УДК 621.315

THE FREQUENCY ERRORS OF CURRENT TRANSFORMER

K. Pacholski, A. Szczęsny, A. Graczyk

Technical University of Lodz, Institute of Electrical Engineering Systems, Lodz, Poland

Current transformers are characterized by the wide of processing bandwidth for the sinusoidal signal. However, the transformers characteristics are wrong when the processing signals are deformed. In that case it can be observed limitation of the bandwidth. This fact isn't presented in the standards. In the paper authors present an analysis-method for calculating of the frequency band of work of current transformers.

Introduction. The subject of this paper is an analysis-method for calculating of the frequency band of work of current transformers, by the processing of deformed current signals. The authors of this paper carried out laboratory experiments, during which they estimated the applicability of these transformers for measuring deformed signals. For this, the authors used the frequency response of this device set during the research, and presented in this paper.

Frequency band of current transformer. When the current transformer work under deformed signals, it schematic diagram can be presented as on fig. 1.

On this diagram R_1' and R_2 are the resistance of primary winding recalculated on secondary side and the resistances of secondary winding. L_1' and L_2 are inductances of primary and secondary winding. Inductance L_1' and L_2 come from magnetic streams coupling only with one winding and closing through air only.

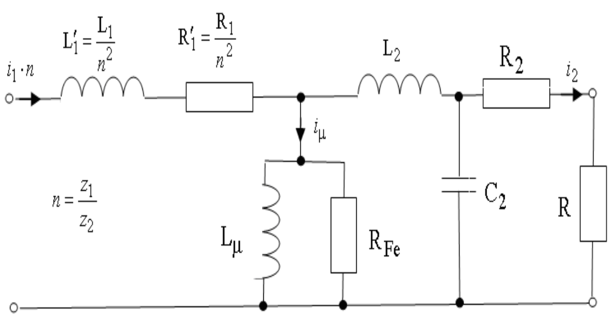

Figure1 - Schematic diagram of transformer working as current transformer (counted on secondary side)

These inductance are insignificant in comparison with L_μ connected from magnetical stream coupling with primary and secondary winding. This stream is closes in ferromagnetical core of the transformer. In converter is applied the magnetic core with air gap, so inductance L_μ was determined from dependence [4].

$$L_\mu = \frac{z_1 \cdot z_2}{\dfrac{l_{Fe}}{\mu_{Fe}\mu_0 S} + \dfrac{d}{\mu_0 S}} \approx z_1 \cdot z_2 \frac{\mu_0 S}{d} \qquad (1)$$

where: l_{Fe} - the average length of magnetical circuit of core,

d -signify the length of air gap,

S - is the surface of cross - section of core,

μ_{Fe} and μ_0 - signify the relative permeability of material of core and the magnetical permeability of air,

C_2 - is the capacity between laps of the secondary winding of converter.

This capacity creates with L_μ inductance the resonant circuit. R_{Fe} - represents the total losses of power in the circuit of core.

In measuring systems, transformer, similarly as current transformers work with extorted primary current, that it is possible to skip L_1' and R_1' element in replacement diagram from fig. 2.

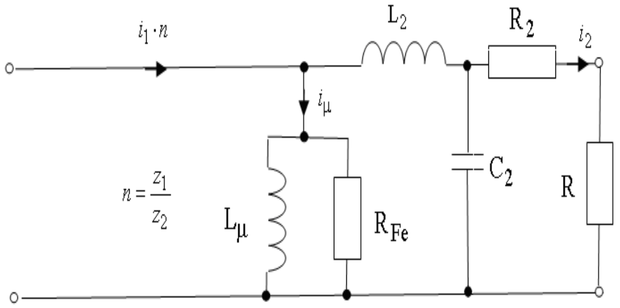

Figure 2 - The reduced supplementary diagram of transducer working as transformer of current (counted on secondary side)

In the central range of frequency processing band can skipped the influence of reactance elements of supplementary diagram (fig. 3a)

The output current of converter for central frequencies of processing band, i.e. for pulsation $1.1 \cdot \omega_d < \omega < 0.1 \cdot \omega_g$ describe dependence:

where: ω_d and ω_g – lower and upper border pulsation the central range of transformer band of converter (fig.4).

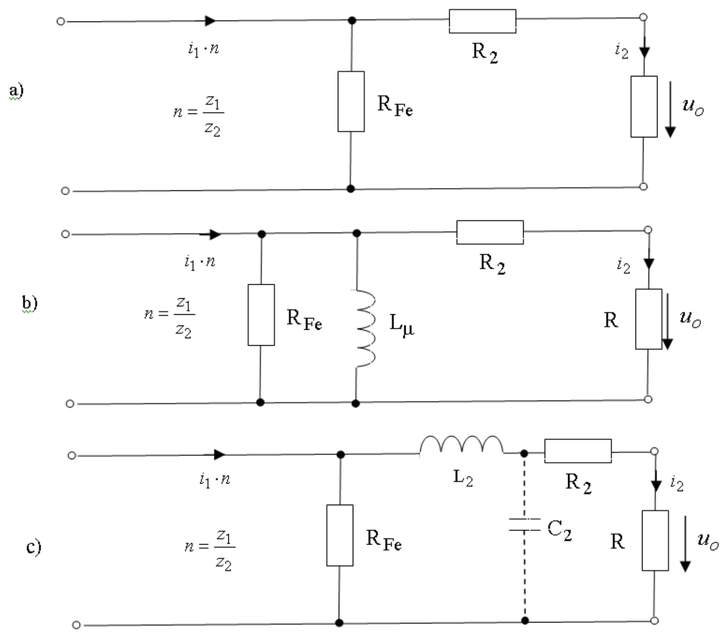

Figure 3 - Supplementary diagram of current transformer for (a) central(b) low (c) the high range of frequency of processing band

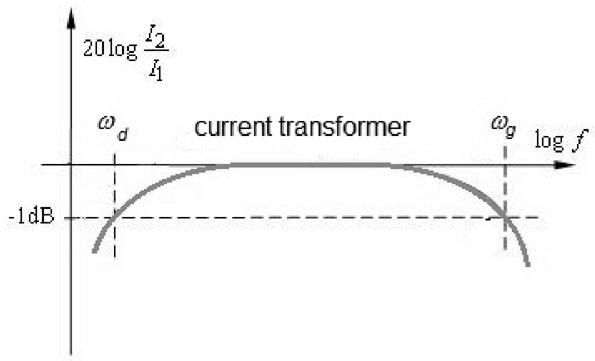

Figure 4 - Processing band of current transformer

$$i_2(s) = \frac{R_{Fe}}{R + R_{Fe} + R_2} \cdot n \cdot i_1(s) = \\ = \frac{R_{Fe}}{R + R_{Fe} + R_2} \cdot n \cdot i_1(s) = k_\mu \cdot n \cdot i_1(s) \quad (2)$$

where $k_\mu = \dfrac{R_{Fe}}{R + R_{Fe} + R_2}$.

The spectral transmittance of transformer for central range of frequency processing band has character:

$$G_t(j\omega) = \frac{i_2(j\omega)}{n \cdot i_1(j\omega)} = k_\mu . \quad (3)$$

From dep. (3) it appear, that frequency current error (amplitude) and angular error (phase) current transformer, describe dependence:

$$\delta = \frac{n \cdot i_1 - i_2}{n \cdot i_1} = 1 - k_\mu \le 1; \quad \varphi = 0 . \quad (4)$$

In range of low frequencies of processing band about dynamic proprieties current transformer decides the main inductance L_μ (fig. 3b). In this case the output current of transformer describes dependence:

$$i_2(s) = \frac{sL_\mu \cdot R_{Fe}}{R_{Fe}(R + R_2) + sL_\mu(R + R_2 + R_{Fe})} \cdot n \cdot i_1(s) = \\ = \frac{s\frac{L_\mu(R + R_2 + R_{Fe})}{R_{Fe}(R + R_2)}}{1 + s\frac{L_\mu(R + R_2 + R_{Fe})}{R_{Fe}(R + R_2)}} \cdot k_\mu \cdot n \cdot i_1(s) \quad (5)$$

Transfer function of transducer working as current transformer has character:

$$G_t(s) = \frac{i_2(s)}{n \cdot i_1(s)} = k_\mu \cdot \frac{s\frac{L_\mu(R + R_2 + R_{Fe})}{R_{Fe}(R + R_2)}}{1 + s\frac{L_\mu(R + R_2 + R_{Fe})}{R_{Fe}(R + R_2)}} = \\ = k_\mu \cdot \frac{sT_\mu}{1 + sT_\mu} \quad (6)$$

where: $T_\mu = \dfrac{L_\mu(R + R_2 + R_{Fe})}{R_{Fe}(R + R_2)}$.

From dep. (6) follow, that the central range of processing band of transformer range of work of converter is limits from bottom by pulsation

$$\omega_d = \frac{1}{T_\mu}. \qquad (7)$$

After replacement to dependence (6) s = jω we receive the spectral transmittance of converter:

$$G_t(j\omega) = k_\mu \cdot \frac{j\omega T_\mu}{1 + j\omega T_\mu}. \qquad (8)$$

Module and phase angle spectral transmittance describe following dependences:

$$G_t(\omega) = k_\mu \cdot \frac{\omega T_\mu}{\sqrt{1 + (\omega T_\mu)^2}}. \qquad (9)$$

$$\varphi_t(\omega) = \text{arctg}\frac{1}{\omega T_\mu} = \frac{\pi}{2} - \text{arctg}\,\omega T_\mu \qquad (10)$$

In range of high frequencies of processing band about dynamic proprieties of current transformer, decide leakage inductance L_2 of secondary winding. The schematic diagram of current transformer in this range of frequency processing band represents fig. 3c. The influence of capacity C_2 with regard on small value of output voltage of converter can be skipped. So the output current of transformer was described by dependence 11:

$$i_2(s) = \frac{R_{Fe}}{R + R_2 + R_{Fe} + sL_2} \cdot n \cdot i_1(s) = \\ = \frac{k_\mu}{1 + s\frac{L_2}{R + R_2 + R_{Fe}}} \cdot n \cdot i_1(s) \qquad (11)$$

$$\text{if: } T_2 = \frac{L_2}{R + R_2 + R_{Fe}}.$$

From dependence 11 we can calculation the spectral transmittance of transformer of current for upper range of frequency of processing band:

$$G_t(j\omega) = \frac{k_\mu}{1 + j\omega T_2}. \qquad (12)$$

Module $G_t(\omega)$ and angle phase $\varphi_t(\omega)$ of spectral transmittance $G_t(j\omega)$ describe following formula:

$$G_t(\omega) = \frac{k_\mu}{\sqrt{1 + (\omega T_2)^2}}. \qquad (13)$$

$$\varphi_t(\omega) = -\text{arctg}\,\omega T_2. \qquad (14)$$

From formula (13) we can conclude, that upper range of processing band of current transformer is limited to pulsation $\omega_g = 1/T_2$.

After regard dep. (12) the current and angular error the converter in upper range of frequency of transformer processing band (i.e. for $\omega > 0{,}1 \cdot \omega_g$) describe formula:

$$\delta = 1 - \frac{k_\mu}{\sqrt{1 + (\omega T_L)^2}}. \qquad (15)$$

$$\varphi(\omega) = -\text{arctg}\,\omega T_2. \qquad (16)$$

The analyses show that for low frequencies, the errors the transducer depend from time constant T_μ which is determinate by the main inductance L_μ and the resistance R_{FE} represents the total losses of power in the circuit of core and effective resistance of secondary winding. In range of central frequencies the frequency propriety of transducer are independent from the reactance parameters. For high frequencies about errors of transducer decide the leakage inductance.

References

1. Pacholski K.: "RAPORT KOŃCOWY z realizacji projektu badawczego własnego 3T10C 010 27", Łódź 2006.
2. Szczęsny A.: "Analiza właściwości częstotliwościowych skompensowanych elektronicznych przekładników prądowych", Rozprawa Doktorska, Politechnika Łódzka, kwiecień 2008
3. Niedźwiecki M., Rausiukiewicz M.: "Nieliniowe elektroniczne układy analogowe", WNT, Warszawa 1997.
4. Horowitz P., Hill W.: "Sztuka elektroniki cz.1".

Аннотация

ЧАСТОТНЫЕ ПОГРЕШНОСТИ ТОКОВОГО ПРЕОБРАЗОВАТЕЛЯ

Пахольски К., Щесны А., Грацик А.

Токовые преобразователли характеризуются широкой пропускной способностью для синусоидального сигнала. При искажении синусоиды наблюдаются ограничения пропуской способности, что не нашло отражения в стандартах. Авторами статьи представлен метод анализа пропускной способности токовых преобразователей с учетом искаженного синусоидального сигнала.

Анотація

ЧАСТОТНІ ПОХИБКИ СТРУМОВОГО ПЕРЕТВОРЮВАЧА

Пахольски К., Щесни А., Грацик А.

Струмові перетворювачі характеризуються широкою пропускною здатністю для сінусоїдального сигналу. При викривленні сінусоїди спостерігаються обмеження пропускної здатності, що не знайшло відображення у стандартах. Авторами статті представлено метод аналіза пропускної здатності струмових перетворювачів з врахуванням викривленого сінусоїдального сигналу.