HIGHER ACCURACY CLASS CURRENT TRANSFORMER USING NANO CRYSTALLINE CORE FOR MEASUREMENT

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Abstract- In this paper some considerations about the application of nanocrystalline alloys in toroidal cores for current transformers used for measurement purposes are presented. Based on the electromagnetic properties of these materials, such as high relative magnetic permeability, magnetic flux density saturation, high resistivity and low hysteresis losses are discussed. Also, will be discussed how the former characteristics affect the current transformer performance. From experimental results, it can be concluded that the use of nanocrystalline alloys in the current transformer cores can contribute to the reduction of phase errors, improving thus the accuracy class.

Keywords- Nanocrystalline Alloys; Toroidal Cores; Current Transformer

I. INTRODUCTION

Current transformer (CT) is a transformer specially designed and assembled to be used in measurement, control, and protection circuits. In CT cores grain oriented (GO) silicon-iron, permalloy alloys, amorphous or nanocrystalline alloys, can be employed wrapped in a toroidal shape. The interest in CT nanocrystalline alloys cores is based on its high relative magnetic permeability, low coercive force, combined with a high magnetic flux density [1]-[3]. The reduction of the grain to the nanometer scale is the key to attain the characteristics of magnetically soft nanocrystalline alloys [4]. In terms of electrical circuit, the primary winding of the CT is composed by only few turns, with diameter compatible with the current one wants to evaluate, while its secondary winding has a high number of turns and smaller diameter. Generally, these windings are made of copper wires. In relation to the magnetic circuit, the toroidal shape is particularly recommended because with this geometry the magnetic flux will propagate in a high permeability direction, without the presence of transversal air gaps. The core magnetic material characteristics is of great importance, because for higher permeability and lower coercive force, lower excitation current is required to establish the magnetic flux density for the proper functioning of the TC within the accuracy class limits The CT measurements quality is directly related to the equipment accuracy class, they must operate with low error ratio and low phase errors.

The accuracy class depends on the quality of the electrical circuit (low leakage inductance) and the quality of magnetic material (high permeability and low losses) that forms the core of the CT. The ideal soft magnetic alloy should have low losses (= high efficiency and no cooling requirements), a high flux density (= small, light and cheap), a high permeability when needed (= low numbers of turns, less copper, lower stray inductivity), a wide temperature range and low temperature coefficients of properties (= no safety margins necessary) as well as robustness against mechanical forces, radiation, corrosion and whatever could harm the device. To the strong relief of all material engineers, Mother Nature simply does not provide such a universal alloy. Materials with high flux densities like SiFe or CoFe have typically relatively high magneti-zation losses and vice versa, materials with high permeabilities are typically more sensitive to-wards mechanical stress (due to a property called “magnetostriction”), and if they have high permeabilities and are less sensitive against mechanical stress, then the shape is limited to toroidal or C-cores.The CT measurements quality is directly related to the equipment accuracy class, they must operate with low error ratio and low phase errors. The accuracy class depends on the quality of the electrical circuit (low leakage inductance) and the quality of magnetic material (high permeability and low losses) that forms the core of the CT. These studies aim to examine the influence of magnetic core material on the CT accuracy class, particularly in relation to the angle phase error.

II. LITERATURE REVIEW

In this some considerations about the application of nanocrystalline alloys in toroidal cores for current transformers used for measurement purposes are presented. Based on the electromagnetic properties of these materials, such as high relative magnetic permeability, magnetic flux density saturation, high resistivity and low hysteresis losses are discussed. Also, will be discussed how the former characteristics affect the current transformer performance. From experimental results, it can be concluded that the use of nanocrystalline alloys in the current transformer cores can contribute to the reduction of phase errors, improving thus the accuracy class. Iron-Based nanocrystalline materials have enjoyed increased acceptance in modern electronic designs only in the past few years. Nanocrystalline materials have a proven record of high performance, there has been improved reliability in the manufacturing process and this material is now available from multiple sources. Nanocrystalline soft magnetic materials are now superior to permalloys, ferrites and even amorphous cobalt based alloys in a growing range of applications. since the exciting current of current transformers alters the ratio and phase angle of primary and secondary currents, it is made as small as possible though the use of high permeability and low loss magnetic material in the construction of the core. in comparison with others soft magnetic materials, nanocrystalline alloys appear as the best material to be used in toroidal core for current transformers.

III. PROBLEM DEFINITION

Current transformers are characterized by some relationships. The first is the marked ratio of the primary current to the secondary current ($Kc = Ipn / Isn$), and it is indicated by the manufacturer. This ratio is a fixed value for a given current transformer. The second is the true ratio of the rms primary current to the rms secondary current ($Kr = Ip / Is$) under specified conditions. The true ratio of a current transformer is not a single fixed value, since it depends on the specified conditions of use, such as secondary burden (Zc), primary current (Ip), frequency (f), and wave form. The third is the ratio correction factor (RCF). It is the factor by which the marked ratio must be multiplied to obtain the true ratio ($RCF = Kr / Kc$). The CT errors exist due to the exciting current Ie at the magnetizing branch Zm. The primary impedance does not affect the CT errors and it is represented by a low-impedance in series with the system circuit where the CT is installed, which value can be neglected. After these considerations, the CT electrical model can be represented in Fig. 1, where Zs is the secondary impedance.

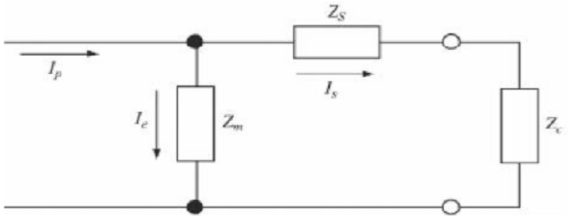

Fig. 1 – Equivalent Electric Circuit of a Current Transformer

In conventional transformers, the exciting current is considered constant, and its absolute value and phase can be determined by open-circuit test. However, this is not true in CT. In a current transformer the exciting current is not constant, neither in its absolute value nor in its phase, due to the great influence of the non-linearity of the magnetic material of which its core is made. Due to the relationship between the primary and the exciting currents, the smaller the value of the first one, the greater the influence of the second, which increases the ratio and phase angle errors of the CT. That is why, when determining the accuracy class of a CT, the technical norms allow the CT to present bigger errors when tested with 10% of the primary nominal current than when it is tested with its exact value.

IV. METHODOLOGY

Resin Cast CTs –PTs: CT-PT design manual defines the procedure and guidelines to be followed while Designing & manufacturing the Resin cast CTs-PTs up to 36kVsystem voltage. Current Transformers (CTs) : Depending on many factors related with application, CTs are manufactured of many varities.In this manual our discussion will be limited to only Resin Cast CTs up to 36kV system voltage. Tape wound CTs and CTs for condenser bushings will also be covered. Before starting the design of CTs following information should be available as the same is application specific and requires input from customer end:

1. Type of construction ie wound primary or window type.
2. System voltage.
3. Short time current & duration.
4. Ratio and no of cores.
5. Specification of each cores as defined in standard.
6. Conformance to standard.

1. **Short time current & duration:**

Raychem & Siemens CTs of various designs have been tested for short time current ratings. This is a binding parameter as it demonstrates the capability of a particular type of CT/mould size to withstand dynamic & thermal stresses arising out of short time current & duration. The product of short time current squared (in kA^2) and duration popularly pronounced I^2t (kA^2x sec) defines the thermal limit of the design.

2. **Ratio & No of Cores :**

Ratio and no of cores are application specific and is given by the Electrical system designer. Ratio of CT is defined as ratio of currents/turns required on primary or secondary side. The primary side is generally considered the electrical power system side on which current measurements are made. The primary current may have multiple currents i.e. 200/1A is defined as single ratio while 400-200/1A is defined as CT with multiple primary current. The multiple CT ratio can be achieved by means of providing taps on secondary corresponding to ratio 200/1A.

3. **Specification of each core as defined in Standards:**

Cores are classified as metering, protection and special purpose. (PS or X) Metering core is defined by Burden in VA, class of accuracy and Instrument security factor (ISF). The standard value of burden could be 5,10,15,20,25 & 30 VA. Burden represents the load on secondary winding of CT and is sum of lead resistance, impedance of instrument coil etc. The class of accuracy could be 0.1,0.2,0.2S,0.5,0.5S,1,3 & 5.

The limits of ratio and phase angle errors are already defined in the standard. The errors are checked at rated and 25% of rated burden at 120%,100%,20% & 5% of primary current for accuracy class up to 1.0. The errors are checked at rated burden at 50% and 100% of primary current. ISF if given can have value less than 5 or 10. Protection core is defined by burden , class of accuracy 5P, 10P and Accuracy Limit Factor(ALF) ranging from 5 to 30 in steps of 5 i.e. 5,10,15.20,25 or 30.Nanocrystalline cores are available in standard sizes ranging from 6 mm to more than 250 mm, and are offered either in plastic protection boxes or with epoxy coating. They are also offered with different permeability levels that are already tailored and optimized for various previously mentioned applications. Although they may appear like a specialty to some magnetic designers, but mass applications like GFCI's and electronic energy meters have proven their competitive-ness thanks to their superior magnetic properties. Nanocrystalline cores simply increase the op-tions for design engineers, they can solve problems which otherwise could be real problems and,when properly used, they are commercially competitive, either directly or indirectly creating function related cost saving options. The reason for the better performance of CT based on nanocrystalline toroidal core alloy in terms of phase angle, is due to the magnetic permeability of nanocrystalline alloy that is higher than the permeability of the magnetic alloy Fe-3 2% Si GO, resulting in lower values of the magnetizing current components and the core loss.

V. RESULTS

Aiming to investigate the behavior of CT with different magnetic materials used in the core, experimental tests were performed at the Testing department of the Automatic Electrical Limited, Ambarnath- Thane. The results of comparative tests to determine the ratio errors and the phase angle errors are presented in Table I & II. In Fig. 4 is shown a photograph of the experimental setup.

Table I: Ratio Error & phase error of CRGO CT

	Accuracy Class	VA	PF	Pri Current %	Ratio Error %	Phase Error Mins
CRGO	0.5	30	0.8	120	0.169	+2.5
		30	0.8	100	0.15	+2.7
		30	0.8	20	-0.076	+6.4
		30	0.8	5	-0.431	+13.6

Table II. Ratio error & phase error of nanocrystalline CT.

	Accuracy Class	VA	PF	Pri Current %	Ratio Error %	Phase Error Mins
Nano Crystalline Alloy	0.2S	15	0.8	120	+0.095	+0.1
		15	0.8	100	+0.086	-0.1
		15	0.8	20	+0.013	+3.1
		15	0.8	5	-0.001	+4.3
		15	0.8	1	-0.058	+3.1

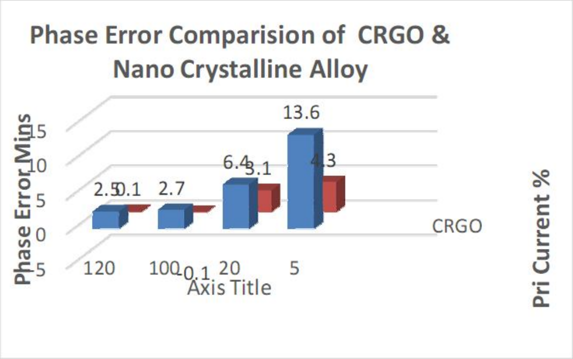

Fig 2. Phase Error comparision of CRGO &Nanocrystalline CT.

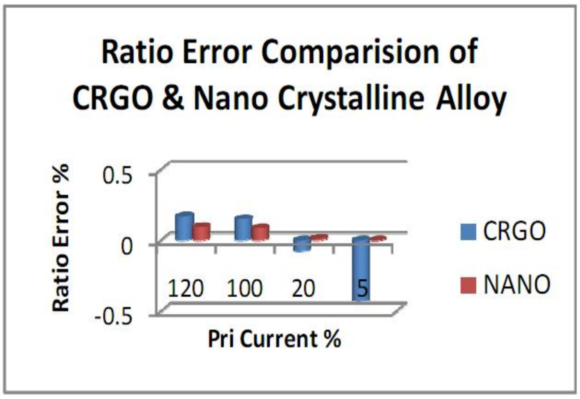

Fig.3 Ratio Error comparision of CRGO & Nano Crysdtalline CT.

Fig.4 Photograph of experimental set up

As presented in Table II, the angle ratio and phase angle errors are smaller for the nanocrystalline alloy

CT core. This difference is more evident for the tests of 10% of rated current (*In*), and this difference is explained by the greater magnetic permeability of nanocrystalline alloys, that reduces the magnetizing current. Thus, the phase angle error, , is reduced. An additional note is worth mentioning: as the primary and secondary windings of the CT were handmade, even if this implementation is done carefully, the coils are not regularly spaced around the core and the presence of flux leakage will contribute to the increase of the CT error ratio. To reduce this effect, the core windings must be made by specialized machines, like those used in instrument transformers manufactory.

CONCLUSION

Nanocrystalline cores are available in standard sizes ranging from 6 mm to more than 250 mm, and are offered either in plastic protection boxes or with epoxy coating. They are also offered with different permeability levels that are already tailored and optimized for various previously mentioned applications.

Although they may appear like a specialty to some magnetic designers, but mass applications like GFCI's and electronic energy meters have proven their competitive-ness thanks to their superior magnetic properties. Nanocrystalline cores simply increase the op-tions for design engineers, they can solve problems which otherwise could be real problems and, when properly used, they are commercially competitive, either directly or indirectly creating function related cost saving options. The reason for the better performance of CT based on nanocrystalline toroidal core alloy in terms of phase angle, is due to the magnetic permeability of nanocrystalline alloy that is higher than the permeability of the magnetic alloy Fe-3 2% Si GO, resulting in lower values of the magnetizing current components and the core loss.

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