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New Inductive Current Transformers Provided for to Work at a Frequency of up to 300 kHz

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Introduction

At present, many devices work in circuits with a frequency above 50 Hz. The wide use of power engineering electronics in systems with an elevated frequency necessitates the usage in these circuits of special constructions in the circuits of these current transformers. Suitably solved windings with special magnetic materials characterize these constructions.

An analysis of functioning current transformers with different constructions at a changing frequency

While analyzing occurring phenomena in conventional current transformer working at area of mean frequencies, one must be attentive to the properties of each constructional solution. The criterion of the current transformer's constructional solution is the degree of the magnetic coupling, which appears between the primary and secondary winding at the defined geometry of the core. Following the above criterion, current transformers can be divided on three principal groups:

- transformers with very small dispersion (i.e. with a very good magnetic connection between windings),
- transformers with average dispersion,
- transformers with very large dispersion.

Current transformer can be introduced with the help of a supplementary scheme, which appears in the form of a four-terminal network of the type T whose secondary circuit contains the resistance of secondary winding R_2, and the reactance of the dispersion X_2, and the impedance Z_B, thus determining a transformer's load. Meanwhile one can write the equation determining the denominative voltage U_μ on the transverse branch representing the core.

$$\underline{U}_\mu = \underline{I}_2\left[(R_2 + R_B) + j(X_2 + X_B)\right]. \tag{1}$$

The efficient value of voltage U_μ directly influences the value of the magnetic induction B_m in the core. The efficient value is a basic denominative parameter, which establishes the working conditions of core. Current transformers with different constructions can assign defined courses to magnetic induction B_m in the function of the circular frequency ω. Accepting the assumption that the transformer load is resistant R_B, then the following examples of magnetic induction $B_m = f(\omega)$ can be assigned:

for current transformers with very small dispersion ($L_2 \approx 0$)

$$B_m = a\frac{I_2}{\omega}\cdot\left(R_2 + R_B\right), \tag{2}$$

for current transformers with average dispersion (L'_2)

$$B_m = a\frac{I_2}{\omega}\cdot\left|\left(R_2 + R_B\right) + jL'_2\right|, \tag{3}$$

for current transformers with large dispersion (L''_2)

$$B_m = aI_2L''_2, \tag{4}$$

where a - construction factor.

On the basis of equations (2), (3), (4) magnetic induction $B_m = f(\omega)$ at I_2=const. can be set up in the form of graphs, as shown in Fig.1. These courses are closely connected with the construction of a given transformer. One can ascertain that the defined variability of the magnetic induction B_m in a pulsation function, on which depend active losses and passive power, has a direct influence on the core temperature and transformer errors. In such a case the character of changes $B_m = f(\omega)$ is the basic decisive criterion determining the possibility of the use of a given solution for a current transformer in circuits with a defined elevated frequency.

The current transformers' work with very small, average and large dispersions at a frequency range of up to 20 kHz

The magnetic induction in a transformer's core with very small dispersion is inversely proportionate to the frequency (equation 2), meaning that with the growth of

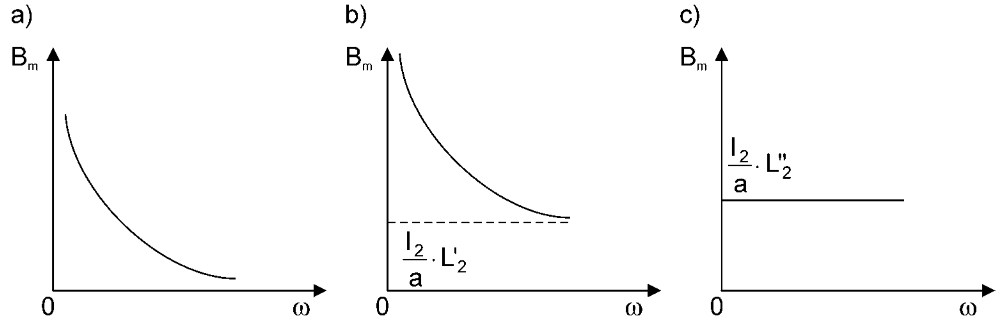

Fig. 1. Dependencies of the magnetic induction B_m from pulsating frequency ω at a constant value of current I_2 for transformers: a) with very small dispersion, b) with average dispersion, c) with large dispersion

the frequency the induction decreases hyperbolically close to a value of zero (Fig. 1a). Active losses ΔP_{Fe} in the core of such a transformer change imperceptibly in the frequency function and are decrescent to a certain amount of it value. At this time dispersions begin to appear. Current transformers with a very small dispersion can be used in a broadband frequency.

In current transformers with average dispersion, during frequency growth, one ought to examine magnetic induction as two independent elements of the equation (3).

The first element of this equation contains component (ω^{-1}) and gives a hyperbolic analogous course, as is seen in Fig. 1a. The second element in the third equation (jL_2‘) gives the magnetic induction a constant value. The magnetic induction in this instance is thereby hyperbolically decrescent and aims for a certain, settled value, which is dependent on the dispersion value of the secondary winding. In this instance, active losses $\Delta P_{Fe,}$ found in the core, are forced by the constant value of the magnetic induction. By certain defined and elevated frequencies these losses can be considerable. Current transformers with average dispersion can be used in systems with an elevated frequency, but the range of their usage is limited.

In current transformers with large dispersion, the magnetic induction has a constant value, independent of changes in the frequency (equation 4). In this instance, with frequency growth, active losses $\Delta P_{Fe,}$ increase sharply. The increase causes the core's temperature to rise. Current transformers with large dispersion are not practical in circuits of a higher frequency.

These transformers constructions are of use at frequencies 50-60 Hz.

Exposures of current transformers in the electrical power engineering system

Current transformers in an energy-circuit-system, except for the determined ratings, are subject to over-currents or short-circuits in the system. At this there occurs a sharp increase of the primary I_1 and secondary $I_{2\ c}$ current. In compliance with equations (2), (3), (4), magnetic induction B_m - found in the current transformer's core- multiplies in proportion to the growth of the secondary current.

The multiplication of the magnetic induction may be the cause of the core's sudden warming of even up to several hundred degree centigrade, and the thermal destruction of the current transformer's core. The increase of active losses in the core dependent on the magnetic induction and the frequency is given in Table 1.

On the basis of active losses (Table 1), with certain approximation and without considering the draining of the heat, one can qualify the increase in the temperature $\Delta\theta$ in the core.

From calculations, the results, with correct conditions, when magnetic induction is B_m=1,5T and the frequency is f=20kHz, are that core's temperature increases to amount $\Delta\theta = 416$ °C after a time of 10 seconds. During a longer working period the increase of the core's temperature is considerably greater and will cause the transformer's thermal destruction from the side of the core.

Table 1. Active losses ΔP_{Fe}[W/kg] , in the core, from a 0,27mm cold rolled tape in a current transformer with a frequency range between 50Hz and 20kHz, at the change of magnetic induction B_m= (0,1 ÷ 1,5)T

f	50 Hz	500 Hz	5000 Hz	10000 Hz	20000 Hz
			ΔP_{Fe} [W/kg]		
B_m=0,1T	0,005	0,2	0,5	30	90
B_m=1T	0,37	14	520	1650	4800
B_m=1,5T	0,85	35	1900	6000	20000

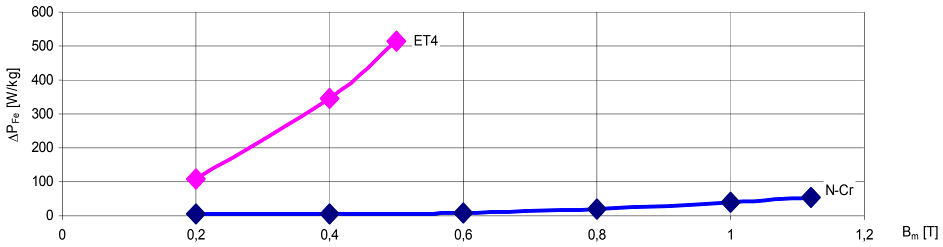

Fig. 2. Characterizations of active losses ΔP_{Fe} in magnetic materials at the frequency f=20 kHz in the function of the magnetic induction B_m, **ET4 -** the magnetic, informed, cold rolled tape Fe3Si, **N-Cr -** the nanocrystalline tape

Table 2. Transformers with very small dispersion ($I_1 = I_{1n}$)

f [Hz]	X_{L2} [Ω]	Z_2 [Ω]	e [V]	B_m [T]	ΔP_w [W/kg]	$\Delta\theta$ [°C] in t=100sek
50	0,025	85	42,5	0,6375	0,14	0,003 ÷ 0,02
1000	0,5	85	42,5	0,0318	0,072	
5000	2,5	85,03	42,51	0,006376	0,05	
10000	5	85,14	42,57	0,003192	0,0407	
20000	10	85,58	42,79	0,001604	0,024	
50000	25	88,6	44,3	0,000664	0,0179	
100000	50	98,61	49,3	0,000369	0,02	
300000	150	84,2	86,2	0,000215	0,17	

Too much heat emitted in the core and in the secondary winding makes for worse working conditions and transient states of over-currents or short-circuits can lead to the thermal transformer's destruction To bring about diminution of the thermal effect in the core in such transformers' constructions, magnetic cores, characterized with low losses and conditioned at an elevated frequency, are used. Amorphous and nanocrystalline magnetic alloys are such materials.

Fig. 2 shows losses in a core executed from an informed cold rolled tape with the thickness of 0,27 mm and in a nanocrystalline core in a function of magnetic induction.

The work of current transformers with very small dispersion at frequency changes of up to 300 kHz

In an area of large frequencies above 100 kHz, conventional transformers require special construction handling, because the change of the magnetic induction at the growth of the frequency can not assure the correct operation of the transformer.

Table 2 introduces a change of the reactance value of dispersion X2 and the impedance Z2 of the current transformer's secondary winding with a very small dispersion at a change of frequency in a range from 50 Hz to 300 kHz. A large variability of the induction results from this table and is also connected with these losses in the core at increase of frequency. The decrease of losses in the core causes a decrease of the transformer's errors. This property is the most important feature of this current transformer.

Conclusion

The value of the magnetic induction B_m in the core decides about the possibility of the conventional current transformer's suitability to work in a range of elevated frequencies. Depending on its growth in the range of elevated frequency changes or over-current and short-circuit conditions, losses grow in the core, which can cause the hyperthermia of the core and the transformer's destruction.

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R. Rajchert, R. Nowicz. Naujos kartos induktyviosios srovės transformatoriai, skirti darbui iki 300 kHz dažniu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr. 8(64). – P. 14–17.

Nagrinėjami reiškiniai, atsirandantys ypatingos konstrukcijos elektromagnetiniuose srovės transformatoriuose, veikiančiuose esant vidutiniams dažniams. Šiems transformatoriams būdinga atitinkama apvijų konstrukcija ir specialios magnetinės medžiagos (amorfinės ir nanokristalinės magnetinės juostos). Transformatoriaus konstrukcijos kriterijumi buvo pasirinktas magnetinio ryšio, atsirandančio tarp pirminės ir antrinės apvijų, laipsnis. Srovės transformatorius galima skirstyti į tris grupes: 1) mažos sklaidos transformatoriai (t.y. su labai geru magnetiniu ryšiu tarp apvijų); 2) vidutinės sklaidos transformatoriai; 3) didelės sklaidos transformatoriai.

Įvairių konstrukcijų srovės transformatoriams galima priskirti magnetinės indukcijos priklausomybes B_m pulsacijos funkcijoje ω. Šios kreivės glaudžiai susijusios su transformatoriaus konstrukcija. Taigi reikia pasakyti, kad tam tikros magnetinės indukcijos B_m pulsacijos funkcijoje, nuo kurios priklauso aktyvieji nuostoliai ir reaktyvioji magnetinio laidininko galia, tiesiogiai veikia šerdies temperatūrą ir transformatoriaus srovės paklaidas. Dėl to pokyčiai $B_m=f(\omega)$ yra pagrindinis kriterijus, lemiantis srovės transformatoriaus taikymą tam tikro padidinto dažnio grandinėse. Galimybė taikyti konvencinį srovės transformatorių darbui didelio dažnio srityje taip pat sąlygojama nominalios magnetinės indukcijos B_m magnetiniame laidininke vertės. Il. 2, bibl. 4 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

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Phenomena occurring in electromagnetic current transformers operating in the areas of medium frequencies have been discussed, above all, with respect to the properties of particular constructional solutions. These constructions are characterized by appropriate solutions to windings and special magnetic materials (amorphous and nanocrystalline tapes). The degree of magnetic coupling that occurs between the primary winding and the secondary winding with a definite geometry of the magnetic core was assumed to be the criterion of a solution of the current transformer. Current transformers should be divided into three basic groups: 1) transformers with very small dispersion (i.e. of very good magnetic coupling between the windings); 2) transformers with medium dispersion; 3) transformers with very large dispersion.

Current transformers can be assigned specified courses of the magnetic induction B_m as a function of pulsation ω. These courses are closely related to the construction of a given transformer. Thus, it can be stated that the specified variability of the magnetic induction B_m as a pulsation function which affects active losses and passive power has a direct effect on the core temperature and the transformer errors. Hence, the character of changes in $B_m=f(\omega)$ is the basic criterion determining the possibility of use of a given solution of the transformer in circuits of a specified elevated frequency. The possibility of application of a conventional current transformer to operate over the range of an elevated frequency is also determined by the value of the rated magnetic induction B_m in the magnetic core. Ill. 2, bibl. 4 (in English; summaries in Lithuanian, English and Russian).

Р. Райхерт, Р. Нович. Новые индукционные трансформаторы тока, предусмотренные для работы с частотами до 300 кгц // Электроника и электротехника. – Каунас: Технология, 2005. – № 8(64). – С. 14–17.

Предусмотрены явления, выступающие в электромагнитных трансформаторах тока особой конструкции, работающих в области средних частот. Эти конструкции характеризуются соответствующим решением обмоток и специальными магнитными материалами (аморфные и нанокристаллические магнитные ленты). В качестве решения конструкционного критерия трансформатора тока была принята степень магнитной связи, выступающая между первичной и вторичной обмотками. Трансформаторы тока можно разделить в основном на три группы: 1) трансформаторы с маленьким рассеянием (т.е. с очень хорошей магнитной связью между обмотками); 2) трансформаторы со средним рассеянием; 3) трансформаторы с большим рассеянием.

Трансформаторам тока разных конструкций можно причислить определенные зависимости магнитной индукции B_m в функции пульсации ω. Эти кривые тесно связаны с конструкцией данного трансформатора. Итак, надо сказать, что определенная изменяемость магнитной индукции B_m в функции пульсации, от которой зависят активные потери и реактивная мощность магнитопровода оказывают непосредственное влияние на температуру сердечника и погрешности трансформатора тока. В связи с этим характер изменений $B_m= f(\omega)$ является основным критерием, решающим о возможности применения данного решения трансформатора тока в цепях с определенной повышенной частотой. Возможность предназначения конвенционного трансформатора тока для работы в области повышенных частот определяется также значением номинальной магнитной индукции B_m в магнитопроводе. Ил. 2, библ. 4 (на английском языке; рефераты на литовском, английском и русском яз.).

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