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Error analysis of current formated by precision voltage-current converter loaded by inductance

Abstract

In scanning microscope the cathode ray tube of high resolution is used. The screen of this tube is formed by raster consisting of 4096×4096 luminous elements, composing the image. This raster allows to form images of investigated microobject on the screen in a wide range without loss of resolution. The accuracy of imaging on the screen depends on the current setting errors in inductive coils of deflection system. The ways of reducing the static error of the current set in a voltage-current converter are proposed.

Keywords: scanning microscope, cathode ray tube, microobject, luminous raster, current control errors.

1. Introduction

Optical scanning television microscopes are used commonly for microscopic studies in biology and medicine. The resolution of microscopes used for optical scanning is similar as for good cathode ray tube. The screen of such tube is formed by a luminous scanning raster consisting of 4096×4096 elements, so the image is composed of the same number of pixels. This grid allows to reconstruct investigated microscopic images in the screen in a wide range without loss of resolution. The accuracy of imaging in the screen depends on the errors of current setting in inductive coils of deflection system. The relative errors of high-resolution raster, taking into account all destabilizing factors can be less of 0.002% [1]. In such case, the formation of sawtooth or step-increasing current in induction load of deflection coils using a precision signal generator voltage is realized. Deviation signal of scanning beam is formed by analog or digital-to-analog method. The signal voltage deflection is converted with voltage-current converter (VCC) into current supplying the inductive load. Voltage-current converter is performed by dc amplifier with great feedback current. Feedback signal is formed on precision resistors, switched on in series with an inductive load. In this case, a static error is determined by the formation of the current, and parameters of both used VCC and complex load [2].

2. A VCC model for determining the static error of current supplying inductive load

Block diagram of the model to precisely determine the error of the static current based on the current formation is shown in Fig. 1. The diagram regards many destabilizing factors.

The relative error (δ_I) of static current formed in deflection system (DS) loaded by inductive component follows the relationship of parameters and VCC elements that define the transfer coefficient, temperature, voltage drift and bias noises. All destabilizing factors are brought to the door of the VCC, to make the analysis easy (Fig. 1).

The relative error of static current in the inductive load is developed due to the change of current in the inductive load in accordance with the expression:

$$\delta_I = \frac{\Delta I_N}{I_L}, \quad (1)$$

where: I_L – the maximum current in the inductive load required for the scanning beam deviation from the center of the screen to the edge of the raster; ΔI_N – the destabilizing change of current in the inductive load.

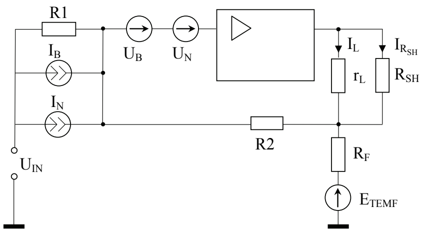

Fig. 1. Block diagram of the VCC model for the analysis of the static current error

3. Components of static error of the current formed in inductive load

To provide high precision convertion of the input voltage to output current, VCC uses direct current amplifier with a large value of the gain voltage. The gain of operational amplifier without the feedback exceeds 100000. In this case, the relative error due to the instability factor converting the input voltage to the load current $G(0)$ will be:

$$\delta_{G(0)} = \frac{\Delta R2}{R2} - \frac{\Delta R1}{R1} + \frac{r_L}{r_L + R_{SH}} \cdot \left(\frac{\Delta R_{SH}}{R_{SH}} - \frac{\Delta r_L}{r_L} \right) - \frac{\Delta R_F}{R_F}, \quad (2)$$

where: $R1$ and $R2$ are resistance values of comparing resistors, R_F – resistance value of feedback resistor, R_{SH} – resistance value of shunting resistor providing the deep aperiodic damping mode of transition process in DS, r_L – the selfresistance value of DS, Δ – absolute deviation of the respective variable.

Herewith change in the resistance of resistors:

$$\Delta R_X = (T.C.R.)_{R_X} \times \Delta t°, \quad (3)$$

where: $T.C.R.$ – temperature coefficient of electrical resistance, which is determined according to [3]; $\Delta t°$ – the given range of ambient temperature change. The index X indicates compliance with the selected resistor.

The current flowing thorough resistor signal feedback R_F controls the deflection of the scanning beam. The great value of the current deviation results in high power dissipation in this resistor. Significant power dissipation leads to heating of the resistor itself R_F. This means that in determining of the change in resistance R_F must be considered not only the temperature changes in the environment $\Delta t°$, but also the temperature changes of the heating resistor itself, $\Delta t°_C$. In this case:

$$\Delta R_F = (T.C.R.)_{R_F} \times \left(\Delta t° + \Delta t°_c \right) \quad (4)$$

The relative errors due to bias drift of both the voltage and the current according to Fig.1:

$$\delta_{U_B} = \frac{TK_{U_B} \cdot \Delta t°}{U_{IN}} \cdot \frac{R1 + R2}{R2} \quad \text{and} \quad \delta_{I_B} = \frac{TK_{I_B} \cdot \Delta t°}{U_{IN}} \cdot R1, \quad (5)$$

where TK_{UB} and TK_{IB} describe the input drift of bias voltage and current, U_{IN} – maximum value of the signal voltage at the input of the VCC.

The relative error due to the induced noise both the voltage and the current at the input of VCC amplifier:

$$\delta_{U_N} = \frac{U_N}{U_{IN}} \cdot \frac{R1 + R2}{R2} \quad \text{and} \quad \delta_{I_N} = \frac{I_N}{U_{IN}} \cdot R1, \qquad (6)$$

where $U_N = U_{NI} + U_{NE}$, and U_{NI} − induced intrinsic noises of the VCC, brought to the input; U_{NE} – extrinsic noise.

Wire resistors are used to form the feedback signal. A characteristic feature of such resistor is electromotive force that appears at different temperatures in connection points of wire resistors, and the electromotive force voltage signal is added to the feedback signal, which leads to additional errors.

The relative error due to thermoelectric force under the conditions of the formula (2):

$$\delta_{TEMF} = \frac{-E_{TEMF}}{U_{IN}} \cdot \frac{R1 \cdot R_F \cdot (R_{SH} + r_L)}{R2 \cdot R_{SH} \cdot r_L}, \qquad (7)$$

where $E_{TEMF}=\alpha \cdot \Delta t^{\circ}_L$, and α − thermoelectric constant of R_F, determined experimentally [4]; Δt°_L– temperature difference of the leads of R_F.

Since the error components are uncorrelated [4], the total static error of forming current in inductive component of DS's impedance is:

$$\delta_{I_L} = \sqrt{\delta^2_{G(0)} + \delta^2_{U_B} + \delta^2_{I_B} + \delta^2_{U_N} + \delta^2_{I_N} + \delta_{TEMF}} \qquad (8)$$

The error due to the instability of the conversion factor (2) is multiplicative and determines the distortion of the current formed in luminous raster of the CRT screen. Errors (5), (6) and (7) are additive and affect the stability of the beam positioning of CRT. Offset raster leads to errors of determining the coordinates of the investigated microobject fragment.

4. Reduction of static error components of the current in inductive load

Analysis of the individual components of static error of the current formed in the inductive load showed that the most significant component is the error due to drift of the offset voltage δ_{UB} (5), and the error due to the instability of the conversion factor $\delta_{G(0)}$ (2).

While designing the VCC it is necessary first to ensure minimal drift of bias voltage at the input of the amplifier. For this, the operational amplifier with a low TK_{UB} is used as the input matching amplifier [1]. Secondly, it is necessary to compensate the deflection of resistances of VCC and DS circuits – ΔR_X (3).

Since the components of the error due to instability of the conversion factor $\delta_{G(0)}$ (2) differ by value, the selection of *T.C.R.* of used resistors can provide some compensation. Components of error due to the instability of resistance of comparing resistors *R*1 and *R*2 can be fully compensated with accordingly selected the temperature coefficient of resistance

$$(T.C.R.)_{R1} = (T.C.R.)_{R2}, \qquad (9)$$

The compensation of the error components due to the instability of the resistance of shunting resistor R_{SR} and active resistance of DS r_L is possible. Here the condition must be met:

$$(T.C.R.)_{R_{SH}} = (T.C.R.)_{Cu}, \qquad (10)$$

where $(T.C.R.)_{Cu}$ − the temperature coefficient of resistance of copper, which corresponds to *T.C.R.* of an active DS resistance, $(T.C.R.)_{RSH}$ – temperature coefficient of resistance of shunting resistor.

In practice, it is very difficult to ensure the condition (10), because $(T.C.R.)_{Cu}$=4.04·10^{-3}K^{-1}, and if condition (9) is met, the $\delta_{G(0)}$ is completely determined by the ratio $-\Delta R_F/R_F$.

If condition of error components compensation due $\Delta R1$ and $\Delta R2$ in $\delta_{G(0)}$, and condition (9) are met, the expression (2) takes the next form:

$$\delta_{G(0)} = \frac{r_L}{r_L + R_{SH}} \cdot \left(\frac{\Delta R_{SH}}{R_{SH}} - \frac{\Delta r_L}{r_L} \right) - \frac{\Delta R_F}{R_F}, \qquad (11)$$

and error is defined as the sum of two linearly descending components (Fig.2).

The Fig. 2 illustrates the dependence of static error due to instability of the conversion factor of VCC $\delta_{G(0)}$ (11) on changes in ambient temperature Δt°, for the practical case of real parameters of DS and R_F. The error is determined as the sum of dependencies of component, which is determined by the change of feedback resistor ΔR_F:

$$-\frac{\Delta R_F}{R_F} \qquad (12)$$

and a component that depends on the change of resistance of parallel connection of DS active self-resistance Δr_L and the shunting resistor ΔR_{SH}:

$$\frac{r_L}{r_L + R_{SH}} \cdot \left(\frac{\Delta R_{SH}}{R_{SH}} - \frac{\Delta r_L}{r_L} \right). \qquad (13)$$

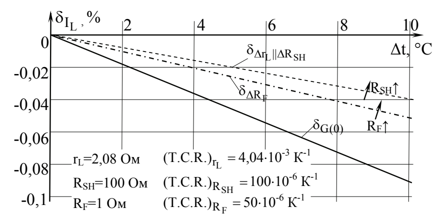

Fig. 2. Dependency of static error of current setting in DS vs. the difference of ambient temperature

Calculations were made with the assumption, that $\Delta t^{\circ}_S \to 0$, because the resistance R_F self-heating is very low and it was not taken into account. In two cases defined by (12) and (13) with an increase of Δt° the error $\delta_{G(0)}$ increases. This is due to the growth of ΔR_F and Δr_L and it is almost not dependent on the changes of ΔR_{SH}. If the dependence (11) is considered in detail, it appears that the increase in nominal resistance of resistors R_F and R_{SH} leads to a reduction in the $\delta_{G(0)}$ error components (12) and (13), while maintaining the values of *T.C.R.* of these resistors.

The maximum value of signal voltage of feedback resistor R_F limits the voltage drop on it during the flow of maximum current in inductive load. It is advisable to choose the resistor R_F regarding the voltage drop on it at the maximum current load. The voltage drop should does not exceed 10 - 20% of the supply voltage at the output stage VCC.

Increasing the resistor R_F causes an increase in power that it dissipates. This leads to an increase in self-heating temperature and, consequently, to an increase in static error component forming current. Graphs of the self-heating resistor temperature for type C5-5, C5-16 and C5-37 resistors, vs. their loads are shown in Figure 3 [1]. The maximum value is limited to the value of resistor R_{SH} formed by the parasitic inductance and load capacitance.

From (11) the possibility of compensation of error due to the instability of feedback resistance R_F and active resistance of DS is determined. When large inductance coils (500 µH) are used, the drift of active resistance of DS makes the largest contribution to the instability of the conversion factor *G*(0).

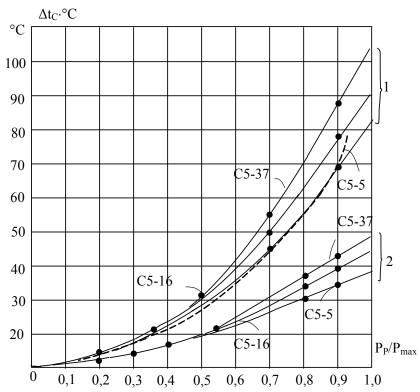

Fig. 3. Temperature dependence self-heating powerful precision resistors of power dissipation: in normal cooling – curve 1, and at forced cooling – curve 2

From the expression (11) and taking into account the condition (9) to compensate the instability due to ΔR_F and Δr_L it is necessary to ensure:

$$(T.C.R.)_{R_F} = \frac{R_F \cdot r_L}{R_{SH} + r_L} \cdot \left[\frac{(T.C.R.)_{R_{SH}}}{R_{SH}} - \frac{(T.C.R.)_{r_L}}{r_L} \right]. \quad (14)$$

For an approximate calculation $(T.C.R.)_{RF}$ can be taken into account:

$$(T.C.R.)_{R_F} = -\frac{R_F \cdot r_L}{R_{SH} + r_L} \cdot \left[\frac{(T.C.R.)_{r_L}}{r_L} \right]. \quad (15)$$

When the appropriate $(T.C.R.)_{RF}$ are ensured, the full compensation of static error due to instability of VCC conversion factor $G(0)$ can be achieved. To get the real values of *T.C.R.* of the selected feedback resistor, it is reasonable to use the fit the needed temperature coefficient by appropriate selection of parameters of multiplier:

$$-\frac{R_F \cdot r_L}{R_{SH} + r_L}. \quad (16)$$

Because r_L of the used DS cannot be changed, it is reasonable to change the nominal resistance R_{SH} of shunting resistor. Thus, a decrease in the resistance R_{SH} results in the increase of the required temperature coefficient of resistance. Reduction of R_{SH} leads to reduction of transient voltage in DS, and as a result to reduction of the speed of current setting. Therefore, the selection of the nominal value of resistance of shunting resistor should be carried out in a pre-specified limits corresponding to the performance of the VCC.

In cases where it is impossible to ensure the selection of R_{SH} or R_F, partial compensation of $\delta_{G(0)}$ is made by the selection as close to the *T.C.R.* determined from expression (14). This way of compensation will ensure reduction in $\delta_{G(0)}$ few times.

If conditions (9) and (14) are met, a complete compensation of relative error due to the instability of the conversion factor of VCC is ensured.

5. Conclusion

The main components of the static error of the current setting in VCC are the error due to the instability of the conversion factor of VCC and error due to the drift of the bias voltage at the input of converter amplifier.

The error due to the instability of the conversion factor of VCC is mainly determined by the temperature coefficient of resistance of resistor, on which a signal of negative feedback is formed, and by the change of DS active self-resistance on the change of ambient temperature.

The ways of reducing the static error in the current setting in VCC are proposed:

- use of an operational amplifier with low values of drifting of bias voltage and high gain at low frequencies as the input gain stage and as VCC matching circuit with the input voltage source;
- use of comparing resistors with the same *T.C.R.* values;
- compensation of static error due to the instability of the conversion factor of VCC by selection of negative *T.C.R.* of feedback resistor;
- reducing the range of variation in ambient temperature, when the operating temperature is reached.

The expression for determining the *T.C.R.* of feedback resistor, which ensures full compensation of error due to instability of the conversion factor of VCC is proposed.

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