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Method for AC Current Measurement Based on Digital Sampling Technology

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Abstract

According to the problem of high cost of standard apparatuses and complex operating for the traditional AC current measurement, this paper introduces a method to measure the AC current with high performance which is based on using digitizing system and the AC-DC difference calculable resistance. Compared verification tests indicate a maximum deviation of 2.3×10^{-5} between the digital sampling measurement system and the traditional method in the typical frequency range of 40Hz to 10kHz, which achieves the equivalent technical specification. Meanwhile, it can provide a more reliable and simpler way for AC current calibration.

1. Introduction

The traceability of AC current usually employed the method based on AC-DC current converter. In the existing technology, thermoelectric converter is generally used to compare the AC and DC current with the thermocouple [1]. Based on the *Seebeck Effect*, the AC current value can be determined by the DC current value.

Thermoelectric converters are of high accuracy but some problems, such as slow converting response, low input impedance, low output voltage range, easily overload burned. Especially for the low frequency AC signals, the thermo-electric converter will reduce the measurement accuracy by introducing a low frequency error [2]. The solid-state RMS sensor provides the 792A with remarkable temperature stability and fast settling time, but it is more expensive, and the operation is more complex.

Therefore, this paper proposes a method for AC current measurement by using a set of customized shunt and high-precision digital sampling system to replace thermos-electric converter and DC voltmeter in the traditional AC-DC current converter. AC current is transformed into AC voltage output by shunts. AC voltage value can be calculated by the digitized sampling. Then AC current can be measured accurately.

2. The Shunt Traced To AC-DC Difference Calculable Resistor

A set of coaxial structure shunts has been designed by using high-quality thin film resistors in this system. Due to the inside structure and precision of components, the shunts perform a good frequency response, small parasitic inductance and parasitic capacitance. At the same time, the skin effect of high frequency of the resistance can be effectively reduced [3]. Thus, the shunts can achieve stable characteristics in a very wide frequency range, which from DC to 100 kHz, and meet high accuracy. In order to accurately know the resistive characteristics of the shunt, an AC resistance transfer device is employed to calibrate the shunts with AC-DC difference calculable resistor.

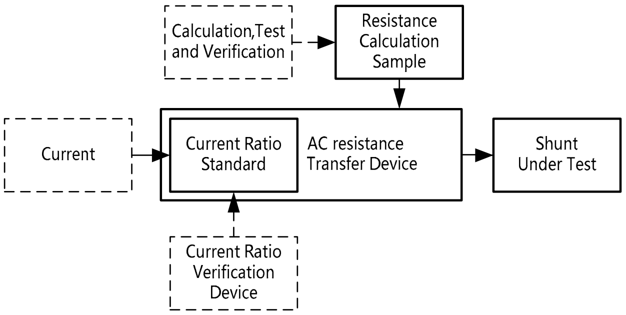

Figure 1. Schematic Diagram for the Tracing Process of Shunt

At the frequency of 1 kHz, the AC-DC difference introduced by the parasitic inductance and parasitic capacitance of the AC-DC difference calculable resistor is in the order of 10^{-10}. The resistance error caused by skin effect is in the order of 10^{-13}. To calibrate by current comparator, the proportion error of AC current ratio standard is in the order of 10^{-6}. It can implement the transfer ratio of 10:1 and 1:1 by providing ratio current using the zero flux current transformer to AC-DC difference calculable resistor and shunt under test. And then, the resistance of the shunt under test can be calculated.

Take 1A shunt for example, the main source of the uncertainty include the standard uncertainty of AC-DC difference calculable resistor in the order to 10^{-6}, the calculate resistance load effect uncertainty of 2×10^{-6}, and the transfer device uncertainty 3×10^{-6}. Therefore, the calibration uncertainty of the shunt is about 6×10^{-6} ($k = 2$) in this method.

Thus, the current in the entire bandwidth range can be measured according to the voltage converted by shunt and the resistance value of the calibrated shunt. In this way, the measurement process of the AC current can be greatly simplified comparing with the traditional AC-DC conversion process.

3. Digital Sampling Measurement System

To achieve accurate measurement of AC current, a high accuracy digital sampling measurement system is built to sample the output AC voltage of shunt. Then algorithm is designed for analyzing and calculating the sampling data. The measurement system composition as is shown in Fig.2.

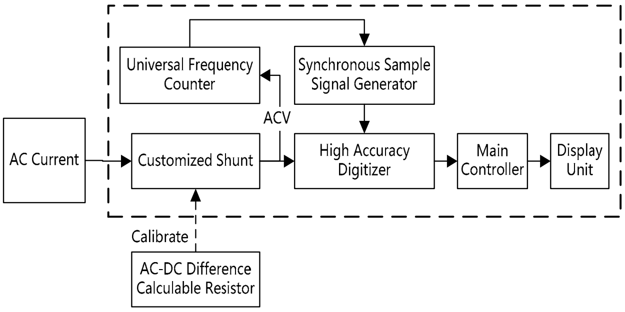

Figure 2. AC Current Digital Measurement System Composition.

Figure 3. AC Current Digital Measurement System

According to the sampling theorem, when digital sampling measurement system achieve integral periodic sampling, the time-domain analysis and frequency-domain analysis can acquire high accuracy. But the frequency of the signal may be volatile or deviates from the set value in fact. If the sampling frequency is fixed, the system will be difficult to achieve strict synchronous sampling. Not only asynchronous error in the time-domain analysis, but also the leak error in traditional DFT spectral analysis will be introduced in and significantly affect the measurement results.

Thus, the frequency counter and the signal generator work as a phase locked loop to achieve synchronization between sampling rate and the measured AC signal, which ensure high accuracy sampling. For data analysis algorithm, data interception strategy is designed to reduce the non-synchronization error based on the method of *the best first point for calculation* [4].

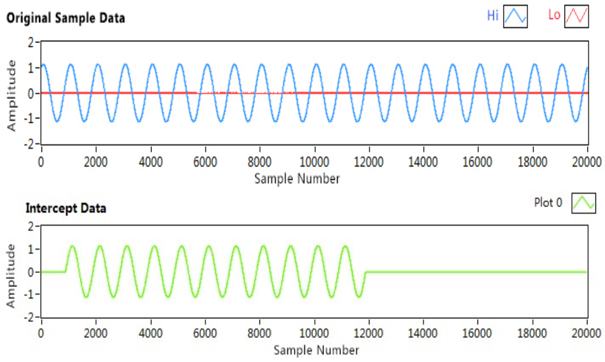

Figure 4. Interception Data for Analysis Algorithm

While the signal period, the number of samples, the relative frequency deviation z and the initial phase $\emptyset_0$ can be obtained by estimating the zero-crossing-time of intercept signal data based on *three-point method* [5]. Then such information can be used to correct the trapezoidal integration method for calculating the RMS of the measured AC voltage. At the same time, the AC voltage signal is sampled by using differential sampling mode which can reduce the influence caused by the low potential floating ground.

4. Verification Tests Result

In order to verify the overall performance of the digital sampling measurement system, two verification tests have been designed as shown in Fig.5 and Fig.6.

4.1 Comparative test of ACV measurement

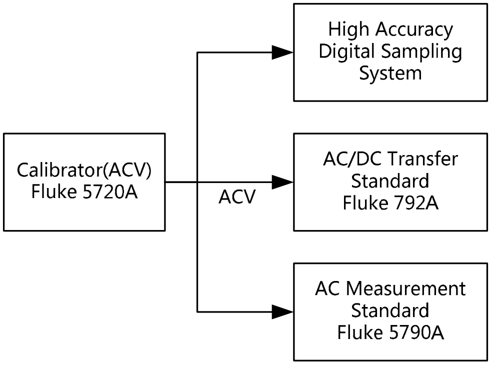

Figure 5. Diagram of the ACV verification test system

By using the digital sampling system, AC-DC transfer standard Fluke 792A and AC voltage measurement standards 5790A to measure the AC voltage output from the same calibrator Fluke 5720A directly, the comparative analysis of the test results show the performance gap among the different schemes. The results are shown in Table.1.

The test results show that the measurement of sampling system has good stability with a standard deviation of 10 measurements below 2ppm. And the maximum relative deviation to 792A is -1.5×10^{-5} for the same AC voltage signal. Under the same conditions, the maximum relative deviation of the measurement of 5790A and 792A is 1.9×10^{-5}.

Table.1. AC Voltage Comparison Test Result

Test Point		**Instrument and Equipment**					
			Digital Sampling System			**5790A**	
Fre.	**Voltage (V)**	**792A (V)**	**Measurement (V)**	**Standard Deviation (ppm)**	**Relative Deviation (ppm)**	**Indication (V)**	**Relative Deviation (ppm)**
40Hz	0.800000	0.800003	0.799994	1.36	-11.2	0.800017	17.5
1kHz	0.800000	0.800002	0.799995	0.55	-8.7	0.800012	12.5
10kHz	0.800000	0.800001	0.799989	1.37	-15.0	0.800016	18.7

Table.2. AC Current Comparison Test Result

Test Point			**Digital Sampling Measurement System**			
Fre.	**Current (A)**	**Standard (A)**	**Voltage (V)**	**Resistance (Ω)**	**Calculated Current (A)**	**Relative Deviation (ppm)**
40Hz	1.00000	1.000005	0.799972	0.7999588	1.000017	11.5
1kHz	1.00000	1.000003	0.799968	0.7999592	1.000011	8.0
10kHz	1.00000	0.999796	0.799861	0.800006	0.999819	22.8

4.2 Comparative test of ACI measurement

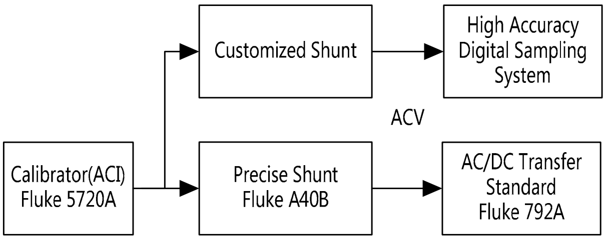

Figure 6. Diagram of the ACI verification test system

The customized shunt and the precision shunts Fluke A40B converted the AC current which output from the same calibrator 5720A into AC voltage, and then the sampling system and 792A are used to measure the AC current respectively. The test results show the performance gap between them.

The frequency range of AC current under test is from 40 Hz to 10 kHz. The experimental data are shown in the Table.2.The results show that, for the same AC current, the maximum relative deviation of the measurement of sampling system and custom shunt combination and the results measured by conventional A40B and 792A AC-DC traditional methods is 2.1×10^{-5}. It achieves a higher specific requirement.

4.3 Estimating Uncertainty of Measurement

Taking 1A, 1 kHz as an example, the main uncertainty of the measurement results including:

1) *The uncertainty introduced by digital sampling system*: According to the experiment, the measurement error for AC voltage of the sampling system is about 2×10^{-5}, according with normal distribution and with coverage factor $k=2$. So the uncertainty introduced by sampling system is 1×10^{-5}.

2) *The uncertainty introduced by superior standard*: The shunt is calculated by AC-DC difference calculable resistor. The uncertainty of the whole calibration device is 8×10^{-6}, with coverage factor $k=2$, so the uncertainty introduced by superior standard of shunt is 4×10^{-6}.

3) *The uncertainty introduced by the frequency error of shunt:* According to the experiment, the frequency error of shunt at 1kHz is about 1.5×10^{-5}, according with normal distribution and with coverage factor $k=2$. So the uncertainty introduced by frequency error of shunt is 7.5×10^{-6}.

4) *The uncertainty introduced by the stability of shunt*: The stability assessment of customized shunt has been taken every 2 months and the standard deviation of 6 groups of stability data is 5×10^{-6}. So the uncertainty introduced by stability of shunts is 5×10^{-6}.

5) *The uncertainty introduced by temperature effect of shunt*: Temperature variation will cause the change of shunt resistance. In the laboratory condition of constant temperature, the effect caused by self-heating power coefficient is more pronounced. The error caused by self-heating power coefficient is about 6×10^{-6}, according with the rectangular distribution and with coverage factor $k=\sqrt{3}$. So the uncertainty introduced by temperature effects is 3.5×10^{-6}.

6) *The uncertainty introduced by load effects of shunt*: According to specification of sampling system, the measuring circuit can be equivalent to the shunt in parallel with a resistor of 1 MΩ and a typical capacitance of 60 pF. And the error caused by the load effect is about 1×10^{-6},

according with normal distribution and with coverage factor $k = 2$. Therefore, the uncertainty introduced by load effects of shunt is 5×10^{-7}.

7) *The uncertainty introduced by measurement repeatability*: The uncertainty introduced by measurement repeatability is type A uncertainty. The standard deviation can be calculated by Bessel formula, and the uncertainty introduced by repeatability is 1.4×10^{-6}.

Table.3. Repeatability Data

1A, 1kHz, 10 Measurements (A)					
No.	1	2	3	4	5
Measurements	1.000011	1.000009	1.000012	1.000009	1.000011
No.	6	7	8	9	10
Measurements	1.000012	1.000010	1.000013	1.000009	1.000010

In summary, the combined standard uncertainty of the measurement is 1.5×10^{-5}, and the expanded uncertainty is 3.0×10^{-5} with coverage factor $k = 2$.

5. Conclusion

The verification tests show that the measurement results of the digital sampling system under different typical frequency points are in good consistency with the traditional AC-DC transfer measurement results. And the performance is better than those mainstream AC current meters. Through further research on the application of AC-DC difference calculable resistor tracing method combining with the precision digital sampling system, it will be applied to daily calibration of AC current that will simplify the existing calibration work, and reduce the measurement uncertainty and the cost of standard apparatuses. It will provide a reliable and simpler way for AC current traceability. Meanwhile, it can be applied in the field of digital measurement of the other AC parameters.

6. Acknowledgements

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7. References

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