A novel hybrid type encoder design for the position control with the high-resolution

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Abstract: The position control is very important in semiconductor manufacturing devices, precision machining tools, precision measuring instruments, etc. The accuracy of measurement for the distance in these devices affect on the performance of the whole devices. Therefore, in those precision instruments, a sensing device that can measure the distance of movement with high-precision resolution is required. In this paper, a novel hybrid (digital and analog) type encoder is proposed. It is shown that from several experiments, a high-resolution angular position measurement device can be designed with a low cost incremental encoder and a DSP controller.

Keywords: High-Resolution, Hybrid Type Encoder, DSP controller

1. Introduction

The demand for high-resolution position control is gradually increasing with the development of the mechatronics engineering and the precision manufacturing machine. Especially, in industrial precision machine tools, industrial robot, high precision control device and semiconductor manufacturing machine, the measurement of precision position value is the main element of the device performance. [1][2][3][4][5] In these machines, the use of poison sensing device is necessary and to acquire high resolution, the optical encoder is preferred rather than magnetic encoder. Generally, the magnetic encoder has the merits in long durability and less effective on environmental condition. But the magnetic encoder is high cost and has limit to acquire the high resolution. The optical encoder, however, is widely adapted to industrial digital machines, owing to its low cost and high-resolution measurement. The rotary encoder has many tiny slits on the corner of the circular plate and the transmitter diode and two receiver diodes detect the optical signal. The receiver diode signals are converted into digital signals and the electric phase of the two signals is 90^0. To increase the position resolution, it is considered to increase the number of the slit, but it is limit in mechanical machining technology.

In this paper, a new concept of position measuring method was proposed. This method is based on the processing of the analog optic intensity signal of a low cost optical encoder. The electric circuit of the optical encoder is modified and a DSP(Digital Signal Processor) controller process the analog signals form the receiver diodes and converts these signals into high resolution position digital signals.

2. The Hybrid Type Encoder

2.1. The General Optical encoder

The optical encoder is composed of the photo transmitting source, receiver devices, and a rotating disk with slits. The pulse output, proportion to the rotational angle, can be detected by rotating the disk with the transmitting source and receiver diodes. Fig. 1. represents the structure of an general optical encoder. The digitalized signals from a comparator are defined as ***A*** and ***B*** phase signals. Generally, 4 division signals are entered into the pulse counter of the DSP controller.

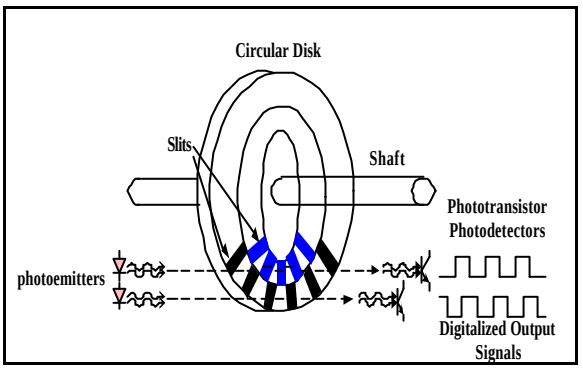

Figure 1. The Structure of an optical encoder

2.2. The Proposed Hybrid Type Optical Encoder

The general digital type incremental encoder uses the digital signal, the outputs of the two receiver diodes. Fig. 2. represents the ***a, b*** signals (the output of the receiver representing the rotational position), the ***A, B*** phase signals, and 4 division signal. A general encoder can detect the angular position and rotational direction by using the two ***A, B*** phase signals. The ***a***

and ***b*** signals are two phase voltage signals having phase difference of 90^0. Actually, these signal have DC offset. The DC offset can be eliminated with a DSP controller. The offset free signals are defined as a, b. The phase angle is easily obtained by following equation.

$$\Delta q = \tan^{-1}(\frac{a}{b}) \tag{1}$$

The angular position by the equation (1) is very sensitive to the noise, if $a \approx 0$. To compensate this noise effect, the equation (2) can be used without generosity.

$$\Delta q = \cos^{-1}(\frac{a}{\sqrt{(a^2 + b^2)}}) \tag{2}$$

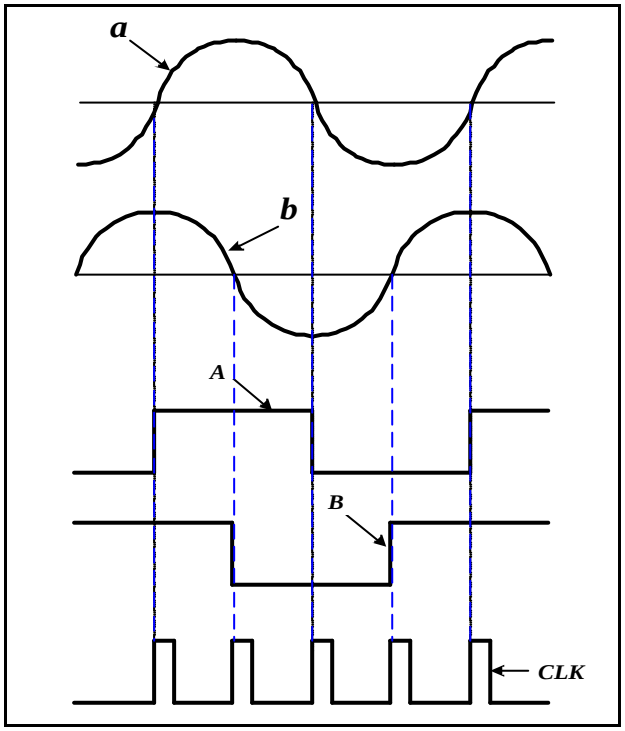

Fig. 2. A, B Phase, 4 Division and received waveform (a, b) according to electrical position of the slit

The equation (2) is calculated with a DSP controller and the resolution is depend on the bit resolution of the DSP controller. If the bit resolution of the A/D converter is ***Q***, the resolution can be determined by the following equation.

$$r = \frac{2p}{2^Q} \quad [rad] \tag{3}$$

If the number of pulse per a round of the encoder is defined as N, The resolution of the encoder is inverse proportion to the number of slit.

$$n = \frac{2p}{N} \quad [rad] \tag{4}$$

If the counting number of ***A*** phase signal of the encoder is defined as ***P***, the rotator angle of at present time is as following,

$$q_i = \frac{2p}{N} p \quad [rad] \tag{5}$$

The actual position angle of rotator is obtained by the combination of the position angle q_i from digital encoder signal, and electric position angle of slit, Δq.

$$q = q_i + n\Delta q \quad [rad] \tag{6}$$

Therefore, the resolution of the hybrid (digital and analog) type encoder is obtained by following equation.

$$z = nr \quad [rad] \tag{7}$$

2.3. DSP Controller

The Texas Instrument DSP Controller (TMS320F241), developed for 'Motion Control Chip' is used for calculation and processing controller for this experiments. This controller is 16 bit high speed Processor. It has 6 PWM (Pulse Width Modulation), 16bit timer and 10 channel 16bit AD converter. Also it has a QEP input devices for position senor, capture device and external interrupt devices. Thus, this processor is suitable for motion control with motor and an excellent DSP controller having good performance with low price. The followings are the specification of the DSP (TMS320F241) controller

- 544 Word ×16 Bits? on-Chip DARAM
- 8K Words×16 Bits? Flash EEPROM
- Event Manager Module
- 8 Compare/PWM Channel
- 2 16-it General-Purpose Timers
- 3 16-Bit Full Compare Units With Deadband
- 3 Capture(2 QEP Interface)
- 1 10-Bit ADC With 8 Multiplexed Channels
- 26 General-Purpose I/O
- Watchdog Timer
- Serial Communications Interface (SCI)
- 16-Bit Serial Peripheral Interface(SPI)
- 5 External Interrupts
- 3 Power-Down Mode for Low-Power
- Scan-Based Emulation

Fig. 3. illustrates the signal detection block diagram for the proposed hybrid type encoder. The QEP port was used for digital signal input and A/D converter port was used for analog input to detect position angle. From two analog signals, the DC offset was eliminated and the symmetric 2 phase signals, a, b are induced. A low pass filter(LPF) was used for canceling of

noise signals. The high-resolution position angle was derived using the sum of the electric phase angle between slit, Δq and the rotator position angle of digital encoder, q_i.

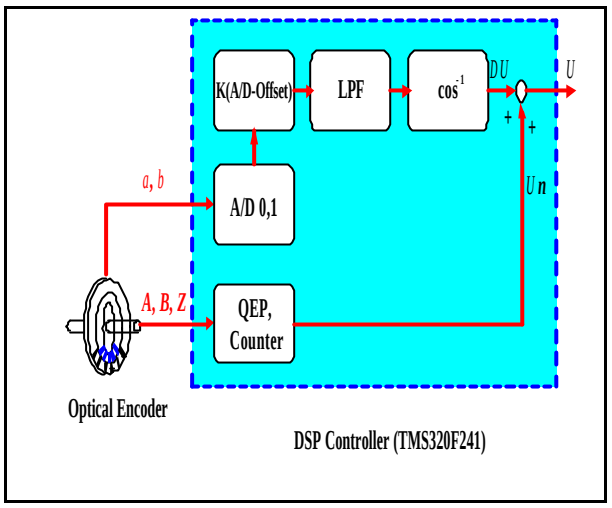

Fig. 3. Signal detection block using DSP controller

3. The Experiments

To verify the performance of proposed hybrid type encoder, an analog amplifier was installed at the general encoder (Tektronix, 1024 pulse) and a DSP controller (TMS320F241) was used as a digital processor.

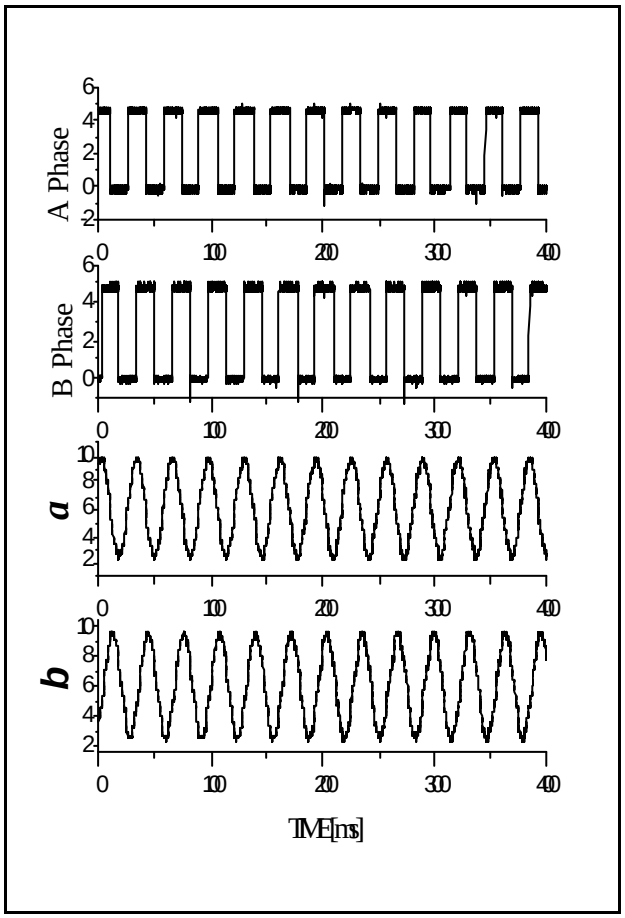

Fig. 4. ***A*** , ***B*** phase and ***a***, ***b*** waveforms of the hybrid encoder.

Fig. 4. represents the ***A***, ***B*** phase signal and the signal of receiver diodes, ***a*** and ***b***. The ***a***, ***b*** signals have the same frequency of ***A***, ***B*** signals and have the shape of sine wave. And the phase difference is also 90^0.

Fig. 5. represents 2 phase a,b signals. These signals have the same magnitude of ***a***, ***b*** and the phase difference is 90^0. And the signals were eliminated the DC offset. The DSP controller calculates the DC offset and eliminates the offset and multiply a proper scale factor *K*.

Fig. 6. represents the electric phase angle signal in a pitch of the slit. These signals are derived by the a,b signals. It is shown that the phase angle signal has the same frequency of ***A*** phase signal of the encoder. The angle signal has gradual pattern and has reasonable behavior.

In the position control, the frequent opposite operations of the motor near the referenced command area are general cases. Therefore, in these cases, it is also necessary that the proposed hybrid type encoder's reasonable behavior will be verified. Fig. 7. represents the **A** phase signal, a,b and slit pitch phase angle signals. The phase angle signal's behavior is reasonable in spite of the transient operation state.

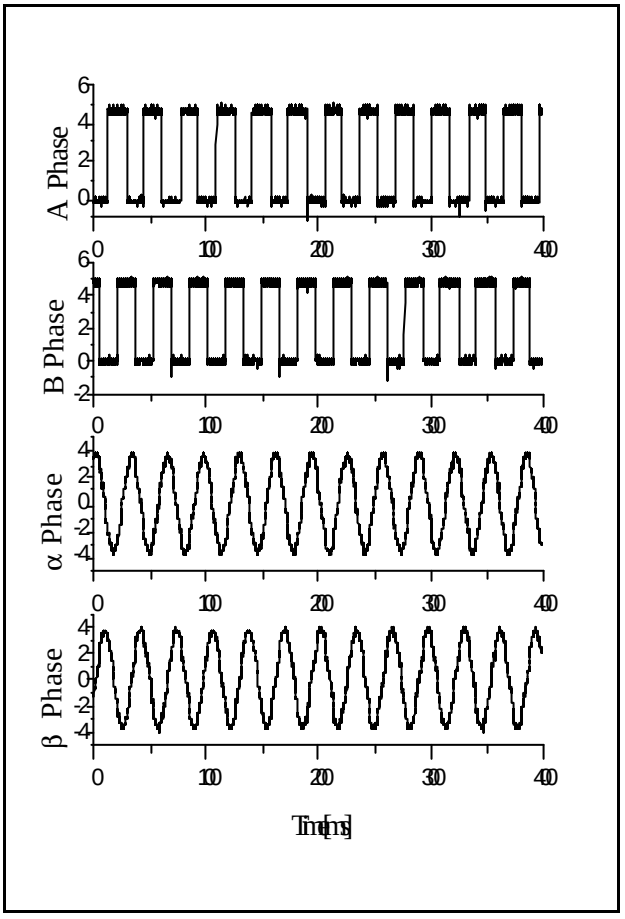

Fig. 5. .***A*** , ***B*** phase and a,b phase waveforms of the hybrid encoder

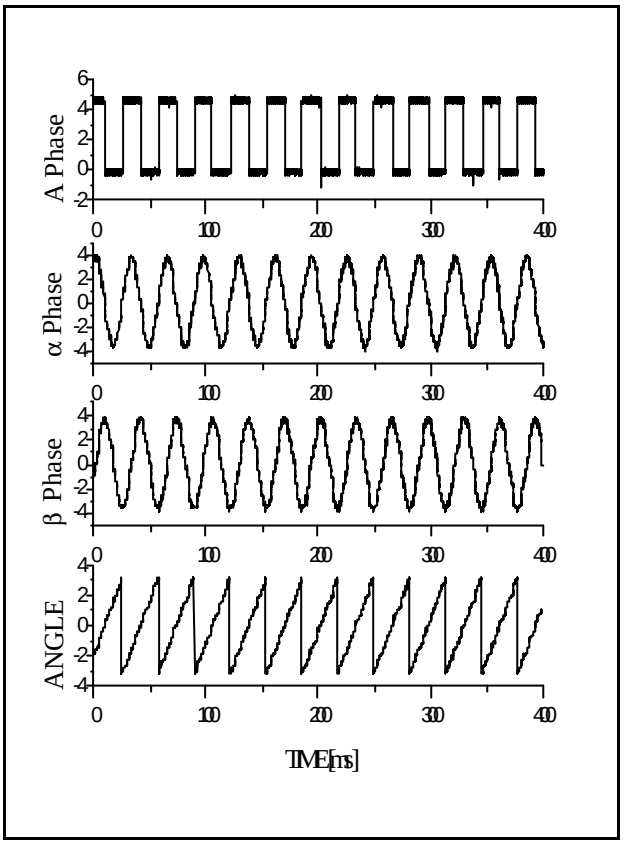

Fig. 6. ***A*** phase, a,b and angle waveforms of the hybrid encoder

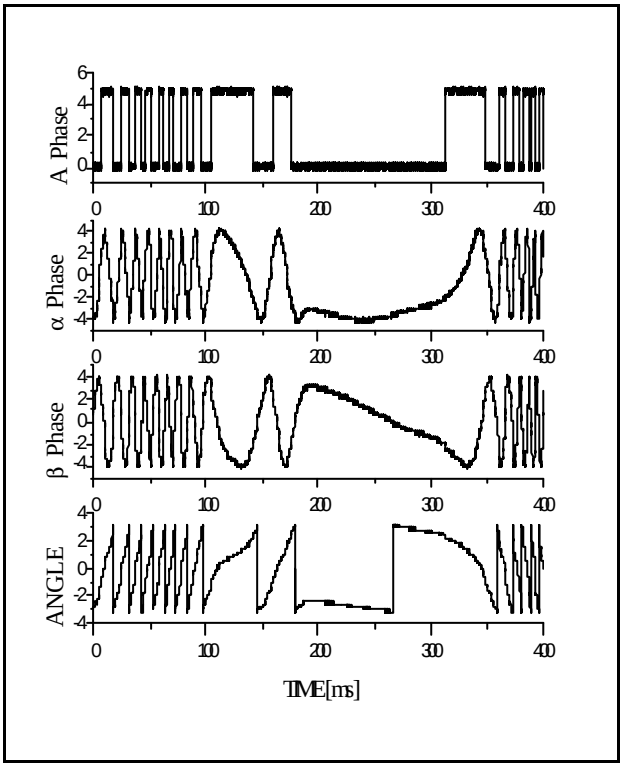

Fig. 7. ***A*** phase, a,b phase and angle waveforms of the hybrid encoder at the transient state

4. Conclusions

In this paper, the new method based on the combination of the digital signal of the general low cost encoder and analog signal form the slit, was proposed. For the digital signal, the electric circuit part was modified and the analog signal is converted into digital signal with a A/D converter in a DSP controller. Therefore, in this new method, the high-resolution position detection is possible and this method can be applied to the semiconductor manufacturing machine, precision industrial robot etc. The experiment was performed using the proposed hybrid encoder. The position between two slits is obtained within the resolution of the A/D converter bit resolution of a DSP controller. In this experiment, the 10 bit A/D converter (TMS320F241) was used. The upper 2 bits were dropped for noise cancellation. Therefore, in this new hybrid encoder, the 256(2^8) times more resolution than that of the general low cost encoder was obtained.

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