Research on Calibrating Device of Daily Clock Time Difference Testers Based on DDS Cascade Technology

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Abstract. According to the specific requirements in the national verification regulations of JJG488-2018 "Instantaneous Daily Clock Time Difference Testers", this paper has developed a calibration device for an instantaneous daily rate measuring instrument. Under the premise of not using FPGA, CPLD, DSP and complex algorithms, the device adopts DDS chip cascade technology and energy conversion principle to ensure that the maximum allowable error of the daily difference is 0.001s/d. Therefore, the device is not only suitable for personnel in the field of measurement to calibrate instantaneous daily clock time difference testers, but also can be used as a general-purpose measuring instrument with frequency measurement functions such as high-resolution frequency synthesizer calibration frequency meters.

1. Introduction
Instantaneous diurnal difference measuring instrument is widely used in the rapid detection of travel time accuracy of instruments in various industries, and its performance directly affects the quality of timing products, so it is of great significance to detect its performance regularly. In February 2018, the revision of JJG488-2008 Verification Regulation of Meter Calibration Instrument undertaken by Shanghai Institute of Metrology and Testing Technology and Guangdong Institute of Metrology has been completed. The verification regulation of JJG488-2018"Instantaneous Daily Difference Measuring Instrument" issued by it has been greatly changed in many aspects such as measurement signal type, test method and measurement frequency, but the related calibration devices have not yet appeared in the market. Therefore, the research group has developed this calibration device of instantaneous daily difference measuring instrument, which conforms to the new metrological verification regulation, and has practical significance [1-3].

2. Measuring principle of instantaneous daily error measuring instrument
After market research, the research group found that the instantaneous daily difference measuring instruments in the market mainly realize the instantaneous daily difference measurement function by mechanical vibration collection principle, electromagnetic field collection principle and current collection principle, which correspond to mechanical stopwatch with mechanical structure and electronic stopwatch with crystal oscillator respectively.

The instantaneous diurnal difference measuring instrument designed according to the principle of mechanical vibration acquisition is mainly used for stopwatches designed completely based on mechanical principles. When this kind of instrument works, it uses microphone to collect its vibration signal, and then compares it with the standard signal after amplification and shaping, and calculates its daily difference.
The instantaneous diurnal difference measuring instrument is designed according to the principle of electromagnetic field acquisition and current acquisition. It is mainly used to detect the diurnal difference of electronic watches with crystal oscillator or RC oscillator (such as quartz clock, electronic stopwatch, etc.).

3. Realization of the calibration device of instantaneous daily error measuring instrument

Through the analysis in the previous section, it can be concluded that the instantaneous daily difference measuring instrument mainly uses sensors to collect magnetic field signals, electric field signals, electronic sound signals and current signals of clocks and watches. Therefore, when calibrating this kind of instrument, it is necessary for the standard instrument to output four energy signals, namely magnetic field signal, electric field signal, electronic sound signal and current signal, with a certain daily difference, so as to realize the calibration of the key indexes of the instantaneous daily difference measuring instrument.

Through analysis, the research group designed the calibration device of instantaneous daily difference measuring instrument with the principle structure in Figure 1. Among them, the 10MHz constant temperature and high stability crystal oscillator will output 10MHz frequency signal to the shaping module, which is mainly composed of Schmitt trigger, which shapes the input 10MHz signal, changes its sine wave into square wave, and sends the shaped signal to MCU module and frequency division module respectively; The frequency division module is mainly used to divide the input 10MHz signal under the control of the MCU module to generate the required frequency FreqA; MCU module is mainly used to control LCD module, keyboard module, DA module and frequency division module to realize the functions of the whole system; LCD module is used to display system status and test results; The keyboard module is used to input control information; DA module is used to realize the output of specified frequency signal; The amplifier module is used to amplify the output signal of DA, so as to push different external transducers to work normally.

3.1. Generation of different forms of energy

The device involves the generation of four energy forms, namely, electric field energy generation, magnetic field energy generation, electroacoustic energy generation and current energy generation.

Generation of electric field energy: According to the knowledge of physics, when current flows through parallel plate capacitors, there is edge effect because the actual area of parallel plate capacitors is not infinite, so there is electric field between parallel plate capacitors and their external edges.
Similarly, if the capacitor is excited by pulse and sinusoidal voltage, it will also generate electric field signals, and then some signals will be "leaked". The electric field energy transducer of this device is developed based on this principle.

Generation of magnetic field energy: According to the knowledge of physics, when current flows through solenoid, solenoid will generate magnetic field, while when alternating current flows through solenoid, alternating magnetic field will be generated inside and around solenoid. According to this principle, alternating current passing through inductance will have the same effect. The magnetic field energy transducer of this device is developed based on this principle.

Electro-acoustic energy generation: The most common method of converting electrical energy into sound (vibration) energy is using a horn. The electroacoustic energy transducer of this device is developed based on this principle. When the pulse signal is transmitted to the horn after power amplification, the horn will make a banging sound, thus realizing the electroacoustic transformation.

Generation of current energy: If the output voltage signal and the equipment to be calibrated form a loop, the loop current can be generated, and then the current conversion can be realized [4].

3.2. Hardware realization of verification device for instantaneous daily difference measuring instrument

A. Implementation of 10MHz Reference Crystal Oscillator Module

Fig. 2 shows the implementation circuit of 10MHz reference crystal oscillator module. The research group uses high-accuracy voltage reference chip ADR4550 and voltage divider circuit to finely adjust the voltage control pin of voltage-controlled crystal oscillator, and adjust its output frequency accuracy to better than $5 \times 10^{-9}$. In the design, the adjusted 10MHz frequency signal is introduced into the shaping module.

B. Realization of Shaping Module

Here, 74LS14 with Schmitt hysteresis trigger ability is used as shaping chip, which can shape sine wave signal output by 10MHz reference crystal oscillator module into square wave signal, increase driving ability and output the signal to frequency division module and MCU module synchronously.

C. The realization of frequency division module

With regard to fractional frequency division technology, Fig. 3 is the concrete implementation of DDS cascade frequency division technology used in this device. Because the voltage of the output signal of DDS chip does not meet the requirement of TTL level, it is necessary to add a voltage comparator during cascade to convert the output signal of DDS to TTL level. Chips U4 and U5 in the figure play this role.

Chips U2 and U3 are the general DDS chips mentioned above. In order to save control pins, this design uses SPI interface to control them. The MCLK pins of U2 and U3 are the external reference frequency input pins. In order to reduce the phase noise of the output signal of DDS chip, it is required that the external reference frequency of DDS chip should not be too low. The research group calculated two frequency division coefficients $N_{\text{Div1}}$ and $N_{\text{Div2}}$, and sorted them in size. The larger frequency division coefficient was input to the first stage (U2) of DDS cascade frequency divider, and the smaller frequency division coefficient was input to the second stage (U3) of DDS cascade.
frequency divider, so as to ensure that the reference frequency entering U3 MCLK pin was high enough and reduce the phase noise of U3 output signal [5-6].

Fig. 3 Concrete implementation of DDS cascade frequency division technology

D. Implementation of DA module

The frequency generated by the frequency division module enters the internal general counter of the MCU module for integer frequency division, and the frequency after frequency division is used as the trigger signal of the real output signal. In order to prevent the need for special waveforms in the future, DA is used as the signal source for output to the amplifier module instead of IO. In addition, in order to further reduce the uncertainty of interrupt response time of MCU, DMA mode is directly used to control DA output in MCU. After each trigger signal meets the requirements, MCU no longer responds to interrupt, and directly controls DA to output a group of waveform data through DMA mode, and then enters the waiting state again. In this way, the output signal waveform of the device can be more abundant, so as to meet the needs of future expansion.

E. Realization of Amplifier Module

In order to improve the driving ability of the output voltage of DA module, which can drive capacitive load, inductive load and 8 Ω/3W horn (corresponding to the transducer mentioned above), an amplifier module is added to the output end of this device. The specific implementation of this module is shown in Figure 4. In order to increase the adjustment ability of the output signal of the device, in the design, the research group added a digital adjustable resistor, which was combined with the thin film resistor to form a digital adjustable resistor divider. The maximum value of the digital adjustable resistor was 50 kΩ, which was divided into 32 gears. The MCU module controlled its output resistance through IIC bus to increase the adjustment ability of the output signal of the device.

Fig. 4 Realization of amplifier circuit module
4. Experimental test
For the convenience of testing and analysis, CNT-91R universal counter produced by Swedish pendulum company is used as the testing instrument, and 5071A cesium atomic frequency standard is used as the external frequency standard. The specific test system connection diagram is shown in Figure 5.

![Schematic diagram of device performance test](image)

Table 1. Statistic of Device Performance Test Results

| Nominal value (s/d) | Measured value (s/d) |
|---------------------|----------------------|
| 1.000               | 1.000                |
| 3.000               | 3.000                |
| 5.000               | 5.001                |
| -1.000              | -1.000               |
| -2.000              | -2.001               |
| -3.000              | -2.999               |

5. Conclusion
This paper analyzes the measuring principle of the instantaneous diurnal difference measuring instrument, the basic composition of the calibration device of the instantaneous diurnal difference measuring instrument and the hardware realization of the main parts. Finally, the index is verified by experiments, and satisfactory results are obtained. With the increasing requirement of calibration of instantaneous diurnal difference measuring instrument and related products, the calibration device has a very wide application prospect.

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