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The Key Technology Research on Standard Current Transformer of Rogowski Coil

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Abstract. Based on Rogowski coil current transformer temperature characteristic, there are problems that conductor in the course of the development of key technologies such as eccentric and multiple range test .this article through to Rogowski coil temperature characteristic optimization, coil processing technology upgrade, the external magnetic field interference shielding, a conductor eccentric accuracy control and the design of the multiscale system key technology research, complete standard 0.05 Rogowski coil current transformer development, implement standard digital signal output and multiple range test switch gear. Rogowski standard current transformer has the coreless coil, light quality, small volume, wide measuring range and open protocols, can meet the development of digital signal electronic transformer calibration accuracy requirements.

Keywords: Rogowski coil; Standard current transformer; Digital signal.

1. Introduction

Rogowski coil is special structure of air-core coil, using even thickness uniform wires tightly wound on the ferromagnetic skeleton, and realize the current signal change [1]. In 1980s, as an sensor component [1], Rogowski coil successful develop the electronic transformer and gradually get the engineering application. Due to frame processing technology and the winding level limit, coil basic variable precision is 0.5%.2010 years later, driven by the smart substation construction, the Rogowski coil transformer has been developed vigorously, prompting Rogowski coil developed rapidly and processing technology level. At present, used in power system, the variable precision of measuring electronic transformer is better than 0.2%.

Compared with the shunt and iron core coil, Rogowski coil current transformer has good isolation, wide bandwidth, wide measuring range, small volume, light weight and other advantages [2-5]. At present, Rogowski coil has been widely applied in the field of intelligent power transmission and transformation.

Through the study on characteristics of Rogowski coil temperature, skeleton and winding technology promotion, shielding bandaging treatment and control of a conductor eccentric Rogowski coil realize high accuracy of output, meanwhile for the measurement of high precision in the field of alternating current flow measurement applications create conditions; By high precision digital signal processing and multiscale control system technology, achieve 0.05 standard current transformer, and expand the application areas of Rogowski coil current transformer, and the accuracy of the calibration for electronic transformer to provide new type of high precision, wide range of test system.

2. High precision Rogowski coil

Used in standard current transformer, the accuracy of Rogowski coil can be 0.05 class. The main technical problems are the following: (1) the outside temperature change will affect the coil skeleton section and winding resistance, causing measurement precision change;(2) in the actual calibration environment, the eccentricity of the conductor will make Rogowski coil transmission signal occurs deviation in each test process;(3) the Rogowski coil is made by fine wire tightly wrapped in a row, which can change by tapping electrodes winding of meet multiple range test;(4) Rogowski coil and small signal, enlarge the relative interference signal, the disturbance effect on calibration accuracy standard transformer.

According to the above problem, through study on characteristics of Rogowski coil structure, process research, shielding technology study and multiscale control system, etc., realize Rogowski coil current transformer in the standard in the field of application.

To solve these problems, this paper have studyded on characteristics of Rogowski coil structure, transferring research, shielding technology and multiscale control system, etc., and realized standard current transformer of Rogowski coil, and introduced the engineering application.

2.1 Precise Rogowski coil transferring control

2.1.1 The influence of external environment temperature change

The change of external environment temperature will lead to Rogowski coil skeleton and copper winding heat bilges cold shrink, and make Rogowski framework and cross-sectional area changing, and sensing winding length changes, affect resistance winding itself at the same time,.The above factors will lead to Rogowski coil variable precision occurs deviation. The mutual inductance of Rogowski coil is M, by theoretical derivation ,we can get that :

$$M = \mu_0 N \frac{\mathrm{h}}{2\pi} \ln \frac{r_2}{r_1} \tag{1}$$

In the type:$\mu0$—Vacuum magnetic permeability, $4\pi\times10^{-7}$; N—The number of turns; r1—Skeleton diameter; r2—Skeleton inside diameter; h—Height of the coil。

Assume that the skeleton material expansion coefficient is x, and the rate is same in all respects, when the temperature change Δ t, mutual inductance coefficient of variation is:

$$\begin{aligned}\Delta M &= \mu_0 N \frac{\mathrm{h} \bullet x \bullet \Delta t}{2\pi} \ln \frac{r_2 \bullet x \bullet \Delta t}{r_1 \bullet x \bullet \Delta t} \\ &= \mu_0 N \frac{\mathrm{h} \bullet x \bullet \Delta t}{2\pi} \ln \frac{r_2}{r_1}\end{aligned} \tag{2}$$

The relative change rate of mutual inductance is:

$$\frac{\Delta M}{M} = \frac{\mu_0 N \frac{\mathrm{h} \bullet x \bullet \Delta t}{2\pi} \ln \frac{r_2}{r_1}}{\mu_0 N \frac{\mathrm{h}}{2\pi} \ln \frac{r_2}{r_1}} = x \bullet \Delta t \tag{3}$$

Base on the formula (3), the relative change rate of mutual inductance coefficient has a linear relation with temperature change, namely the temperature change of Rogowski coil linear influence the output signal.

According to the theory of Rogowski coil mass change, mainly considering the circuit temperature characteristic, and simplify circuit model of Rogowski coil temperature characteristic, which is shown in figure 1:

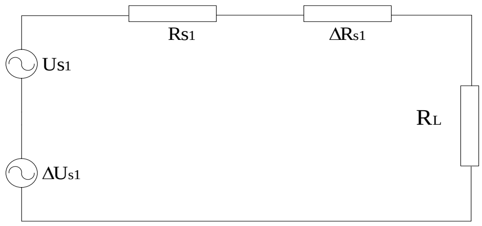

Fig. 1 Rogowski coil temperature characteristic simplified model

As shown in figure 1, which is including: Us1 is Rogowski coil electromotive force in the rated primary electricity flow induced;Δ Us1 is temperature change under the induced electromotive force increment;Rs1 is Rogowski coil resistance;Δ Rs1 is the change of internal resistance increment under temperature; RL is Rogowski coil load resistance. According to the theory of circuit ,the Rogowski coil output electromotive force is shown as follow:

$$U_L = \frac{R_L}{R_{S1} + \Delta R_{S1} + R_L} (U_{S1} + \Delta U_{S1}) \tag{4}$$

By the formula (4), in the temperature change of external environment, induction electromotive force $\Delta Us1$ and Rogowski coil impedance increment $\Delta Rs1$ should be as small as possible to zero, so Rogowski coil will keep variable voltage signal into the optimal.

Based on the analysis of Rogowski coil variable temperature characteristic, in order to ensure the precise of Rogowski coil under the condition of temperature change and stability, this paper study on Rogowski coil skeleton characteristics, winding turns and the error matching, etc. respectively, in order to improve the variable precision and temperature characteristic.

2.1.2 The optimum selection of Rogowski coil skeleton material

Based on analysis of Rogowski coil temperature characteristic ,while the changes in -40 ℃ ~ + 70 ℃ temperature range meet the Rogowski Us1 coil induction electromotive force output rate is 0.1%, the relative rate of mutual inductance change is 0.1%, and we can get :

$$\frac{\Delta M}{M} = x \bullet \Delta t = (70+40)x \le 0.1\% \tag{5}$$

Base on formula (5) , it can be computed that the Rogowski coil expansion coefficient x should be less than 9.09 PPM /℃.

In the process of machining Rogowski coil, in order to reduce the skeleton material expansion coefficient, this paper study respectively on characteristic of GF1004 polysulfone material, F881 epoxy glass cloth laminated board and epoxy resin material. By choosing different material skeleton, and in the same size, analyze the high and low temperature test coil skeleton features available skeleton section with the temperature change. we can get that:

1) GF1004 polysulfone material expansion coefficient is about 8.2 PPM / ℃;

2) F881 epoxy glass cloth plate expansion coefficient is about 13.4 PPM / ℃;

3) Epoxy resin casting is about 19.4 PPM / ℃.

Based on the research of skeleton material temperature characteristic. This paper choose GF1004 as the as coil skeleton, which can satisfy to 40 ℃ ~ + 70 ℃ temperature range. The skeleton material has low temperature coefficient, can satisfy Rogowski coil variation signal and high precision, high stability requirements.

2.1.3 Influence of skeleton processing error and variation signal precision

Due to the Rogowski coil does not contain iron core, the winding circle number can reach tens of thousands of turns. skeleton cross-sectional area resulting from machining error of winding circle number amplification process will affect Rogowski coil mass variable precision.

Assuming frame processing error is a, according to the maximum error to consider, generate into the formula (1) , the mutual inductance of Rogowski coil can be obtained:

$$M_1 = \mu_0 N \frac{\mathrm{h+a}}{2\pi} \ln \frac{r_2 + a}{r_1 - a} \tag{6}$$

Select high precision Rogowski coil skeleton size as: h=50 mm;R1=210 mm;R2 = 250 mm; The error of high precision 3d Skeletons machining is ±0.02 mm, so we can get:

$$\frac{M_1 - M}{M} \times 100\% = 0.14\% \tag{7}$$

Considering the maximum error conditions , by the formula (7) available to Rogowski coil skeleton processing error maximum error of 0.14%.Under the condition of the skeleton of the actual machining error is inevitable, can be combined with high precision digital setting winding circle number N to compensate for the effect of the error precision of Rogowski coil skeleton.

2.1.4 Winding circle number for the effect on accuracy variation signal and error optimization

Based on the theory of Rogowski coil , the induction electromotive force satisfy the following equation:

$$e(t) = -\frac{\mu_0 N h}{2\pi} \ln \frac{r2}{r1} \bullet \omega I \cos(\omega t + \theta) \tag{8}$$

Rogowski coil winding circle number N is:

$$N = \frac{e(t)}{\frac{\mu_0 h}{2\pi} \cdot \ln\frac{r2}{r1} \cdot \omega I \cos(\omega t + \theta)} \tag{9}$$

In the type: ω=2πf; f=50Hz; I= 1200A; e(t)=2V; Ө is initial angle of primary current.

Considering the error frame processing account, when the change of Rogowski coil produces 0.14% error, the actual output electromotive force as:

$$e_1(t) = 2\times(1\text{-}0.14\%)=1.9972\text{V} \tag{10}$$

Assuming that the theoretical output value is 2V, the calculation can be coil number of turns for N1 ideal; The skeleton error based on the actual 1.9972 V induction electromotive force, the calculation can be real effective number of turns for N2;Therefore, we need to by changing the number of winding ΔN=N-N1 to offset the processing error of the effect on accuracy Rogowski coil output electromotive force.

Based on skeleton error and number of Rogowski coil winding and performance analysis, under the condition of the skeleton of processing error by changing the winding of matching error, namely under the condition of machining error frame ±0.02 mm, by adjusting the setting winding circle number ΔN to match the skeleton leads to the change of variable precision machining error, meet the Rogowski coil high precision characteristics.

2.1.5 Integral circuit temperature characteristic optimization

The analog signal changed by Rogowski coil is the differential signal, which phase transformation should be carried out by the integrator. The temperature change will affect operational amplifier of integrator, temperature drift characteristics of impact resistance and capacitance at the same time, the output voltage deviation and the precision of the output signal error and so on, which may affect the precision of converted signal[6].

By choosing inertial link instead of the integrator to realize signal integral transform, namely in the integral capacitance and resistance of the UN general assembly on both ends feedback resistance, good inhibition of integral drift, so as to reduce the influence of input offset voltage[6]. Among them, the operational amplifier using small high-performance op-amp input offset voltage, the integral circuit is shown in figure 2.

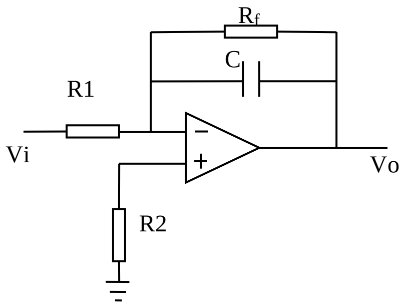

Fig. 2 Integrating circuit

Based on the above integral circuit, transfer function can be obtained:

$$H(S) = -\frac{1}{R1} \bullet \frac{R_f}{jwCR_f + 1} \tag{11}$$

Amplitude ratio is:

$$A = |H(S)| = \frac{R_f}{R1} \bullet \frac{1}{\sqrt{(wCR_f)^2 + 1}} \tag{12}$$

In the type: R1=300K; R2=300K; Rf=4.4M; C=0.01uf.The data in formula (12) available:

$$A=1.059 \tag{13}$$

In -40 ℃~ + 70 ℃ temperature range, in order to ensure the integrator and variable precision is less than 0.1%, the relative change rate of the integral gain to meet:

$$\frac{\Delta A}{A} \leq 0.1\% \tag{14}$$

When the temperature changes from - 40 ℃ ~ + 70 ℃, then Δ T = 110 ℃, the maximum temperature limit range.

Temperature coefficient of capacitance C is $+30\times10^{-6}$, R1 temperature coefficient is $-30\times10^{-6,}$ Rf temperature coefficient is -10×10^{-6}.Put in formula (13) and formula (14), and we can get this:

$$\frac{\Delta A}{A}=0.09\% \tag{15}$$

Through temperature matching, optimal selection resistance, temperature coefficient of capacitance signal integrator and variable precision can reach 0.1% requirement, and realize its own temperature compensation.

2.2 Anti-interference upgrade of Rogowski coil

As the accuracy of calibration equipment, the standard current transformer required relatively high electromagnetic interference performance, and ensure the accuracy of calibration when in a single turn or more turns winding of electric conductor. Through the study on conductor eccentric condition and the external magnetic field interference, this paper improve the reliability of Rogowski coil.

2.2.1 The effect of conductor eccentricity

Under the eccentrically condition of conductor and Rogowski coil, the theoretical calculation model is shown in figure 3[7] :

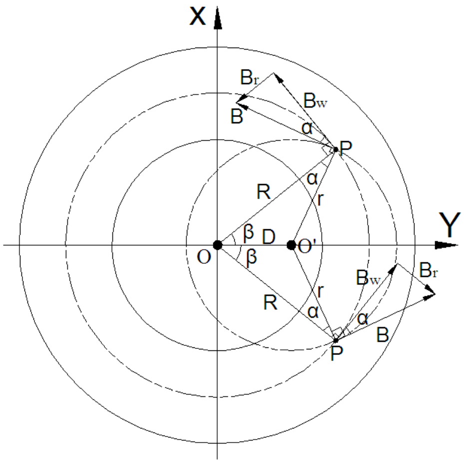

Fig.3 The average magnetic field vector diagram of the conductor which is uncoaxial with the Rogowski coil

Based on the vector analysis, the total magnetic flux chain can be get under the condition of eccentric Rogowski coil [7]:

$$\psi=\frac{\mu_0 ISn}{R} \tag{16}$$

The inductive electromotive force produced by Rogowski coil is[7] :

$$e(t)=\frac{d\psi}{dt}=\frac{\mu_0 \mathrm{n}S}{R}\cdot\frac{dI}{dt} \tag{17}$$

Such as formula (17), the number of coil turns density, the equivalent sectional area and the equivalent radius are not affected by an eccentric conductor, so the output of Rogowski coil induction electromotive force is only related to a current time rate of change when under the condition of eccentric conductor.

Through a conductor eccentric theory research, when Rogowski coil winding circle number density, coil skeleton under the condition of uniform cross-sectional area, conductor eccentricity will not affect Rogowski precision coil [7].

2.2.2 The external magnetic field and change influence of roche coil

The standard current transformer of Rogowski coil, which using in engineering application are inhomogeneous magnetic field. Non-uniform external magnetic field in Rogowski coil near side reference point A and distal reference point B induced electromotive force respectively $e_1(t)$and $e_2(t)$, density of Rogowski coil number of turns n, coil area s is not affected by non-uniform magnetic field.

According to theoretical derivation , the inductive electromotive force of Rogowski coil making by non-uniform magnetic field is [8] :

$$e_1(t) = ns \cdot \left[\frac{u_0}{\pi r} \cdot \arctan(\frac{D+r}{D-r}) - \frac{u_0}{4r} \right] \frac{dI}{dt} \tag{18}$$

$$e_2(t) = -ns \cdot \left[\frac{u_0}{\pi r} \cdot \arctan(\frac{D+r}{D-r}) - \frac{u_0}{4r} \right] \frac{dI}{dt} \tag{19}$$

The non-uniform magnetic field in the coil the general induction electric potential is:

$$e(t) = e_1(t) + e_2(t) = 0 \tag{20}$$

By the formula (20) available in coil circle number density, cross-sectional area under the condition of uniform and non-uniform magnetic field wrong Rogowski coil influence variable electromotive force[8].

2.2.3 Shielding technology for Rogowski coil

To improve the resistance to electromagnetic interference characteristics of standard current transformer, this paper study on the shielding technology research to increase Rogowski coil anti-interference characteristics of high and low frequency electromagnetic field. Based on the principle of shielding, Rogowski coil shield structure schematic are designed as follows.

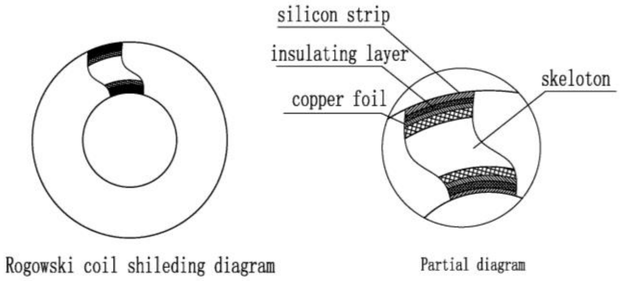

Fig. 4 Rogowski coil shielding structure diagram

As shown in figure 4, put Rogowski coil into shielding enclosure, taking external package good conductor copper foil as shielding material, effective high frequency electromagnetic interference shielding, insulation medium filled with middle as electrical insulation, and the outer package is high permeability shielding materials, in addition, it need to reserve air gap, and avoid affect transformer characteristics.

(1)High frequency magnetic field shield

Based on Faraday's law of electromagnetic induction, the copper foil in the induction electromotive force will produce eddy current IW in impedance copper foil. As H1 effect of high frequency magnetic field generates ,the magnetic field eddy current induction H2 will offset the original magnetic field, as shown in figure 5:

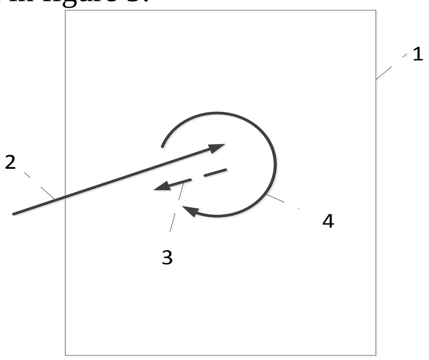

Figure .5 High frequency magnetic field shield

As shown in figure 5:1 is the copper foil, 2 is the high frequency magnetic field H1, 3 is the magnetic field H2, 4 is eddy current IW. Then:

H2= -H1 (21)

Based on the theory of formula (21), this paper choosese low resistivity conductor copper foil as for wound coils. According to the copper foil generates the magnetic field eddy current IW induction in H2, to offset the high frequency interference magnetic field interference of H1, and shielding high frequency magnetic field effect.

(2)Low frequency magnetic field shield

Selects high permeability silicon steel sheet material for dc or low frequency magnetic field shielding. Silicon steel sheet reluctance to R_{m1}, coil and the equivalent air-gap magnetic resistance for R_{m2}, flux for Φ. Due to the magnetic resistance is:

$$R_{m}=\frac{l}{uA} \tag{22}$$

In the type: A is the cross-sectional area ; *l* is the length of the magnetic circuit; *u* is magnetic permeability of materials. Relative permeability of high permeability material for u1=7000 ~ 10000;Coil relative permeability u0 = 1, then:

$$R_{m1} \ll R_{m2} \tag{23}$$

By type (23) can get high permeability material magnetic resistance is far less than the coil magnetic resistance, the magnetic flux has a good shunt effect, reach the role of blocking interference magnetic field.

Above all, to enhance the anti-interference characteristics of Rogowski coil, this paper use bandaging with multi-layer shielding material to realize the high frequency magnetic field and low frequency magnetic field shield.

2.3 The variable multiscale signal control design

Rogowski coil is composed from continuous, uniform closely on skeleton by enameled wire winding and become, not tapped lead way, interrupt lead change winding turns and variable range more than meet the standard current transformer measurement requirements. Based on Rogowski coil multi-range switch control technology research, through the development of software for digital signal storage coefficient of configuration and the curing, realize a multi-range measuring current and switch gear.

2.3.1 Multiscale control system scheme

The rated current of high precision Rogowski coil is 1200A, through the multiscale system design realize the different range of primary current signal processing. Assume different rated primary current corresponding signal as F(I), changed into constant digital signal by A/D convertor. Assuming output of Rogowski coil is 2V in the rated power flow.

$$F(1200)=2 \tag{24}$$

Under different conditions of rated current signal I preach change, output analog signals of Rogowski coil is:

$$F(\mathrm{I})=2\cdot\frac{\mathrm{I}}{1200} \tag{25}$$

According to different rated primary electrical current analog signal F (I), changed by A/D convertor, and set matching parameters based on the digital signal, and through the modification of Kn debugging coefficient, meet the output digital signals to 2D41H (hexadecimal number) constant value.

$$F(\mathrm{I})\bullet \mathrm{Kn}=\mathrm{2D41H} \tag{26}$$

After digital signal parameter configuration, Rogowski standards of the coil current transformer output digital signal, and in accordance with GB/T 20840.8 2008 specifications[9], for transformer accuracy calibration standard variable digital signal.

Based on the principle of signal modulation, standard current transformer of Rogowski coil multiscale digital signal control plan is shown in figure 6.

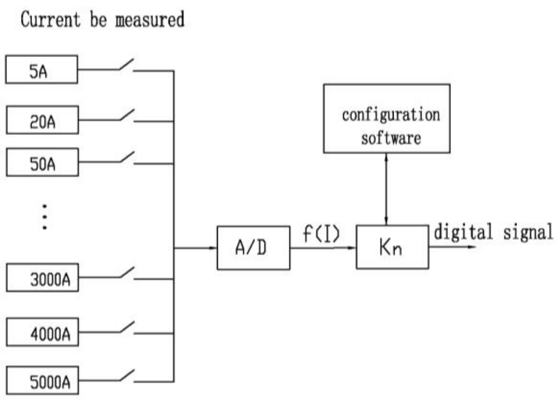

Fig. 6 Multiscale control system scheme

As shown in figure 6 , different rated primary electrical current analog sign is changed into digital signal by A/D convertor, and modulating the digital F(I),and the meeting the calibration standard output signal digitization and standardization requirements.

2.3.2 Application process and software development

Based on multiscale plan research of standard current transformer of Rogowski coil, the program control flow chart of control software is shown as follow:

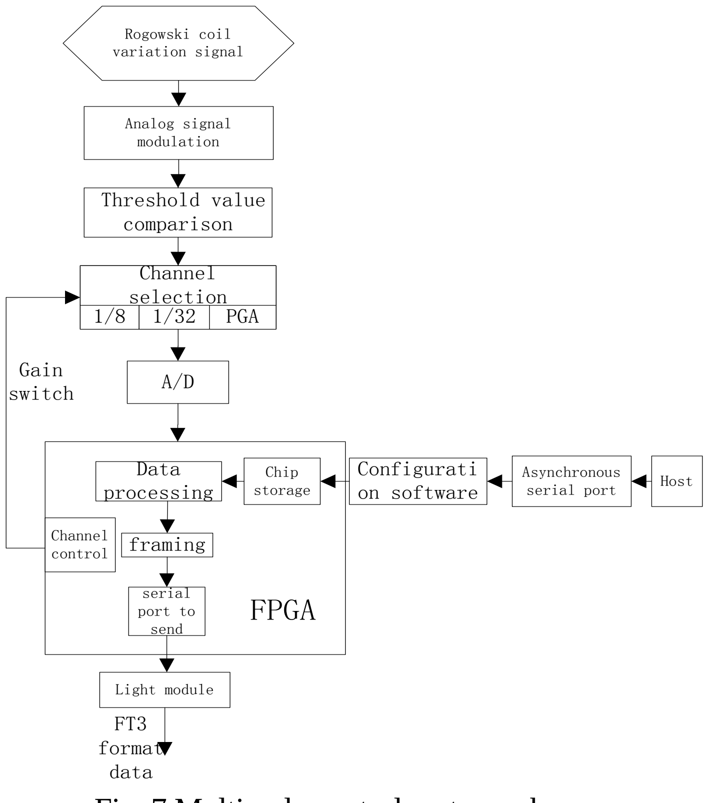

Fig. 7 Multiscale control system scheme

As shown in the above , the host will download configuration parameters into FPGA by multiscale switch range program, and finish switch range and signal processing. The calibration of standard current transformer of Rogowski coil can meet 5A ~ 5000A measuring range, and accuracy can achieve 0.05.Multiscale parameters configuration and test plan is shown in figure 8:

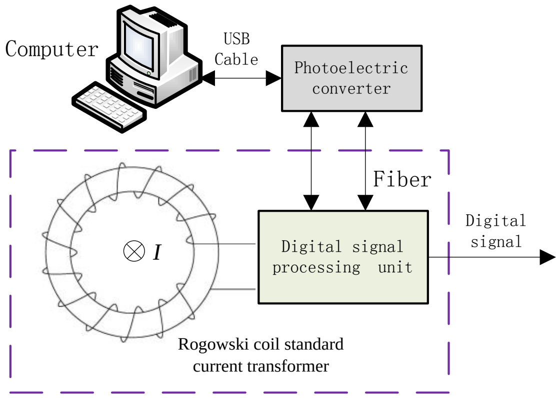

Fig. 8 Multiscale flow chart of control signals

As shown in figure 11, based on the software platform, we can realize computer mainframe gear switch function by a key.

Through calibration of different rated primary current amplitude, zero drift and phase parameters configuration, it can achieved that the switch gear can debugged by a key , and meet the standard current transformer calibration accuracy.

2.4 Large current measurement accuracy control by Rogowski coil

2.4.1 The magnetic saturation analysis of core type current transformer

Based on the principle of electromagnetic induction, core type current transformer achieve an electrical current by iron core flux. Assume primary side current is i1;core excitation current is im ; Secondary side load resistance and inductance is L_2 and R_2,respectively;the secondary side current is i_2.iron core excitation magnetic chain satisfies the following equation[10]:

$$\frac{d\psi}{dt} = L_2 \frac{di_2}{dt} + R_2 i_2 \tag{27}$$

To integral the formula ,and we can get :

$$\psi(t) = \psi(t_0) + L_2 i_2 + \int_0^t R_2 i_2(t) dt \tag{28}$$

The secondary side current satisfy:

$$i_2 = i_1 - i_m \tag{29}$$

Put into type (28) ,and we can get :

$$\psi(t) = \psi(t_0) + L_2(i_1 - i_m) + R_2 \int_0^t (i_1 - i_m) dt \tag{30}$$

Based on the core excitation theory analysis, in the steady state and transient current conditions, the core type current transformer excitation flux bits will increase, appear even magnetic saturation, transformer secondary side preach variable current i_2 will not be able to get a current signal, the signal waveform and its accuracy will be affected.

1) when in the steady state large current test conditions, the steady-state ac component due to a high peak, excitation current increase, leading to secondary current signal waveform can't become a current, a waveform distortion, the phenomenon such as distortion.

2) when in transient current testing conditions, due to the measured current mutation, mainly in the decaying aperiodic component under the action of iron core flux will continue to increase, when the time constant is bigger, will rise along excitation curve until saturated, measuring signal distortion phenomenon [10].

2.4.2 The Rogowski coil analysis of current measurement

Rogowski coil skeleton is non magnetic material, there is no problem of magnetic saturation. The measuring range can be from several amperes to tens of thousands of amp, at the same time it can also be used to measure the transient and large current pulse and industry, etc. Rogowski coil measuring principle is shown in figure 9:

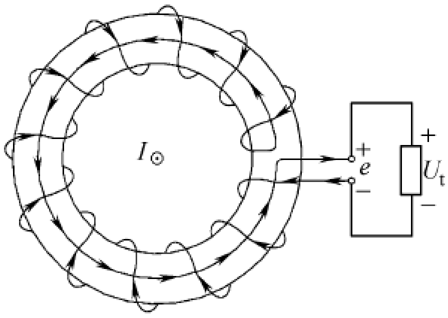

Fig. 9 Rogowski coil principle diagram

Assumed that the wire flowing current is I, the induction electromotive force of Rogowski coilε is:

$$\varepsilon = -\frac{\mu_0 NA}{l}\frac{dI}{dt} = -M\frac{dI}{dt} \tag{31}$$

In the Type: u0 is Rogowski coil magnetic permeability;N is Rogowski coil number of turns;A is the cross-sectional area for coil; M is Rogowski mutual inductance coil; L is Rogowski coil skeleton equivalent circumference.

According to formula (31), Rogowski induction coil is proportional to the voltage across the rate of change of current, is associated with a current rate of change, only could theoretically infinite current measurement, the measurement range is restricted by an electrical current flow.

2.4.3 The precision control of electrical current variable for Rogowski coil

Based on the high precision technology of Rogowski coil, and standard current transformer measuring range can be achieved 5A - 5000A, changing analog signal transferred by A/D to realize digital signal conversion. This paper choose AD chip is 16 bit, and it has low power consumption, successive approximation ADC converter. The working voltage is 4.5 V ~ 5.5 V. The voltage reference Vref for internal reference is 2.5 V, analog signal sampling range is 2Vref = +5 V; the sampling precision is 10/216 = 0.152 mV.

When measuring large current such as 5000 A, the changed analog voltage signal F(I) by Rogowski coil is shown as follows:

$$F(\mathrm{I}) = 2\cdot\frac{\mathrm{I}}{1200} = 2\cdot\frac{5000}{1200} = 8.333\mathrm{V} \tag{32}$$

When measuring low current such as 5 A, the changed analog voltage signal F(I) by Rogowski coil is shown as follows:

$$F(\mathrm{I}) = 2\cdot\frac{\mathrm{I}}{1200} = 2\cdot\frac{5}{1200} = 0.00833\mathrm{V} \tag{33}$$

By formula (32) and (33), when measuring large current the analog voltage signals will be beyond the biggest AD + 5V analog signal sampling range; when measuring low current ,because the signal is weak, and impacted by outside noise, with the help of the quantization error of the AD itself, will induce a larger influence on measurement accuracy.

Based on the different range analysis of characteristics, to satisfy the Rogowski standard transformer coil signal measurement and high accuracy requirements, through the analog signal PGA gain amplification technology, this paper achieve current multiscale signal processing, and the solution diagram is shown as below[11].

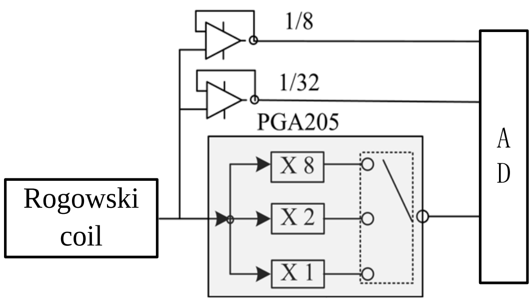

Fig. 10 PGA optimization design schematic diagram

As shown in figure 10, Rogowski coil produces analog signal F (I), after signal conditioning is divided into three channels, respectively is 1/8 channel, 1/32 channel and channel the PGA, then three channels respectively from the AD sampling channel, sequence generated by the FPGA, control AD to complete data collection, to control the switch of PGA gain[11].

1) when measuring a large current rating, select 1/8 channel data through program control as the effective value; When the signal to 1/8 channel saturation increased, the jump to 1/32 of a channel.

2) when measuring a small current rating, in order to improve the processing accuracy for the small signal simulation, control the selection PGA channel data as valid data, by controlling the gain amplification was carried out on the small signal gain amplifier, improve small signal processing precision.

Through the 1/8 channel, 1/32 channel and PGA channel switch control, realize Rogowski coil changing analog signal conditioning, guarantee the precision of digital signal processing, satisfy the standard of Rogowski coil type current transformer wide range, high precision, high reliability validation requirements.

3. Application of standard current transformer by Rogowski coil

3.1 The develop of standard coil current transformer

Based on the key technology research of standard current transformer of Rogowski coil, this paper has completed the standard current transformer prototype development, and it can meet the demand of electronic current transformer calibration accuracy. Physical prototype as shown in figure 11.

Fig. 11 Rogowski type standard current transformer coil physical figure

As shown in figure 14, the machine is trolley type structure, and the external panel adopts using high performance magnetic materials, at the same time it also has the configuration of 220 AC power interface and fiber output interface. The quality of the machine has the advantage of lightweight, compact structure, easy to carry and digital output characteristics, which can meet the demand of digital electronic transformer calibration.

3.2 The accuracy of calibration

According to 0.05 magnitude measurement using standard current transformer error limit requirements[12], under the rated primary current range, the standard current transformer of Rogowski coil applied respectively 5%, 20%, 100% and 120% of the rated primary current accuracy test, the test environment is shown in figure 12.

Fig. 12 Accuracy field figure

As shown in figure 12, the output of standard current transformer is digital signal, after merging unit resampling an input checking instrument, by using electronic transformer with a magnitude of

0.01 core type current transformer and become standard analog signal to carry on the contrast and difference computing accuracy test, and it can be get that in the following table from 5 A~ 5000A range:

Table 1 The accuracy of test data

Primary current(A)	Ratio error(±%)	Phase error (′)
5	+0.01	+0.77
20	+0.01	+0.57
50	+0.01	+0.70
100	+0.01	+0.88
200	+0.01	+0.88
300	+0.01	+0.45
400	+0.01	-0.92
500	+0.01	+0.14
600	+0.01	+0.24
800	-0.01	+0.08
1000	-0.01	+0.33
1200	-0.01	+0.61
1500	+0.01	-0.52
2000	+0.01	+0.01
2500	+0.01	+0.17
3000	+0.01	-0.27
4000	+0.01	-0.09
5000	-0.01	-0.01

Through the test data, standard current transformer of Rogowski coil satisfies the requirement of 0.05 magnitude measurement with current transformer error limits.

3.3 The calibration and application by standard current transformer of Rogowski coil

Through the key technology research on 0.05 class standard current transformer of Rogowski coil and cooperating with measurement merging unit ,electronic transformer can realize accuracy calibration of the electronic transformer. Standard current transformer of Rogowski coil can be used for calibration of test accuracy scheme as shown in figure 13.

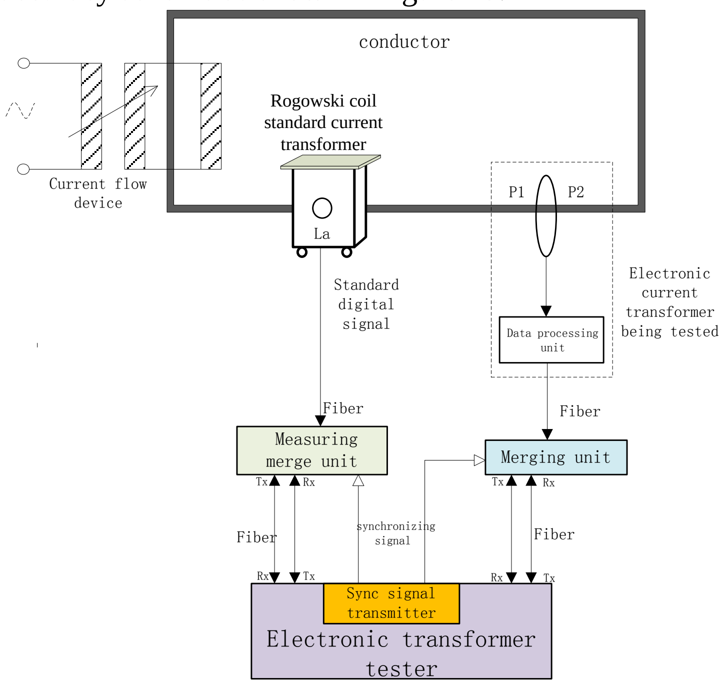

Fig. 13 Rogowski coil type standard current transformer calibration scheme

As shown in figure 13, the output of standard current transformer is a standard digital signal, by measuring with merge unit and input electronic transformer verification as standard signal source; With electronic transformer output variable signal transfer were asked to contrast and difference computing in electronic transformer verification shows that waveform and test data, and complete accuracy check.

4. Conclusion

It has the problems such as the signals of change such as affected by temperature, a conductor eccentric interference and not easy to realize tap fuses when using standard current transformer of Rogowski coil, through the studying on Rogowski coil skeleton material and winding process, the external magnetic field interference and multiscale control research, this paper complete 0.05 class standard current transformer of Rogowski coil, and performance through experiment verify its accuracy. Combining with the characteristics of Rogowski coil standard transformer digital signal output, this paper expounds the Rogowski coil standard current transformer engineering application, and provide a new calibration equipment for electronic transformer calibration accuracy. The output of Rogowski coil standard transformer is digital signal, and has a wide current measuring range, wide range of frequency response characteristics and transient change master, at the same time, it also has the digital signal output and open protocols, which is meaningful for the development of digital electronic transformer calibration.

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