Design of 100A High Stability Sampling Resistance

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Abstract. In this paper, multiple manganese-copper resistance wires are connected in parallel as the basic structure of the sampling resistor. The stability of the resistance wire is analysed when the conductor is connected in parallel and twisted, and the resistance wire of the sampling resistor is determined to be connected in a twisted manner to reduce the influence of interference on the measurement. Sampling resistance is annealed in a thermostat to release the internal stress of the stranded wire. Experiments show that the resistance has a stability of 7 ppm for 8 hours. The resistance is connected to a high stability constant current source for testing. The short-term stability of the constant current source is better than 10 ppm, which meets the design requirements.

1. Introduction
With the continuous development of power technology, more and more large ships begin to use integrated power system for power supply[1-2]. The integrated power system adopts DC power system, which has high requirements for monitoring and power quality. In order to better carry out related tests, it is necessary to build a stable DC current source system, and the high stability sampling resistor is the core component of the DC current source, and its stability and accuracy directly affect the quality of the DC power supply[3-6]. When simulating the current of the medium voltage DC power system of the ship, it is necessary to provide a precision DC current of 100A or more. In order to facilitate the sensor calibration, the current source stability is better than 100ppm, and the accuracy is better than 0.1. Sampling resistance should have good expansibility, which is convenient for current source to output different levels of current. At the same time, sampling resistance should have certain anti-interference ability. These restrictions put forward high requirements for resistance design.

The structure of the sampling resistor is varied, and its stability is mainly related to the temperature coefficient of the material. The temperature variation usually comes from the fluctuation of ambient temperature and the heating of current flowing through the resistor[7-8]. In the paper [9], a precise sampling resistor of 1Ω is fabricated with a distributed structure, and its short-term stability reaches 10-10Ω. In the paper [10], a 20Ω resistor is developed by using a chain circuit. The relative variation is only 10-9 orders of magnitude.

Based on the comparison of resistance material and structure, the design scheme of high stability sampling resistance is given, and the experimental platform is built and the stability test is carried out. Finally, the resistance is connected to the current source, and the output result of the current source is analyzed.
2. Material selection
At present, the commonly used resistance wire materials are silver, constantan, manganin, etc. In the case of high stability and low temperature coefficient of standard resistors and measuring precision resistors, according to the resistivity and temperature resistivity of each resistor material, the manganese copper material with the smallest average temperature coefficient of resistance was selected as the designed resistance wire material.

| Material | Resistivity ρ(20℃)Ωm | Temperature coefficient α(0~100℃)1/℃ |
|----------|----------------------|-------------------------------------|
| Silver   | 1.62×10^{-8}         | 3.5×10^{-3}                         |
| Constantan | 4.4×10^{-7}       | 5.0×10^{-6}                         |
| Manganin | 4.2×10^{-7}         | 5.0×10^{-6}                         |
| Ni-cr    | 1.08×10^{-6}        | 1.3×10^{-6}                         |

Manganese-copper wire with a diameter of 0.45mm and a resistivity of 0.42uΩm is selected as the basic material for the fabrication of high-stability resistors. As shown in Figure 1.

3. Structural scheme
The large current shunt is usually composed of network structure or multi-conductor parallel structure. On the one hand, the large current is dispersed through multi-conductor parallel connection. On the other hand, the heat dissipation area can be effectively increased to avoid the increase of heat accumulation temperature, which leads to the excessive change of resistance value. When multiple resistor wires are connected in parallel directly, the induced potential will be generated at both ends of the resistor wires due to space electromagnetic interference. The resistance stability of twisted resistance wire and single resistance wire is compared by experiment.

First, two 1Ω resistors are directly connected in parallel using manganese copper wire, and then a 0.5Ω twisted pair resistor is fabricated. The resistance stability is tested under air condition. The test results are shown in Fig. 2.

The average value of the resistance of the two parallel manganese wire resistance wires was 0.576085Ω, the standard deviation was 9.26×10^{-5}, the average value of the resistance measured by the twisted pair was 0.561125Ω, and the standard deviation was 9.0102×10^{-6}. By comparison, it can be concluded that under the same space electromagnetic conditions, the resistance stability of twisted pair is better than that of two resistance wires connected directly in parallel. Therefore, the sampling resistance should adopt the twisted-wire structure.
4. Resistance fabrication
Since the rated resistance current is 100A, the resistance joint impedance should be minimized. The L-shaped copper plate with length of 10 cm, width of 10 cm and thickness of 1 cm is used to reduce the impedance of the joint and increase the heat dissipation area. Insulated wooden rods are connected between two L-shaped copper plates.

Figure 2. Resistance manganin wire
(a) Parallel resistance
(b) Twisted pair resistance

Figure 3. Schematic diagram of the resistor skeleton structure
On one side of the L-shaped copper plate, 1000 holes were machined by laser drilling technology for welding manganese copper wire. Two round holes are machined on the other side of the L-shaped copper plate as terminals, which can be connected by a four-wire resistor for testing.

Manganese copper wire 0.45mm in diameter, rated current 1A. In order to achieve the design goal of 100A current, 100 resistance wires need to be made for parallel connection. A single 1 Ω resistance wire was intercepted, and each of the two strands was twisted together to form a twisted pair structure. The 50 twisted pairs were soldered to two L-shaped copper plates, and the total resistance was 10 mΩ in parallel.

Since the copper plate dissipates extremely quickly, it is necessary to use an auxiliary heating platform to complete the welding of the resistance wire. The welding of the resistance wire on the copper plate is done on a welding heating platform. The welding platform is shown in Figure 4. The welding platform can preheat the copper plate. The preheating temperature should be lower than the melting temperature of the solder wire. The temperature can be controlled at about 195 °C to prevent the wire from falling off after welding. The resistance wires are welded successively by electric soldering iron, and the resistance wires are connected to L-type copper plate.

After welding, insulating wood bars are used as rotating axes, and copper plates at both ends are rotated to make the resistance wires twisted together so as to minimize the influence of space electromagnetic field on resistance stability. The finished resistor is shown in Figure 5.

5. Resistance annealing
In order to eliminate the stress, the fabricated resistor needs to be annealed to release the stress inside the resistance wire, thereby achieving the effect of resistance stabilization. Annealing is a metal heat treatment process, which means that the metal is slowly heated to a certain temperature, maintained for a sufficient time, and then cooled at an appropriate speed. The aim is to reduce hardness and improve machinability, eliminate residual stress, stabilize size, reduce deformation and crack tendency, refine grain size, adjust structure and eliminate structural defects. Low temperature annealing is usually used to eliminate the change of internal stress. The heating and holding time of the low-temperature annealing need not be too long, and the cooling method may be cooling in the furnace or air cooling.

The finished manganese copper wire resistor is placed in an annealing chamber for intermittent annealing aging. The temperature was raised to 120°C, the temperature was maintained for 8 hours, the annealing chamber was closed, and the natural cooling was carried out for 2 hours, and the annealing
chamber temperature was again raised to 120°C. Repeat the process five times, a total of 50 hours to complete the resistance annealing process.

6. Resistance testing
The stability index was tested using a kethley seven and a half multimeter. The test conditions were humidity 57.1%, temperature 28.3°C, and resistance exposure to air. The resistance test waveform is shown in Figure 6.

![Resistance test waveform](image)

After 8 hours of testing, the average value of the resistance was 0.0100097 Ω, and the standard deviation was 6.83 × 10⁻⁶ Ω. The relative error between the actual resistance of the resistor and the design resistance is less than 1‰, and the stability is less than 7ppm, which meets the design requirements.

7. Conclusion
In this paper, 100 manganese-copper wires are twisted together and welded in parallel to form a high-stability precision sampling resistance. After annealing and aging treatment, the accuracy reaches 0.1 level, and the stability in 8 hours is less than 7 ppm. The structure resistor has strong application capability, and can weld different numbers of manganese copper wires according to different flow requirements, and has low cost and excellent performance index, and is suitable for various types of precision current sources.

References
[1] Li, F.J., Liu, L.F., Wang, G. (2016) The research progress of the medium voltage DC integrated power system in China. Chinese Journal of Ship Research, 11: 72-79.
[2] Xiao, Y.T., Zhao, Y.P., Cao, S. (2010) The integration power system technique actuality at home and broad. Ship Science and Technology, 32: 24-29.
[3] Dunn A F. Increased Accuracy for Resistance Measurements[J]. Instrumentation and Measurement. 1966, 15(4): 220-226.
[4] Jiang Lan, Zhonghua Zhang, Zhengkun Li, Qing He, Yaqiong Fu, Shisong Li, Bing Han, Jianting Zhao, Yunfeng Lu. A Compensation Method With a Standard Square Wave for Precise DC Measurement of Mutual Inductance for Joule Balance[J]. Instrumentation and Measurement. 2012, 61(9): 2524-2532.
[5] Zhonghua Z., Qing H., Zhengkun L., et al. Recent Development on the Joule Balance at NIM[J]. Instrumentation and Measurement, 2011, 60(7): 2533-2538.
[6] Basu S K., Kusters N L. Comparison of Standard Resistors by the DC Current Comparator[J]. Instrumentation and Measurement. 1965, 14(3): 149-156.
[7] Fernqvist, G., Dreesen, P., Hudson, G., et al. (2007) Characteristics of Burden Resistors for High-
Precision DC Current Transducers. In: Proceedings of the Particle Accelerator Conference. pp. 317-319.

[8] Lan, J., Zhang, Z., Li, Z., et al. (2012) High Precision Measurement of the Load Effect of the Resistor. In: Proceedings of the 2012 Conference on Precision Electromagnetic Measurements. pp. 380-381.

[9] Wu, J. (2014) Research of Distributed Low Load Coefficient $1\Omega$ Precision Resistance [D]. China Institute of Metrology.

[10] Zhang, Z.H., Wang W., He Q. A Distributed Low Load Coefficient Precision Resistance and Its Implementation: CN103149410[P]. 2013.