Model of the Electronic Current Transducer

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Abstract: This paper presents the model of closed loop Hall effect current transducers. The model complies with the physical proprieties of the real system and it is useful for the analysis of the transducer's work with deformed input signal.

I. Introduction

The closed loop current transducers with magnetic coupling are at present most frequently applied as the main element of current feedbacks of power electronic systems [1, 2, 3, 4, 5, 6, 7]. The function of these circuits is to control the currents and to protect the semiconductive electronic executive elements from destruction in the case of overcurrent or short-circuit in the load. The course of the voltage or current output signal of transducers has to be in accordance with the course of the measured. current. According to the information supplied in catalogues, this condition is met by the current transducers with full compensation of the flux in a magnetic core which is achieved through an electronically controlled negative feedback loop. These transducers are produced, among others, by the Swiss company LEM [4, 5, 6, 7]. So far, the functioning of these transducers was analyzed without taking into the account the properties of the real system [1, 2, 3] and with the assumption that the loop of negative feedback which compensates magnetic flux in core is controlled by voltage. Also the nonlinearity of the transducer's electronic block was not taken into the account. The simulative model of current transducer presented in this paper is free of such defects. The model was created with the help of Matlab – Simulink program.

II. Closed loop current transducers

The schematic diagram of the current transducer, for which the model was prepared, is presented in Fig. 1 [1, 4, 5, 6, 7].

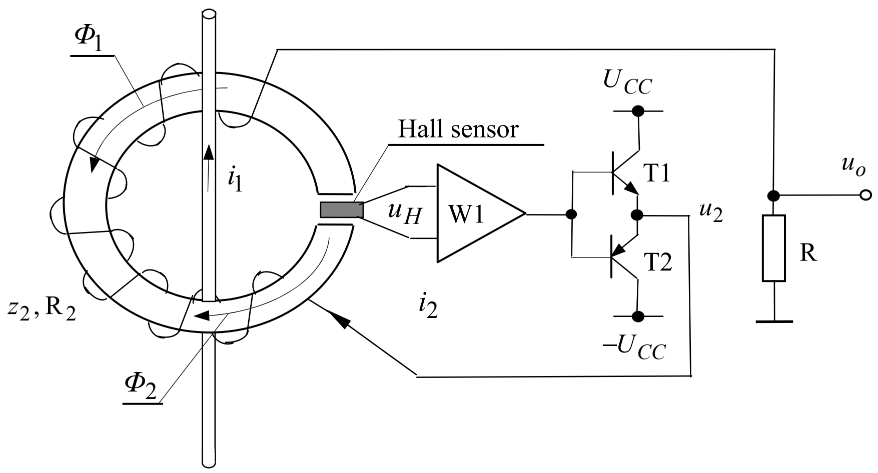

Fig.1. Schematic diagram of the closed loop current transducer

In the main part of the transducer there is the ferromagnetic core with the slot, where the Hall sensor is situated, the sensor's W1 output signal amplifier, and power output amplifier created by a pair of complementary transistors T1 and T2. The function of the Hall sensor is to detect the zero instantaneous value of the resultant magnetic flux in core of the transducer. The feedback loop in the system is made up of the compensation coils at

z_2 number of coils through which the i_2 current, generated by the transistor pair T1 and T2, passes. The instantaneous value of the i_2 current is proportional to instantaneous value of output voltage of the Hall sensor measuring the magnetic induction in core. The z_2 number of coils and the direction of winding in the compensation coils were chosen so that the stationary value of flux in core is near zero $\Phi_2 - \Phi_1 \approx 0$. This means that the magnetic flow produced by the measured current $\Theta_1 = I_1 \cdot z_1$ is compensated be the magnetic flow $\Theta_2 = I_2 \cdot z_2$ generated by current from negative feedback loop: $\Theta_1 = \Theta_2$. The output voltage of the transducer is calculated as follows [1, 4, 5, 6, 7]:

$$U_o = I_2 \cdot \mathrm{R} = I_1 \cdot \mathrm{R} \cdot \frac{z_1}{z_2} \tag{1}$$

where: R is the effective resistance of measuring resistor, z_1 mark the number of prime laps and z_2 mark the number of laps in compensation winding.

III. The transducer model

The processing band of electronic current transducers is limited by the top frequency f_g, where the transducer's deviation reaches -10%, which corresponds to the decrease of the conversion coefficient value by -1dB (Fig.2). Depending on the type of the transducer f_g reaches values from 100 to 200kHz [1, 4, 5, 6, 7].

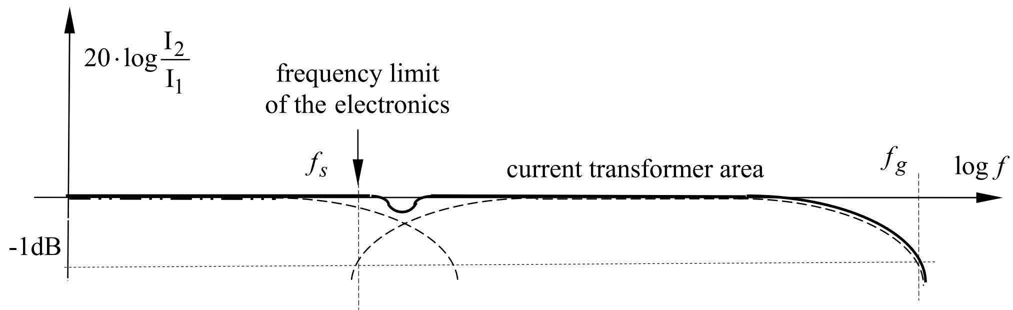

Fig 2. Bandwidth of the "electronics" and "current transformer"

As shown on the above diagram of the frequency characteristics of the processing, there appears an off-peak period which divides the processing band into two sub-ranges (Fig. 2) [1, 4, 5]. The bottom sub-range where the compensation of flux in core takes place is limited at the top by f_s frequency. When the i_1 current frequency is equal or greater than f_s, the saturation of the transistors T1 and T2 occurs of power stages, feeding the compensation coils. At these frequencies of measured current, the transducer behaves as the current transformer without compensation of flux in core. For transducers with a rated current lower than 100A stages of power the saturation occurs at frequency $f_s \approx 10\mathrm{kHz}$. Transducers which measure currents at values higher than 100A saturate at frequency $f_s \approx 1\mathrm{kHz}$.

When analyzing the frequency characteristics of current deviation (amplitudinal) and the angular deviation (phasal) of the electronic current transducers produced at present [4, 5, 6, 7] it was possible to confirm that in the frequency range where the flux in core is compensated, the values of the deviations mentioned before are much lower in comparison with the deviations in the transducers which work without electronic support, with open feedback loop. This means that the electronic transducers examined in this paper are capable of measuring deformed signal, whose frequency belongs to the band limited by the top frequency f_s.

For the analysis of the electronic current transducers with compensation of magnetic flux in core, which measure the i_1 current of frequency lower than f_s, it is possible to use the model whose block diagram is shown in Fig. 3.

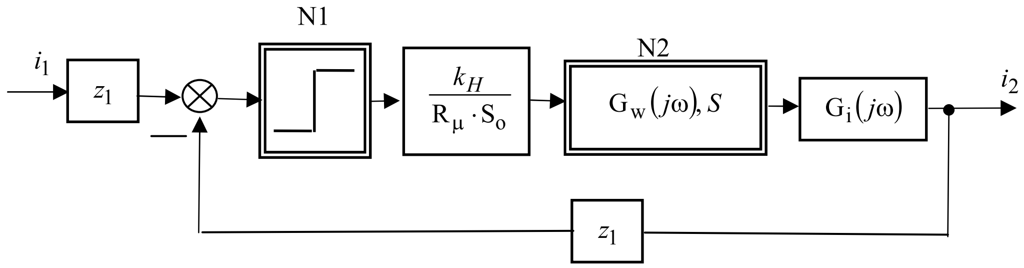

Fig 2. The block diagram of the current transducer model (z_1, z_2 - mark the number of laps in primary and secondary winding; k_H - is the Hall sensor constant, Rµ - the reluctance of magnetic core, S_o - cross-section of the air-gap; R – measuring resistor)

In the diagram in Fig. 2 the non-linear block N1 imitates the effect of saturation of permalloy core on properties of the transducer. In the simulative research, it was assumed that the relationship of magnetic voltage U_μ on the air-gap equals:

$$U_\mu = R_{\mu 0} \cdot S_0 \cdot B \tag{2}$$

where: B - is the induction of magnetic field in core, in function of changes in flow in core is abrupt (Fig. 3).

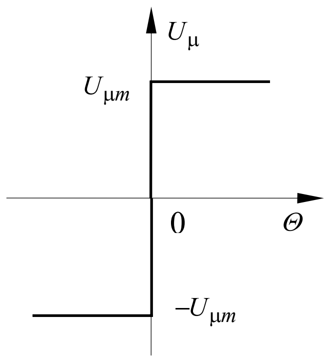

Fig. 3. The characteristic of the curve $U_\mu = f(\Theta)$ of non-linear block N1 ($U_{\mu m}$ - the value of magnetic voltage on the air-gap when core is saturated $(B = B_m)$)

$G_i(j\omega)$ is the spectral transfer function of the power stages of electronic block of the transducer $(G_i(j\omega) = g_i)$. The authors of this paper assumed, that in the examined transducer (Fig. 1) the output signal of Hall sensor is strengthened by means of an operational amplifier with a negative feedback loop. Block N2 is the model of this system. The internal structure of block N2 is presented in Fig. 4. In this schematic diagram, the β is the loop gain of the system ($\beta = \frac{1}{K_{V0}}$, K_{V0} - the constant voltage gain of the amplifier W1), the cascade connected blocks B1, L, and B2 represent the operational amplifier. The non-linear block B1 represents the input stages of amplifier, where its saturation is defined by the level $u_{d\max}$ of the input differential voltage signal u_d . When the value of the signal u_d is higher then $u_{d\max}$, the rate of changes in the amplifier's output voltage u_o is limited to level S .

The S parameter is called the maximum rate of changes in the amplifier's output signal. In the model, the value of the S parameter is defined by the dynamic proprieties of linear block L. In this block, the other pole of spectral transmittance of the operational amplifier was also taken into account. The authors have assumed that this pole appears for elementary gain pulsation: $\omega_T = 2\pi f_T$. The influence of the limited value of feeding voltage on the amplifier's performance was considered with the help of the non-linear output block B2. Limitation of the peak value of the input signal in this block was determined to be at the level about 1V lower than the absolute value of

voltage feeding the U_z system. The drop of voltage 1V determine the sum of voltage of saturation the transistors in output stages and fall of voltage in protective circuit before fault to frame of exit terminal of operational amplifier.
The model, whose schematic diagram is presented in Fig. 2, was used in simulating research of electronic transducer type LA 25 - NP/SP13 produced by LEM [1, 5]. This transducer is designed for measuring the current of RMS value ≤ 0.5 A in frequency band from 0 to 150kHz. The aim of the research was to check the usefulness of this model.

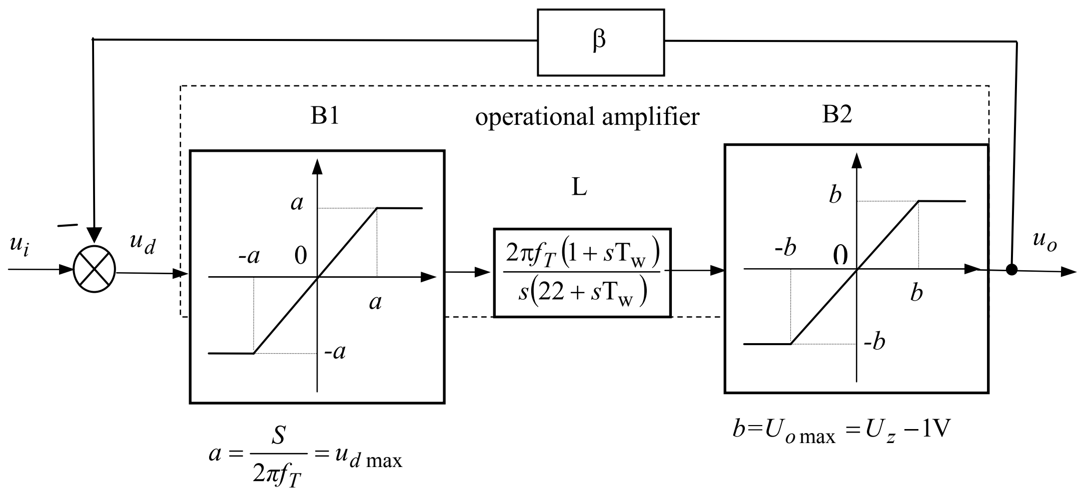

Fig. 4. Block diagram of amplifier W1 model (Fig. 1) (u_d - the input differential voltage of operational amplifier, $U_{o\max}$ - maximum output voltage of the system, U_z - the feeding voltage of the amplifier, S – slew rate of the output signal u_o, f_T - the unit gain frequency of amplifier, β - the loop gain, T_w - the time constant of the correction circuit of frequency response of the amplifier)

Simulating testing was realized in software environment of Matlab - Simulink. The following values were accepted: $k_H = 100\mathrm{V/T}$, $K_{V0} = 1000\mathrm{V/V}$ and $f_T = 3.5\mathrm{MHz}$. The time constant of the system correction of the amplifier frequency response was $T_w = 2.63 \cdot 10^{-4}\mathrm{s}$. The authors of this paper determined the value of time constant T_w analyzing the course response of transducer LA 25 - NP/SP13 to elementary stroke of the current measured from 0 to 0.5 A.. The course of this signal was also used to calculate the maximal increase of the speed rate of S output signal of the amplifier W1 (Fig. 1). The results of the research have shown, that $S = 0.25\,\mathrm{V/\mu s}$. After disassembling the core of the transducer was found to be made of permalloy wire of cross-section area $S_0 = 1.77 \cdot 10^{-6}\mathrm{m}^2$ and the core air-gap of the length $l = 1 \cdot 10^{-3}\mathrm{m}$. Thus, magnetic resistance of this air-gap has the value:

$$R_\mu = \frac{1}{\mu_0 \cdot S_0} = 4.51 \cdot 10^{-8}\,\frac{1}{\mathrm{H}} \tag{3}$$

In simulating research the induction of the core saturation was assumed to have the value $B_m = 0.85\mathrm{T}$. It results from catalogue data of a current converter LA 25 - NP/SP13 that $z_1/z_2 = 50/1000$ and the constant of the power stages (transistors T1 and T2 – the Fig. 1) has the value $g_i = 1.79 \cdot 10^{-3}\,\mathrm{A/V}$ [4].
In the course of the simulating research, the frequency response (amplitudinal and phasal) of the model of transducer measuring current i_1 deformed by the third harmonic of RMS value 0.5 A was determined. The third harmonic deforming the current i_1 has 40% share and the phase in accordance with the phase of the basic harmonic. Then, the authors compared the course of the frequency characteristic of the model with appropriate characteristics of the transducer LA 25 - NP/SP13 (Fig. 5), which were determined in the course of laboratory investigations. Compatibility of the course of the characteristics of the model and the transducer LA 25 -

NP/SP13 for the measured current, the frequency of which is lower than the frequency of saturation f_s = 4kHz of the electronic block of transducer LA 25 - NP / SP13 is the proof of correct construction of the model.

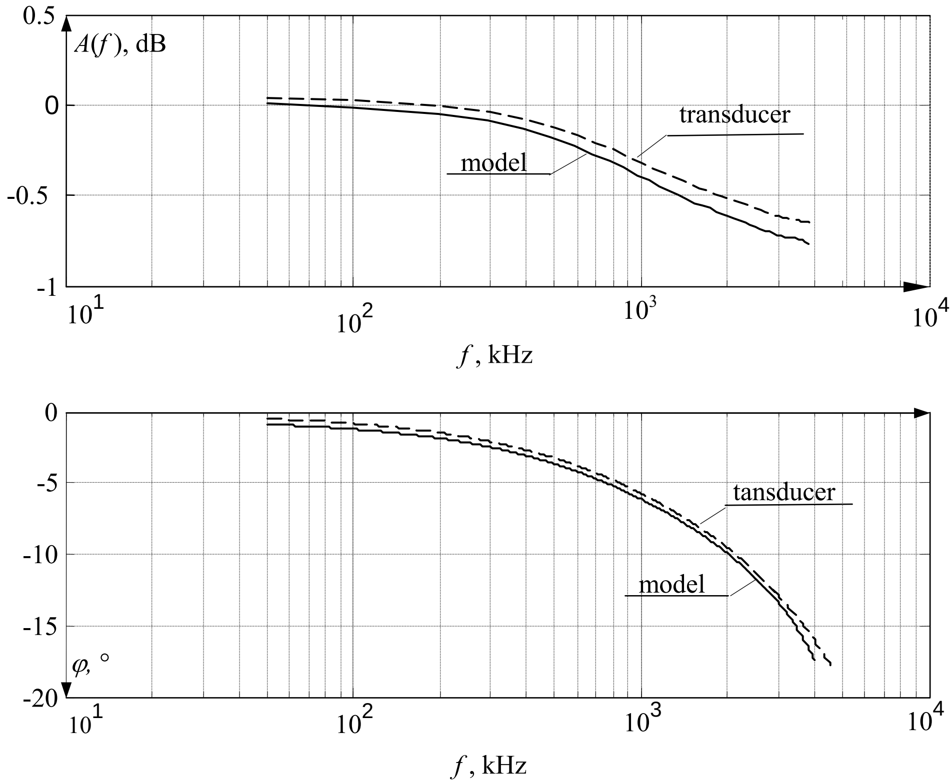

Fig. 5. Frequency response of LA 25-NP/SP13 and frequency response of the Simulink model of this current transducer

IV Conclusion

In conclusion, the simulative model presented in the paper can be used to study the influence of deformation in the measured current on the characteristics of metrology of electronic current transducers with compensation of flux in core. This model takes into account, besides the saturation of the transducer's magnetic core, the limitations of the processing band and the limitations of speed of changes in the output voltage in the electronic block of transducer.

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