Technical research on continuous two-speed shaft angle converter

1 Introduction

With the increase in precision requirements for weapons and equipment, as well as the development of manufacturing technologies for Synchro and Resolver in recent years, multiple systems have been used in large numbers. The two-speed system is widely used, and its specific speed is mainly 1:8, 1:16, 1:20, 1:30, 1:32, 1:36, and 1:64.

The two-speed shaft angle converter is used for the two-speed system. The conversion technology has undergone two stages of rough and fine combination conversion principle and continuous conversion principle, and makes the corresponding combined two-speed converter and Continuous two-speed converter.

In this paper, the conversion principle of the combined speed converter is briefly described, and some design techniques of the continuous two-speed converter are emphasized.

2 The comparison between combined and continuous dual speed converter

To compare the differences between the combined two-speed converter and the continuous two-speed converter, we first briefly describe the conversion principle of the combined two-speed converter. The principle block diagram is in figure 1.

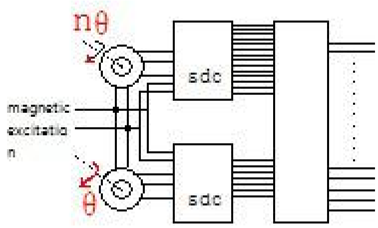

Figure 1

In a combined two-speed converter, an analog synchronous machine or resolver signal containing angle information is input via two independent single-speed SDC/RDCs (where a coarse channel is connected to the original fixed speed motor; and an N-speed motor is connected) The refined channel is converted into a coarse channel and a fine channel digital signal including angle information, and the digital combination logic circuit performs error correction processing on the two coarse channels and the proficient digital signal, and outputs a digital signal representing an angle to realize the conversion of synchronous machine or a resolver-Signal-to-digital.

The conversion principle of the continuous two-speed converter, the principle block diagram is shown in Figure 2:

It has two sets of error signal generation circuits, which are controlled by the same reversible counter. The cross detector selects one of the coarse and fine error signals according to the size of the coarse axis error signal. Then it controls the voltage controlled oscillator, so that the counter work and the tristate latching output.

The continuous two-speed converter is mainly composed of the following parts:

1. a specific speed processing circuit. 3. a function generator circuit. 4. a cross detection circuit. 5. a false zero elimination circuit. 6. a synchronous reference circuit.

The coarse and fine two-way synchronous/decomposer signals are respectively connected to the analog signal input terminal of the continuous synchronous machine resolver-digital converter (the original multiple is the coarse channel, 36 times the fine channel). After converting by the converter, the latch output binary code with up to 20 digits representing the angle.

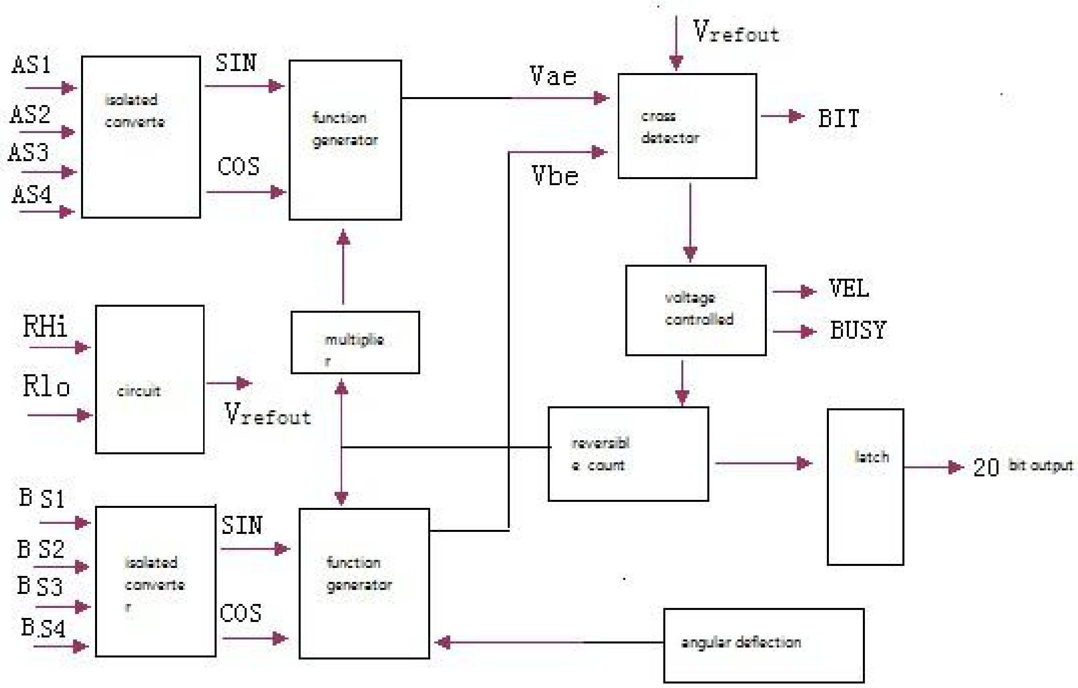

Figure II

3 specific research on continuous two-speed converter

3.1 Technical study of function generator circuit

The working principle of the two sets of function generator circuits is exactly the same, but there is a difference in resolution: the resolution of the function channel of the fine channel is higher than the resolution of the function generator of the coarse channel, the two channel function The specific value of the resolution of the generator depends on the specific speed, that is, the resolution of the function generator that requires the coarse channel should be smaller than the angle of the coarse channel that the perfect channel can represent. Taking the specific speed n=36 as an example, the angle of the coarse channel that the fine channel can represent is 360/36-10°, so the resolution of the coarse channel function generator is at least 6 bits.

The function of the function generator circuit is to multiply the input analog angle and the digital feedback angle:

Set the input self-aligning machine signal to:

$S1=VmSin(\omega t+\alpha)Sin\theta$

$S2=VmSin(\omega t+\alpha)Sin(\theta+120°)$

$S3=VmSin(\omega t+\alpha)Sin(\theta+240°)$

Output digital angle is ψ

The three-phase self-aligning machine signal is isolated and converted into $Vs=kVmSin(\omega t+\alpha)Sin\theta$ and $VC=kVmSin(\omega t+\alpha)Cos\theta$, and the function generator circuit realizes multiplication of the two orthogonal signals with the digital angle of ψ. And the subtraction of the analog angle θ and the digital angle ψ is realized by the operational amplifier:

$$Vs\times Cos\psi - VC\times Sin\psi = kVmSin(\omega t+\alpha)Sin\theta\times Cos\psi - kVmSin(\omega t+\alpha)Cos\theta\times Sin\psi$$

$$= kVmSin(\omega t+\alpha)\,(Sin\theta\times Cos\psi - Cos\theta\times Sin\psi)$$

$$= kVmSin(\omega t+\alpha)Sin(\theta-\psi)$$

When the input is a resolver signal, since the resolver signal itself is a quadrature signal, it is only necessary to perform differential isolation amplification at the input end, and the subsequent processing is completely consistent with the above.

3.2 Technical Research on Synchronous Reference Circuit

As a micro-motor with a measuring angle sensor, whether it is a sine-cosine rotary transformer or a controlled self-aligning machine, there is always a certain phase shift between the analog signal representing the angle information and the input excitation signal, such as the sine and cosine at the single speed. In a resolver or a controlled self-aligning machine, this phase shift can be up to ±15°; in a multi-pole sine and cosine resolver, this phase shift will be larger, mostly ±40° to ±60°.

The error caused by the phase shift can be estimated as follows:

$$\text{Error} = \frac{\text{revolving*phase shift}}{\text{excitation frequency}}$$

If the specific speed of a speed measuring angle system is 1:36, the speed of the rough channel motor is 120°/second, the phase shift of the output signal of the fine channel motor and the excitation is 40° and the frequency of the excitation is 400Hz, the error is 2 cents. The actual two-speed angle measuring system with a specific speed of 1:36 has an accuracy requirement of 10 arc seconds. It can be seen that the conversion error caused by the phase shift is not allowed and must be processed, so the two-speed test is performed. In the angular system, a synchronous reference circuit is introduced. Its principle block diagram (taking 1:36 as an example) is shown in Figure 3.

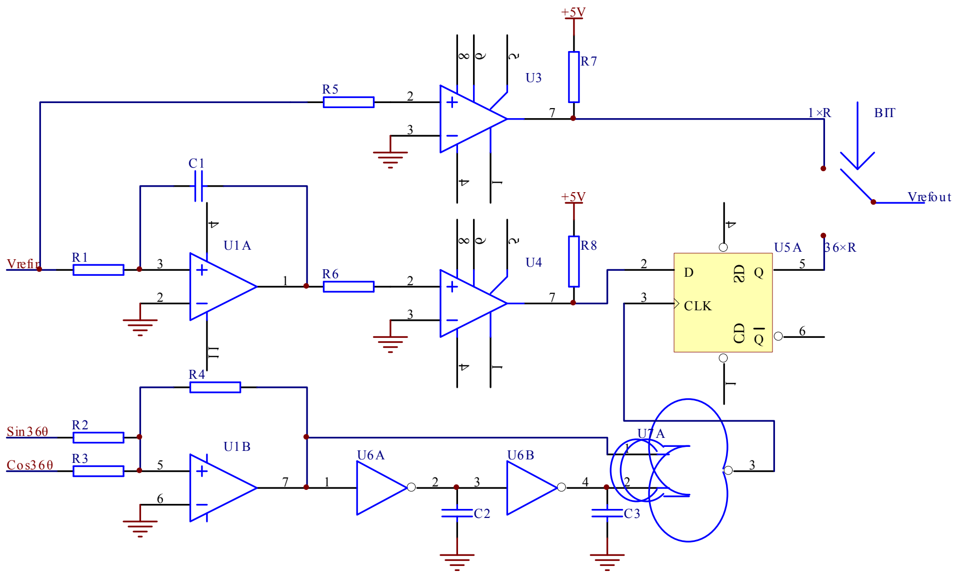

Figure III

After the introduction of the synchronous reference circuit, the phase shift of the output signal of the fine channel motor and the excitation can be reliably ensured within 0.01°, and the error of the two-speed angle measurement system is 0.03 arc seconds, compared with the actual specific speed. The accuracy requirement for a 1:36 two-speed angle measurement system is negligible compared to 10 angular seconds.

3.3 Research on Cross Detection Circuit

In the continuous two-speed converter, since there are two independent coarse and fine channel error generation systems, after the coarse channel error is less than the set threshold voltage; there must be a cross-detection circuit to be the only voltage-controlled oscillator in the system. The input control voltage is switched to the fine channel, and the error voltage of the fine channel controls the voltage controlled oscillator to output a counting pulse, so that the system can approach the actual rotation angle of the rotating shaft with higher precision. Its principle block diagram is shown in Figure 4.

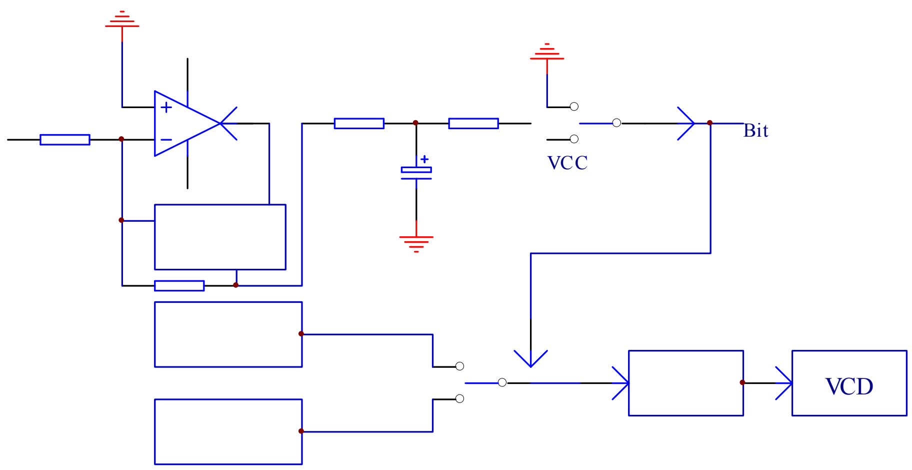

Figure 4

A cross-detection circuit simultaneously generates a logic signal of TTL(BIT, a built-in test signal). If the signal is always at a logic high level, the continuous two-speed converter is in an error state.

3.4 Research on steady-state zero point and false "zero point".

In the range where the angle changes by one week (0 to 360°), the points at which the sinusoidal signal Sin（θ-ψ）=0 can be: 0° and 180°. Let's discuss these two zeros separately:

3.4, 1a at 0°

a at 0°, that is around θ-ψ=0 and 0°, any disturbance of the angle of the shaft:

When the a1 axis angle positive resistance is +α,

Sin（θ+α-ψ）≈Sinα≈α

After the phase detection and rectification, the reversible counter is counted forward, so that the digital angle a is also positively increased by +α, and Sin[（θ+α）-（ψ+α）] is always guaranteed to be =0.

When the a2 axis angle positive resistance is -α,

Sin（θ-α-ψ）≈Sinα≈α

After the phase detection and rectification, the reversible counter is negatively counted, so that the digital angle is reduced and negatively increased, and Sin[（θ-α）-（ψ-α）] is always guaranteed to be 0.

The conclusion is that the 0° point is the steady-state zero point of Sin（θ-ψ）.

3.4, 2a at 180°

b at 180°, that is around θ-ψ=0 and 0°, any disturbance of the angle of the shaft:

When the b1 axis angle positive resistance is +α,

Sin（θ+α-ψ）=Sin（180°+α）≈-α

After synchronous phase rectification, the reversible counter is controlled to negatively count, so that the digital angle 0 is also negatively increased by –α, then Sin[（θ+α）-（ψ-α）]= Sin（180°+2α）≈-2α , so that Sin（θ-ψ）deviates from zero.

When the b2 axis angle positive resistance is -α,

Sin（θ-α-ψ）=Sin（180°-α）≈+α

After synchronous phase rectification, the reversible counter is controlled to count forward, so that the digital angle 0 is also negatively increased by +α, then Sin[（θ-α）-（ψ+α）]= Sin（180°-2α）≈+2α , so that Sin（θ-ψ deviates from zero.

The conclusion is that the 180° point is the unsteady zero point of Sin（θ-ψ）, which is a false “zero point”.

In the two-speed system, since the speed of the fine channel is n times than the speed of the coarse channel, in the range of one-degree change of the angle of the coarse channel (0°~360°), there should be n steady-state zeros and n false "zero points" in the phase channel.

Take n=8 as an example:

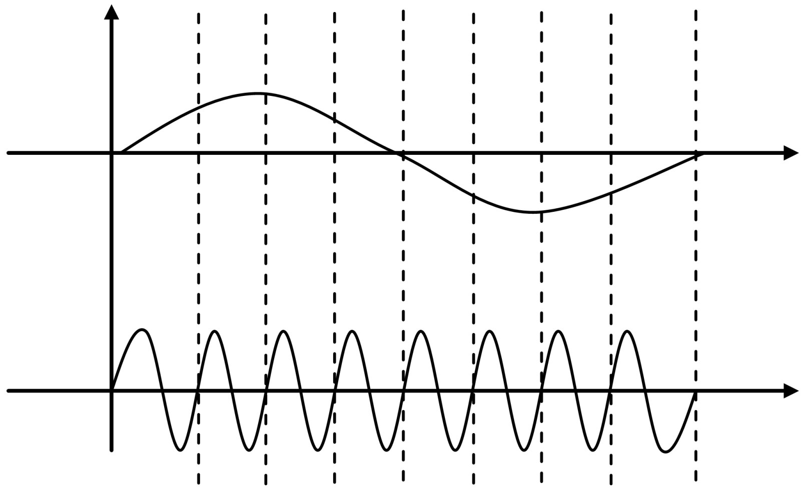

Figure 5

Take m=5 as an example. See Figure 6:

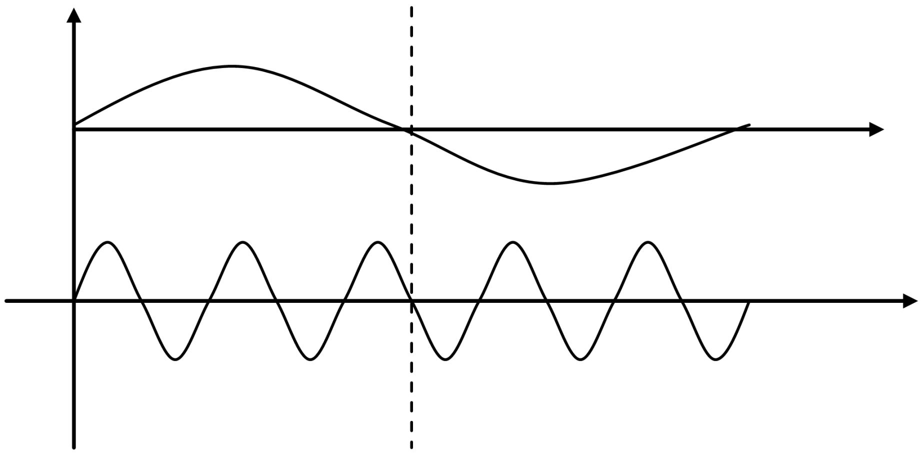

Figure 6

It can be seen from the above two figures that when the specific speed n is an odd number, the false “zero point” (180° point) of the coarse channel corresponds to the false “zero point” (180° point) of the fine channel, but when the specific speed n is even, the coarse The false "zero point" of the channel (180° point) corresponds to the steady-state zero point (0° point) of the fine channel.

If the specific speed n is even, the cross detection circuit jumps to the fine channel near the false “zero point” (180° point) of the coarse channel, because it corresponds to the steady channel zero point (0° point), so there is no busy. Pulse, the output of the reversible counter is unchanged, causing the input and output to be 180° out of phase, making the two-speed system useless.

In the engineering system, the two-speed converter with accidental speed is used, such as: 1:8; 1:16; 1:20; 1:32; 1:36; 1:6451:30.

For this reason, the problem of false "zero point" must be dealt with in the two-speed conversion system, otherwise the two-speed converter will be lost in use value.

In order to eliminate the false "zero point", an effective measure is to select a zero-shift voltage V_{ST} on the error signal of the coarse channel, the voltage has the same frequency as the error signal, and the error signal of the coarse channel becomes:

$$V_{Be} = V_m \sin\omega t \sin(\theta - \varphi) - V_{st}$$

The addition of Vst is that the stable zero of Vbe leaves 0°; in order for the stable zero of the coarse axis signal to remain at 0°, an additional phase shift Δa is introduced into the signal.

$$V_{Be}' = V_m \sin\omega t \sin(\theta - \varphi + \Delta\alpha) - V_{st}$$

Since the zero point of Vbe is still 0, that is, when 0-1=0°, Vbe=0, then

$$V_{Be}'\big|_0 = V_m \sin\omega t \sin\Delta\alpha - V_{st} = 0$$

$$V_{st} = V_m \sin\omega t \sin\Delta\alpha$$

$$V_{Be}' = V_m \sin\omega t \sin(\theta - \varphi + \Delta\alpha) - V_m \sin\omega t \sin\Delta\alpha$$

$$= V_m \sin\omega t[\sin(\theta - \varphi + \Delta\alpha) - \sin\Delta\alpha] = Z V_m \sin\omega t \sin\frac{\theta-\varphi}{2}\cos(\frac{\theta-\varphi}{2} + \Delta\varphi)$$

For the unstable zero of Be, we require that it be moved to an unstable zero of the nearest precise channel signal, and the comparison becomes a 1:36 converter, which is

$$\theta - \varphi = 180^0 - \frac{180^0}{N} = 180^0(1 - \frac{1}{N}) = \frac{35}{36} \times 180^0$$

$$V_{Be}'\Big|_{\frac{35}{36}\times 180^0} = 0 \quad , \quad \sin\frac{\theta-\varphi}{2} = 0 \ \text{ or } \ \cos(\frac{\theta-\varphi}{2} + \Delta\alpha) = 0$$

$$\frac{\theta-\varphi}{2} + \Delta\alpha = 90^0$$

$$\theta - \varphi = 180^0 - 2\Delta\alpha = \frac{35}{36} \times 180^0 \rightarrow 2\Delta\alpha = \frac{180^0}{36} \rightarrow \Delta\alpha = \frac{180^0}{2 \times 36}$$

$$\Delta\alpha = 2.5^0$$

In summary:

$$V_{Be}' = V_m \sin\omega t[\sin(\theta - \varphi + 2.5^0) - \sin 2.5^0] \leftarrow \text{ the specific speed is 1:36}$$

The general formula is derived: $V_{Be}'=V_m \sin\omega t[\sin(\theta-\varphi+\frac{180^0}{2N})-\sin\frac{180^0}{2N}]$

Or: $V_{Be}'=V_m \sin\omega t[\sin(\theta-\varphi-\frac{180^0}{2N})+\sin\frac{180^0}{2N}]$

Illustration:

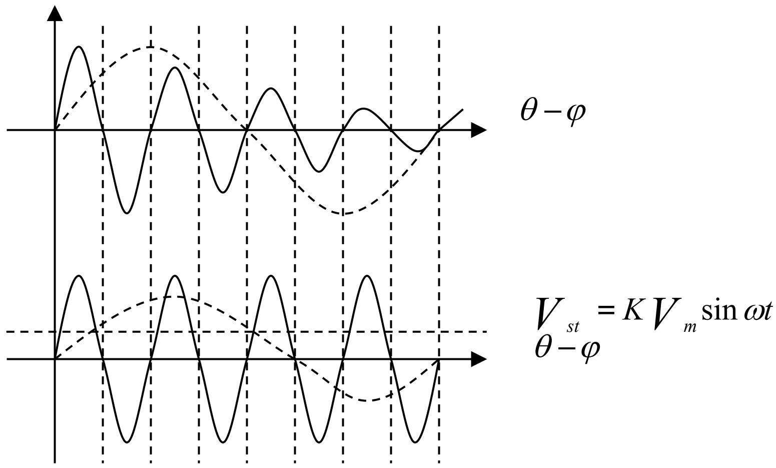

Figure 7 Graphical illustration of the Vbe formula

After introducing the offset voltage and the offset angle, the coarse channel error becomes an irregular waveform.

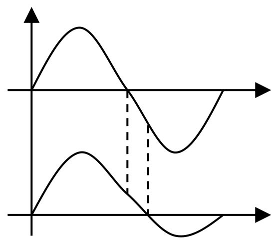

Figure 8 rough channel error

And to make its phase stable zero point move to one of the unsteady zero points of the nearest fine machine, to achieve the elimination of the false "zero point" (that is, when the coarse channel error becomes smaller to the threshold voltage, the voltage control voltage is switched to the fine In the case of channel error, the corresponding non-steady-zero point is also achieved, and normal tracking is achieved.

Circuit principle:

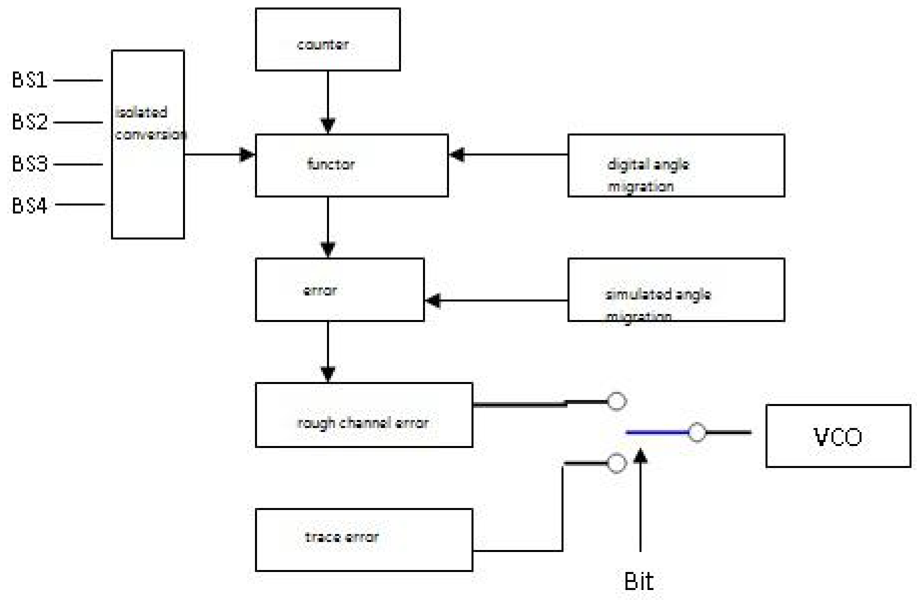

Figure 9 shows the principle block diagram of normal tracking

4 development prospects

After nearly two years of research, we have produced a two-speed shaft angle converter with a resolution of 20 bits and a continuous working mode with an accuracy of ±5 degrees. However, since some circuits in foreign finished devices are still used, it is necessary to further study the circuit for the localization of the continuous two-speed shaft angle converter, and efforts are made for miniaturization and serialization of the product.