Design of integrated test system for current/frequency conversion circuit

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Abstract. In order to quickly and accurately measure the performance parameters of the current/frequency conversion circuit (I/F conversion circuit) of inertial navigation system, an I/F conversion circuit test system is designed. Constant current signal, sinusoidal current signal and transient step current signal are provided to the measured system by a program-controlled constant current source. Through the designed frequency measurement circuit, the output frequency signal is measured accurately, the static, dynamic and transient responses of three kinds of I/F converter circuits are analyzed.

1. Introduction
I/F conversion circuit is applied in inertial navigation system as a unit circuit. It can transform the analog current signal output by accelerometer in inertial measurement module into pulse frequency signal which is proportional to it. The special application field determines the strict requirements on its electrical performance. In the production process, the test and acceptance of I/F conversion circuit are often conducted by manual testing, which is inefficient. In order to quickly and accurately measure the performance parameters of I/F conversion circuit, an I/F conversion circuit test system is designed, which can not only quickly measure the static characteristics, dynamic characteristics and transient characteristics of I/F conversion circuit, but also complete the storage and display of data. Thus, the test efficiency, test precision and test process reliability of I/F conversion circuit test system are significantly improved.

2. System design scheme

2.1. Overall design
This system based on FPGA using Verilog language code, through static control and high precision constant current source module output current signal, sine current signal and transient step current signal, drive the I/F conversion circuit under test. The pulse signal output by the I/F conversion circuit passes through the isolation circuit and is sent to the frequency measurement module for measurement. The measurement data is uploaded to the upper computer through the RS232 serial communication module for display and storage. The hardware structure of the system is shown in figure 1:
2.2. Static characteristic test

The principle of static characteristic test is that constant current source circuit is designed to input constant current signal for I/F conversion circuit, and pulse signal output by measured circuit board is sent to frequency measurement module for measurement after being isolated by optocoupler. When the input constant current signal varies from 1mA to 20mA, the corresponding output pulse signal frequency can be obtained.

2.2.1. Constant current source circuit design. The constant current source circuit [1] is shown in figure 2, which is a very important part of the test system, mainly composed of D/A converter and integrated operational amplifier. Its purpose is to output a set of current signals in the range of 1mA~20mA during static test.

![Constant current source circuit principle diagram](image)

Figure 1. Constant current source circuit principle diagram.

D/A converter is the core circuit to generate drive control voltage. Its main function is to convert the digital control signal input by the processor into analog signal and transmit it to the constant current circuit to provide the drive voltage for the constant current circuit.

The integrated operational amplifier USES the bipolar operational amplifiers OPA2604 with high voltage and large current, S1 and S2 as electromagnetic relays. During the test of the test system, when the output current is less than 5mA, the resistance R4 is disconnected, and when the output current is more than 5mA, the resistance R4 is connected. By controlling the output voltage of R4 and D/A, the constant current source can output the constant current source signal in the range of 1mA~20mA.

2.2.2. Signal isolation circuit design. The pulse signal output by the I/F conversion circuit is photoelectric isolated by the nonlinear optocoupler chip 4N25 before being sent to the frequency measurement module for frequency measurement. The purpose of isolation is to prevent the signal from burning out the FPGA's main control chip and other electrical signals from interfering with the test system. In the isolation process, nonlinear photocoupling will not change the signal pulse width, but only change the signal amplitude, which is determined by the power supply amplitude connected by 4N25.

2.2.3. Frequency measurement module design. Static characteristic test frequency measurement adopts multi-period synchronous-step frequency method [3]. The principle is shown in FIG. 4. Synchronize and count multiple cycles of the reference signal \( f_s \) and the measured signal \( f_x \), and record the pulse number \( N_x \) and \( N_s \) of the measured signal \( f_x \) and the reference signal \( f_s \) respectively, for the measured signal frequency is \( f_x = f_s \times N_x / N_s \). Multi-period synchronous-step frequency measurement method is shown in figure 3.
2.3. Dynamic performance test

The principle of dynamic characteristic test is to input sinusoidal current signal of 1~100Hz for I/F conversion circuit, and output pulse signal of ac frequency conversion by conversion circuit. The pulse signal is isolated by optocoupler and sent to frequency measurement module for measurement.

2.3.1. Sinusoidal signal generation design. The principle of sine signal generation is: generate a 32-bit accumulator by writing Verilog language, and pass the accumulator accumulation result to the sine look-up table ROM for look-up table, and send the query address to the D/A converter to convert into smooth waveform. When the accumulator produces an overflow, the output sinusoidal signal of a period, change the frequency control word K size, change the output sinusoidal signal frequency [4].

Under the effect of clock FCLK, the phase accumulator linearly accumulates the frequency control word K, and when the phase accumulator accumulates fully, an overflow will occur, and the overflow frequency of the accumulator is the frequency of the sinusoidal signal output. The frequency control word K is used as the step of the system for accumulation, and the time needed for overflow of the accumulator is:

\[ T = \frac{1}{f_{clk} \times 2^N} \times k \]

So the output frequency is:

\[ f_{out} = \frac{Kf_{clk}}{2^N} \]

Thus, the output frequency is determined by the frequency control word K and the crystal oscillator of the system. The system selects 50M crystal oscillator, the accumulator bit width is 32 bits. This system requires the output of sinusoidal signal in the range of 1~100Hz, so the use of this sinusoidal signal generation module can fully meet the design requirements.
Due to the dynamic test frequency output is constantly changing, need to measure the frequency of each of the output frequency value, weeks to measure frequency measurement is adopted. The principle of cycle measurement method is to record the number of pulses $N_s$ of the reference frequency signal $f_s$ within one cycle $T_x$ of the measured pulse signal $f_x$. The measured signal frequency is $f_x = f_s / N_s$ [6]. Frequency measurement module as shown in figure 5.

![Figure 4](image.png)

**Figure 4.** Frequency measurement module of measurement cycle method.

1. int\_div is the frequency division module, which is used to obtain the reference frequency of the measurement frequency by the tenths of the system clock signal.
2. fre\_calc for frequency measurement module, function is the reference signal pulse counting after through the formula to calculate.

Dynamic characteristic test is to input sinusoidal current signal with amplitude of 5V for I/F conversion circuit through the constant-current source circuit, and the pulse signal output by the tested circuit board changes with the sinusoidal current signal. When peak voltage sine signal output pulse signal frequency peak, relationship between input and output as shown in figure 6.

![Figure 5](image.png)

**Figure 5.** Relationship between sinusoidal input and output.

When the input sinusoidal current signal varies from 1 to 100Hz, the maximum value of the output pulse signal can be measured. When the maximum value of the measured pulse signal attenuates to 0.707 times (cut-off frequency) of the pulse signal corresponding to the 5V amplitude, the pass frequency band of the circuit under test can be obtained [5]. The frequency response characteristics of the circuit board under test are obtained.
2.4. Transient characteristic test

Transient testing is at the instant of the constant current input, measuring the output signal frequency for the transient response of the circuit under test. Through control constant current source circuit, the output opening and closing of electromagnetic relay S2 produce transient step current signal, the step signal input to the I/F conversion circuit, the output of the pulse signal frequency values change gradually increase finally stabilized, the output frequency value through measuring every week to measure change frequency values, get under transient step signal is the interval of reaching stability state of the output signal, which can get the circuit being measured in step signal under the action of transient response. Transient characteristics of input and output as shown in figure 7.

![Figure 6. Transient response of transient step signal and output signal](image)

3. Conclusion

According to the performance parameters of the current/frequency conversion circuit (I/F conversion circuit) of inertial navigation system, a set of conversion circuit test system is designed. The system to be measured by programmable constant current source to provide 1 ma ~ 20 ma current signal, 1 ~ 100 hz sinusoidal current step signal and transient current signal, the frequency of its output signal is measured accurately, to complete the I/F conversion circuit of static, dynamic and transient three test function, through the I/F conversion circuit of static, dynamic and transient response characteristics of three kinds of analysis, show that the test system to improve the test efficiency, and stable and reliable performance.

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