The Linearized Design Of Thermocouple Sensor

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***Abstract*—There are large errors of linear measurement when the thermocouple measure temperature as temperature sensor. In order to improve the measurement precision, the sensor cold junction compensation and nonlinear compensation are usually needed. For the circumstances that the cold junction's temperature is determinate, there is biggish nonlinear between thermoelectric power and temperature signals of the thermocouple sensor's output. In order to solve the problem, this paper proposed a practical method of linear compensation, introduced the principle of linear compensation and gave the corresponding compensation circuit and circuit analysis. This circuit has the characteristic of simpleness, high reliability, small linear error and so on.**

Keywords*—nonlinear; thermocouple; compensation

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1 Background

Temperature is physical quantity to express the substance's degree of cold and hot, it is one of the very common and important thermal parameters for all kinds of production and scientific experiments. Many products' quality, production and process control are directly related with temperature. Therefore, it has the extremely vital significance to realize accurate temperature measurement. Thermocouple has advantage such as stable performance, simple structure, convenience, economies, durable and easy to maintain. We convert temperature signal to electrical signals through the thermocouple, to realize the signal's remote transmission and multi-point measurement. Therefore, thermocouple are widely used for measuring temperature in industrial production and scientific research fields.

2 Linear temperature measurement principles

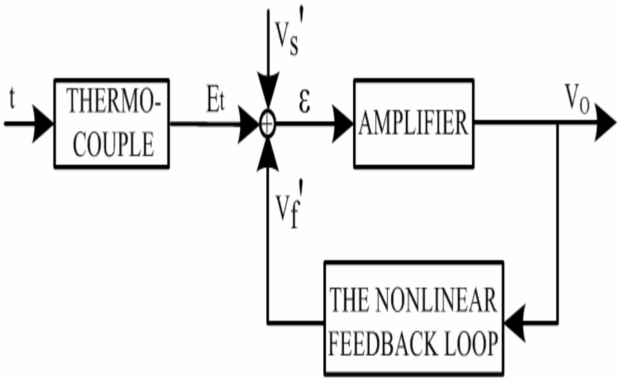

Fig. 1 The block diagram of thermocouple temperature sensor linearization principle

It is nonlinear between thermoelectric potential E_t outputted by thermocouple and the represented temperature t, And as the measurement range different for different types of thermocouples or the same kinds of thermocouples, its characteristic curve is different. In order to guarantee the linear relationship between measured temperature and output signal of the thermocouple sensor, we must take linear compensation.

The block diagram of thermocouple temperature sensor is shown in Fig. 1.From Fig. 1 we know that the input amplifier signal$\varepsilon= E_t+V_s'-V_f'$, Among them, V_s' is constant for that the thermocouple cold junction temperature doesn't chang, and the relationship between E_t and t is nonlinear. If the relationship between V_f' and t is also nonlinear. And correspond with the non-linear relationship of thermocouples (E_t-t),so the relationship between D-value of E_t and V_f' equal ε and t is linear relationship, the output signal of the ε amplified via linear amplifier is linear relationship with t. Therefore, to realize the thermometric linearization, The characteristics of feedback loop(the characteristic of $V_f'\sim V_0$ that is the characteristic of $V_f'\sim t$) must be consistent with that of thermocouples.

3 Linearization hardware circuit

We design a linear circuit according to the thermocouple linearization compensation principle, that a nonlinear operation circuit actually is broken

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line circuit, it is used polygon method to approximately represent the thermocouple characteristic curve. Fig. 2 shows the nonlinear characteristic curve approximately represented by the four segment broken line. In the diagram, V_f is the input signal of feedback loop,V_a is the output signal of nonlinear operation circuit,γ_1, γ_2, γ_3 and γ_4 respectively represent the slope of four characteristic curve. The number of broken line and the size of the slope are up to the thermocouple characteristics. Normally, the error is less than 0.2% as 4~5 broken line approximately represent a segment of thermocouple's characteristic curve.

As shown in Fig. 3,we designed a kind of typical operation circuit which is applied in thermocouple linear compensation according to the characteristic curve(Fig. 2).

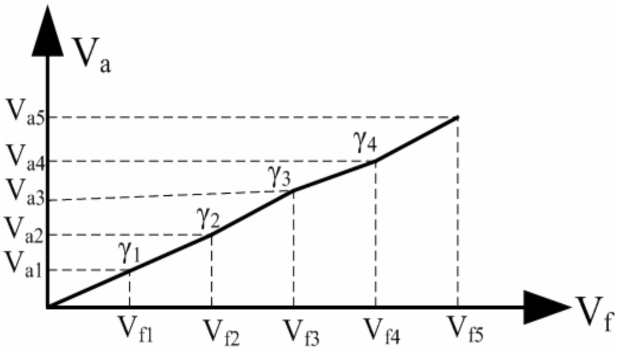

Fig. 2 The characteristics curve of nonlinear arithmetic circuit

We design a typical arithmetic circuit used for linear compensation that is shown in Fig. 3, witch depends on the characteristic curve(Fig. 2).

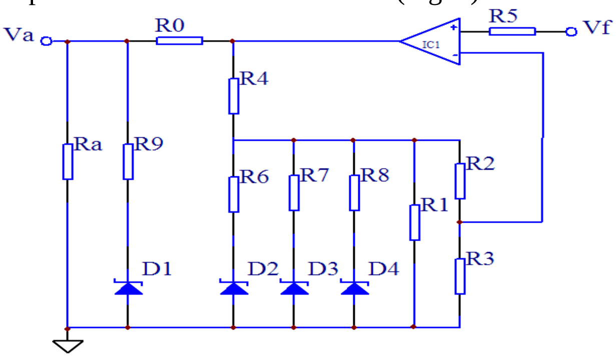

Fig. 3 The schematic diagram of nonlinear arithmetic circuit

In this figure,D_1, D_2, D_3 and $D_4$are stabilivolts, V_D is their value. Its resistance is maximum before breakdown, this circumstance equal to open circuit, and the resistance is very small after breakdown, this circumstance equal to short circuit.V_{S1},V_{S2},V_{S3},V_{S4} are reference voltage offered by reference voltage circuit, for common point, they were negative value.IC_1,R_1,R_2,R_3,R_4,R_0,R_a constitute the basic circuit of the operation circuit, this circuit decides the first rectilinear's slopeγ_1.When the after line's slope greater than before, that is γ_2>γ_1,we can parallel a resistor with R_1,the feedback is decreased and the output is increased. If require the after line's slope smaller than before, that is γ_3>γ_2, we can parallel a resistor with R_a, the output is decreased. The size of the resistance in parallel depends on the request of the new lines' slope, the value of reference voltage and the stabilivolt's breakdown voltage depend on the time when one line transit to another,that is the break point of the broken lines.

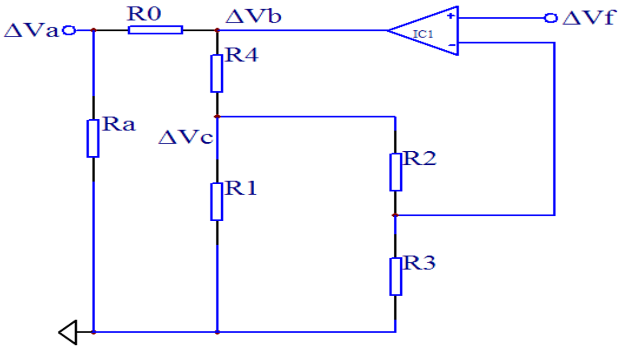

Fig. 4 The sketch diagram of nonlinear arithmetic circuit

For the first part line(V_{f1}≤V_{f2}),the slope is γ_1 As V_C≤V_D+V_{S1},V_C≤V_D+V_{S2},V_C≤V_D+V_{S3},V_C≤V_D+ V_{S4} , then DW_1~ DW_4 are all breakover, Fig. 3 is reduced to Fig. 4,when IC_1 is ideal operational amplifier, we can obtain ΔV_a and γ_1 by the Fig. 4:

$$\Delta V_a=\left[1+\frac{R_2}{R_3}+\frac{R_4}{R_3}\left(1+\frac{R_2+R_3}{R_1}\right)\right]\times\frac{R_a}{R_0+R_a}\Delta V_f \tag{1}$$

$$\gamma_1=\frac{\Delta V_a}{\Delta V_f}=\left[1+\frac{R_2}{R_3}+\frac{R_4}{R_3}\left(1+\frac{R_2+R_3}{R_1}\right)\right]\times\frac{R_a}{R_0+R_a} \tag{2}$$

From the formula (2) we can see that the first line's slope is determined by R_4, R_1~ R_3, $R_0$and R_a, it generally can be adjusted by changing R_1.

For the second part line(V_{f2}< V_f≤V_{f3}), The slope of this line is γ_1>γ_2.the range of this line requires V_D+ V_{S1} < V_C≤ V_D+ V_{S4} ,V_C< V_D+ V_{S3} and V_a< V_D+ V_{S4},then DW_1~ DW_3 are not breakover, D_4 is breakover. Because the dynamic resistance and the internal resistance of reference voltage(V_{S1}) is very small when D_4 is breakover, this is equal that resistance R_8 parallel resistance R_1,from this we can acquire ΔV_a and γ_2:

$$\Delta V_a=\left[1+\frac{R_2}{R_3}+\frac{R_4}{R_3}\left(1+\frac{R_2+R_3}{R_1//R_8}\right)\right]\times\frac{R_a}{R_0+R_a}\Delta V_f \tag{3}$$

$$\gamma_2=\frac{\Delta V_a}{\Delta V_f}=\left[1+\frac{R_2}{R_3}+\frac{R_4}{R_3}\left(1+\frac{R_2+R_3}{R_1//R_8}\right)\right]\times\frac{R_a}{R_0+R_a} \tag{4}$$

Compare the slope formula of the first and the second line with (2) and (4),we can see:$\gamma_2 \geq \gamma_1$, we let the R_1 to parallel a resistance, then can increase the slope of the thermocouple characteristic curve. Therefore, we just choose the proper R_8 based on γ_1 to satisfy the required slope γ_2. According to the same methord, can we get γ_3 and γ_4. In order to make the output properties of the nonlinear operation circuit consistent with the characteristics of thermocouples, we select corresponding value of parallel resistance to achieve the purpose of linearization.

4 Test results

In order to validate the compensation performance of this linear circuit, we do calibration experiment depending on the thermocouple indexing table. The Linear compensation range is 0~1000℃,the signal magnification of nonlinear compensation circuit is 100 times. We use CN65M/HD thermocouple signal generator as the input signal (V_f), This generator can generate thermocouple standard voltages signal from 0℃ to 1000℃, its accuracy can reach 0.1 level,and can meet the occasions of the standardization for the thermocouple high-accuracy signal.

From the obtained data we know that the output signal of thermocouple's temperature– millivolt has large nonlinearity. After nonlinear compensation, the nonlinear error is less than 0.4%.

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Fig. 8 The timing system in classroom use

9. Conclusion

A portable timing system for debating activities has been described, which has the advantages of portability and simplicity of operation.

Although intended initially for debating in English, the unit is obviously equally applicable to the large number of Chinese debates which are now popular on the mainland. Indeed, the equipment can be used in any situation where oral speech has a time-critical element. As such, it may be applicable to conferences, workshops and in the business environment.

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