High precision capacitance displacement measurement circuit design

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Abstract: A high resolution digital integrated chip capacitor measurement system was designed. The major components of the system mainly included main control chip, capacitance transducer, data storage and communication interface. ARM7-based micro controller STM32F207 was used as the main control chip, capacitance measurement chip AD7747 produced by AD Company with sensitivity can be up to 20 aF was used as capacitance transducer. The capacitance measurement range of AD7747 is -8 pF to +8 pF, the maximum common-mode immutable capacitance can reach 17 pF and data update rate range is between 5 Hz to 45 Hz. The absolute error of test circuit was calculated by the fixed capacity test and error analysis. The final results were obtained after subtracting the absolute error, and the final test error is less than 3%.

Introduction

With the high-speed development of modern science and technology, the requirement for the accuracy of the instrument processing has been increased. Nowadays, precision machining technology has become an important index of the development of industry and science technology [1-4]. The ultra-precision measurement technology is always explored and gained more attention. The precision measurement technique is the key part of the measurement of machinery industry development in almost all developed countries. Capacitive displacement sensor technology is the most mainly used measurement method. This technology obtained more attention and has been applied in many different fields.

Currently, commonly used displacement measurement sensor mainly included capacitive and inductive displacement sensor and optical fiber displacement sensor. These different sensors have their own advantages and disadvantages and can be used in various occasions [5-7]. The capacitance displacement measurement sensor chosen here has many advantages compared with other capacitive displacement sensors: (1) the dynamic response is sensitive. (2) the structure is simple. (3) stable enough at high temperature. Most capacitive sensors use air as a dielectric, the problem of self-heating is negligible. Therefore, the stability is guaranteed under the stable-temperature environment. (4) the amount of change is significant. (5) non-contact measurement is feasible. The internal friction exists in resistive and optical fibersensor because of the mechanical parts. This kind of deviation is always difficult to eliminate, so the structure of capacitive displacement measurement has been widely used.

Plate capacitive displacement sensor is the most basic sensor, it measures by converting the value of the capacitance to measure displacement. The framework of unipolar plate capacitive sensor was shown in Figure 1.
The coefficient of capacitive sensors can be adjusted and four basic parameters can be changed. Capacitance between the two plates is \( C \). \( s \) is the plate effective area. \( d \) is the plate spacing. \( k \) is the plate medium between the dielectric constant.

**The hardware circuit design**

Mainly parts of measurement system included: main control chip, capacitance transducer, data storage and communication interface. The main control chip using micro controller STM32F207 based on ARM7, capacitance transducer using the capacitance measurement chip AD7747 produced by AD Company. AD7747 has many advantages such as the height that other chips can not reach. AD7747 can take advantage of the single chip solution and can interface with single sensor, the resolution is relatively high. The system structure was shown in Figure 2.

The minimum resolution of AD7747 can reach 20 aF. The linearity and precision of the AD7747 can reach 0.01% and 10 fF. AD7747 capacitance measurement range is from -8 pF to 8 pF. Its maximum common-mode immutable capacitance can reach 17 pF. AD7747 update rate range is from 5 Hz to 45 Hz. AD7747 is not only a kind of active shielding to protect sensor, or a piece of internal temperature sensor, the piece of temperature sensor in its resolution can reach 0.1 °C, precision can reach 2 °C, AD7747 is roughly divided into three parts, including voltage input channel part,
two-wire serial interface parts, i.e. I2C part and internal clock generator parts. The working voltage of AD7747 is from 2.7 V to 5.25 V.

Data memory has a nonvolatile memory FLASH and high-speed power loss of SDRAM. These components were used to store the STM32 configuration information, long-term preserve information and obtain data from the high-speed data acquisition. Generic 232 interface Uart was used as the communication structure to swap data with the computer.

Herein, STM32F207 was selected as the capacitance displacement digital master control chip of the circuit. STM32 was selected as the main control chip and the I2C signal module, power supply and the clock module, serial communication module, a button control module and PC display module constitute the capacitance displacement measurement circuit of the control module of hardware system. The acquisition and transmission were achieved by the upper machine controller.

**Fixed capacitor test**

The design of acquisition system for fixed capacitor was tested, and obtained the accurate absolute error and the correcting error. The difference variable capacitor test got no results due to the uncertainty of the differential capacitance. Table 1 shown a record of the average values of 20 times measurements for each item. The absolute error is 0.222 pf, and the measurement error is less than 3%. 
Table 1. The average values of 20times measurements

<table>
<thead>
<tr>
<th>Standard capacitance (pf)</th>
<th>Measured value (pf)</th>
<th>error</th>
<th>Standard capacitance (pf)</th>
<th>Measured value (pf)</th>
<th>error</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>3.365</td>
<td>0.06</td>
<td>3.3</td>
<td>3.290</td>
<td>0.01</td>
</tr>
<tr>
<td>3.3</td>
<td>3.129</td>
<td>0.17</td>
<td>4.3</td>
<td>4.323</td>
<td>0.02</td>
</tr>
<tr>
<td>4.3</td>
<td>3.992</td>
<td>0.30</td>
<td>4.3</td>
<td>4.582</td>
<td>0.28</td>
</tr>
<tr>
<td>7.0</td>
<td>7.161</td>
<td>0.16</td>
<td>7.0</td>
<td>6.581</td>
<td>0.41</td>
</tr>
<tr>
<td>7.0</td>
<td>7.285</td>
<td>0.28</td>
<td>8.2</td>
<td>8.148</td>
<td>0.05</td>
</tr>
<tr>
<td>8.2</td>
<td>7.934</td>
<td>0.26</td>
<td>8.2</td>
<td>8.474</td>
<td>0.27</td>
</tr>
<tr>
<td>15.0</td>
<td>15.017</td>
<td>0.01</td>
<td>15.0</td>
<td>15.092</td>
<td>0.09</td>
</tr>
<tr>
<td>15.0</td>
<td>14.801</td>
<td>0.19</td>
<td>5.0</td>
<td>5.220</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Conclusion

ARM7-based micro controller STM32F207 was used as the capacitance displacement digital master control chip. The measurement results were consistent with the standard values after subtracting the absolute error. The AD7747 was used to measure the differential capacitance and the satisfactory results were obtained. The differential capacitance plate of the linear range is too low, since the AD7747 is very easy to enter the saturated zone output, so there is higher demand for the design of differential capacitance..

References