressed by (1).

$$\theta_{digit} = 360^\circ / M \quad (1)$$

θ_{digit} obtained by (1) represents a period of sinusoidal encoder output signals. They are converted to digital values throughout A/D converter for final microprocessor calculation, and the resolution of A/D converter determines rotor position control accuracy within each sector obtained by (1). From the above relationship, the theoretical total resolution rotor angle can be obtained by (2).

$$\theta_{final} = \theta_{digit} \times K \quad (2)$$

Here, K is the resolution of A/D converter

Assuming that V_s and V_c are ideally sinusoidal and do not have offset and amplitude errors, they can be expressed by (3) and (4).

$$V_s = V_p \sin\theta \quad (3)$$

$$V_c = V_p \cos\theta \quad (4)$$

Here, θ : analog rotor angle, V_p : the amplitude of analog signals

Analog rotor angle based on 'Arc-tangent method' can be obtained by (5).

$$\theta = tan^{-1}\left(\frac{V_s}{V_c}\right) \quad (5)$$

By using θ of (5) and counted numbers of V_s in Fig. 1, mechanical rotor angle can be obtained by (6).

$$\theta_{mech} = \frac{1}{M}\left[\,(N \times 360\,) + \theta\,\right] \quad (6)$$

Here, θ_{mech} : mechanical rotor angle, N : counted numbers of V_s after reference signal V_z is generated.

As shown in Fig. 1, mechanical rotor angle θ_{mech} of a servomotor control system using a sinusoidal encoder can be calculated by either look-up table method or microprocessor calculation.

3. Implementation of the proposed method

3.1 System Configuration of the proposed method

The proposed method basically depends on both analog and digital rotor position information. Analog rotor position is obtained by (7), and sector distinction over the symmetrical output is performed by zero-crossing V_s. Digital rotor position is acquired by counting comparator outputs of V_s. From the obtained analog and digital rotor position, mechanical rotor position of servomotor can be calculated by (6)[1]. Main hardware configuration for the proposed method represents Fig. 2.

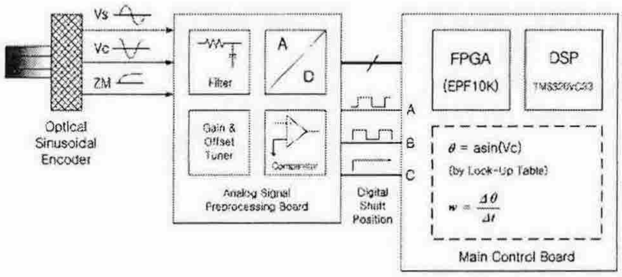

Fig. 2 Hardware configuration for the proposed method

For the accurate calculation of analog rotor position, V_c is tuned to A/D converter full input range and its offset errors are compensated by controlling a gain and offset tuning device. The compensated analog output is converted to digital values throughout A/D converter, and matched with analog rotor angle value within arcsine lookup table. Arcsine lookup table can be configured by (7), and the sector is determined by zero-crossing signal of V_s.

$$\theta_{asin} = \sin^{-1}(Vc) \quad (7)$$

For the calculation of digital rotor position, comparator output signals of the compensated V_s and V_c are applied to the inner counter of FPGA. The digital rotor position is obtained by the counted numbers of V_s comparator output, and this value is reset by reference signal V_z.

3.2 A/D converter input signal limitation

Fig. 3 represents the path and errors of sinusoidal encoder outputs.

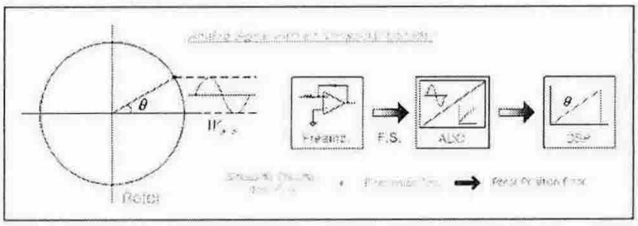

Fig. 3 Analog signal path and errors

The errors of sinusoidal encoder output signals can be divided into sinusoidal encoder itself errors and electronics errors for signal processing when amplitude and offset errors are completely compensated. For the convenience of analysis, ignoring the encoder itself and electronics errors, the sinusoidal encoder output signals are satisfied with the following conditions:

(1) A/D converter input signals should be adjusted to full scale input range of A/D converter.

(2) Input signal errors of A/D converter should be satisfied with (8).

$$V_{error} \le \frac{A_{fs}}{(2^n - 1)} \qquad (8)$$

Here, V_{error} : input signal errors of A/D converter, A_{fs} : adjusted A/D converter input full scale range, n : bits of A/D converter

3.3 Amplitude and offset error compensation

The proposed method for amplitude and offset error compensation of sinusoidal encoder output signals represents Fig. 4, and the compensation sequence is as the following:

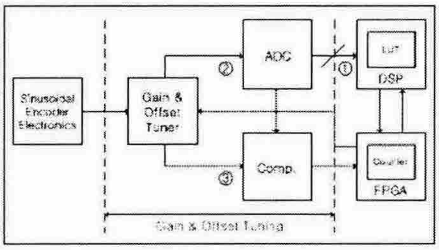

Fig. 4 Signal flow diagram about the proposed gain & offset compensation

(1) Observe the output of A/D converter controlling an amplitude and offset tuning device.
(2) Adjust the amplitude of A/D converter output to full scale input range of A/D converter, and compensate offset errors.
(3) Observing the tuned input signal V_c amplitude of A/D converter, control the amplitude and offset errors of V_s.
(4) Confirm whether or not V_s and V_c are synchronized. If not, synchronize them using logics in FPGA.

4. Experimental Results

4.1 Configuration of the proposed system

The parameters of the applied PMSM used are shown in the Table 1. Digital incremental 50,000ppr encoder used in the experiment is TS5178N60, Damagawa product. The sinusoidal encoder is ERN1387, Heidenhain product, and it is attached to the motor shaft.

Table 1 Nominal parameter of PMSM in experiment

Nominal Parameters of PMSM.			
Rated voltage	220[V]	Poles	8
Rated current	7.2[A]	Stator registor	0.91[Ω]
Rated speed	1000[rpm]	Stator reactance	4.7[mH]
Maximum speed	2000[rpm]	backEMF constant	0.147[V/rad/s]

4.2 Experimental waveform

4.2.1 Characteristics of rotor position accuracy

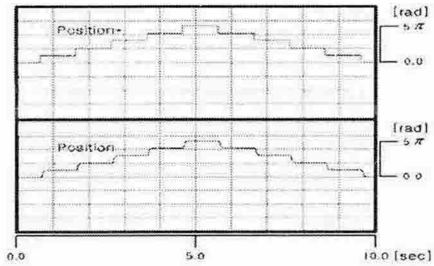

Fig. 6 Position Control Characteristics of 50,000ppr Encoder

4.2.2 Characteristics of torque and speed ripple (in process of experiments)

5. Conclusions

This paper suggests the ultra precise position estimation of a servomotor using the sinusoidal encoder based on Arcsine Interpolation Method. This paper introduces a compensation method for amplitude and offset errors utilizing a low cost programmable gain and offset tuning device. To theoretically evaluate the practical resolution of this system, the relationship between the amplitude of A/D converter input signal errors and the anticipated resolution is briefly dealt with. The performance of the proposed system is verified throughout the experiments. The test results show that the proposed method exhibits better performance both in both position and adjustable speed control characteristics than the 50,000ppr optical encoder.

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