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USING NANOCRYSTALLINE MATERIAL IN TOROIDAL CORES FOR CURRENT TRANSFORMERS ANALYTICAL STUDIES, COMPUTATIONAL SIMULATIONS AND AGEING TESTS

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Abstract: Within the last years, by means of new developments and rapid increase in material researches, nanocrystalline material instead of conventional nickel-iron material has been started to use in measurement type current transformers. Through proper modifications, revolutionary contributions can be made to better current transformers with nano material. Based on electrical and magnetic properties, in this work, some considerations about the possibilities of applications of nanocrystalline alloys in toroidal cores for current transformers are presented. It is discussed how the magnetic characteristics of the core material affect the performance of the current transformer. Also in this paper, magnetic field distributions of the current transformers, some diagrams of ratio error and phase displacement and a study about ageing of nanocrystalline material have been presented.

1 INTRODUCTION OF CURRENT TRANSFORMERS

Current transformer (CT) is an instrument transformer specially designed and assembled to be used in measurement, control, and protective circuits. Its primary circuit consists of a few turns – sometimes even a single turn – and is connected in series with the circuit whose current is desired to be measured, and the secondary circuit is connected to the current-measuring instruments.

The theory about CT is basically the same of any other iron-core transformer. The secondary circuit is closed through the typical low impedance of the instruments connected to it. In the ideal CT, the secondary current is inversely proportional to the ratio of turns and appositive in phase to the impressed primary current.

Current transformers can be used to supply information for measuring power flows and the electrical inputs for the operation of protective relays associated with the transmission and distribution circuits or for power transformers. These current transformers have the primary winding connected in series with the conductor carrying the current to be measured or controlled. The secondary winding is thus insulated from the high voltage and can then be connected to low-voltage metering circuits.

Since the exciting current alters the ratio and phase angle of the primary and secondary currents, it is made as small as possible through the use of high permeability and low loss magnetic materials in the construction of the core, such as silicon steel and amorphous alloys. In many industrial applications, designers need to select the magnetic core material and its shape. In this work, it is presented a study about the possibilities of application of nanocrystalline alloys in toroidal cores for current transformers.

2 NANOCRYSTALLINE TECHNOLOGY

For HV Systems, High Voltage Current Transformers are the key equipment's for protection as well as metering. In the past; i.e. from 1930 to 2000, Nickel alloys were being used to produce the core of high accuracy current transformers. In the recent years, new alloys and methods have evolved, like nanocrystalline, for the production of HV CT's.

Some technical advantages for the user are;

* Lower magnetic losses than nickel alloys
* Higher permeability than nickel alloys
* Lower coercive fields than nickel alloys
* Smaller sizes and lower weight than nickel alloys
* Better stability at wide range of temperature than nickel alloys

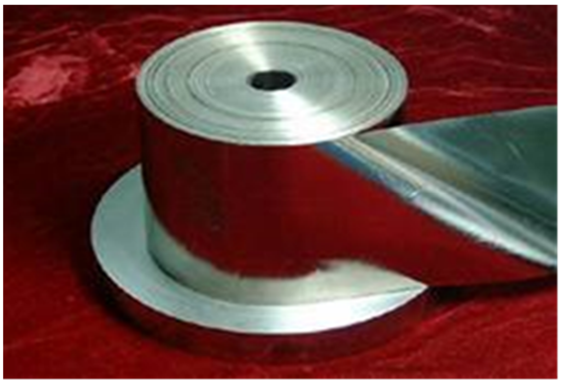

Figure 1: Basic structure of nanocrystalline

Nanocrystalline ribbons are superior at wide range of permeability properties compared to nickel alloys. Nanocrsytalline cores are mainly used in the production of current transformer cores with the accuracy class 0,2 ; 0,2 s ; 0,1 ; 0,5 ; 0,5s. Moreover, it can be used in bushing type current transformers, Gas Insulated or Oil-Immersed Switchgears, LV, MV and HV Switchgears.

Density of nanocrystalline ribbon is 7,25 g/cm³ which is 20% lower than the nickel alloy , therefore, the final product has 20% lower cost than the same product produced with the nickel alloy core. In addition, stacking factor in nanocrystalline ribbon is 0,72 which is lower than the nickel alloy cores allowing for reducing the weight by 10% which results further cost saving.

Thanks to its wide range of permeability properties and superior magnetic values, the core dimensions can be reduced up to 30% on some projects. Having a high saturation induction of 1.25 T, it can be used in a wide range of transformer accuracy class and also can replace the mix-cores in some applications. Finally, it has a high operation temperature of 150℃ which is much stable on high temperatures and providing low core losses.

3 ANALYTIC STUDY AND A SAMPLE PROJECT COMPARISON OF NANOCRYSTALLINE AND NICKEL ALLOYS CORES

Nanocrystalline cores are superior at wide range of permeability properties compared to nickel alloys cores. Nanocrystalline cores are also very promising for use in instrument current transformers. Relative current ratio error of the transformer with core from nanocrystalline is very small and phase error is almost constant even for low values of primary current. This is due to the material small loss angle and constant permeability over wide field amplitude range (Table-1). Another advantage of this core is its larger situation induction than commonly used nickel alloys, which allows significant reduction of the core dimension.

Table 1: Basic value comparison with nanocrystalline and the other materials

Parameter	Nanocrystalline	Nickel alloy	CRGO
Saturate Induction (T)	1.25	0.80	2.03
Initial Permability	40.000-80.000	> 75.000	1.000
Max. Permability	> 250.000	> 175.000	> 40.000
Density (g/cm³)	7.2	8.7	7.65
Curie Temp. ºC	570	410	740
Thickness (mm)	0.025-0.035	0.2	0.3
Stacking Factor	> 0.72	0.93	0.95

3.1 A Project Sample for 300/1A CL0, 2S Fs10 25VA 1,20xIn 50Hz

Based on magnetic characterization and the computational tables such as magnetization and permeability results shows that nanocrystalline material is more useful for this type of CT's. From the test results, using the nanocrystalline , it has been verified that, the nanocrystalline material properties reinforce the hypothesis that the use of this material in measurement CT cores can reduce the ratio and phase error (Table-2), less core weight (less than min.%30) and can also improve its accuracy class.

Also in this project, nickel-alloy core weight is 38,3kg and nanocrystalline core weight is 13,3kg therefore difference is approx. %65. This difference variated between %30 and %70 according to CT characteristic. Copper weight is 0,9kg for Nickel-alloy core design, 0,63kg for nanocrystalline core design therefore difference is approx. %30. This difference variated between %15 and %40 according to CT characteristic.

Table 2: Computation and test results (ratio-phase error) of nanocrystalline and nickel-alloy project

	Ip / Ipn	1%	5%	20%	100%	120%
NICKEL Comp.	RE (%)	-0.08	-0.07	-0.05	-0.009	-0.008
	PE (min.)	5.20	4.81	3.09	1.03	0.48
NICKEL Test Results	RE (%)	-0.09	-0.09	-0.07	-0.01	-0.01
	PE (min.)	7.3	6.47	5.31	1.45	1.19
NANO Comp.	RE (%)	-0.11	-0.10	-0.09	-0.01	0.002
	PE (min.)	15.12	14.09	8.86	1.37	0.75
NANO Test Results	RE (%)	-0.10	-0.09	-0.08	0.001	0.025
	PE (min.)	12.26	11.85	7.86	1.33	1.03

Table 3: Computation and test results (Security Factor) of Nanocrystalline and Nickel-alloy project

	Guaranteed Value (Fs)	< 10
NICKEL Computation	Security Factor (Fs)	9.33
NICKEL Test Results	Security Factor (Fs)	9.06
NANO Computation	Security Factor (Fs)	6.15
NANO Test Results	Security Factor (Fs)	7.40

Nanocrystalline cores are used in the production of measuring type current transformers especially at 0,1 ; 0,2 ; 0,5 ; 0,2S and 0,5S classes. If nanocrystalline cores are used instead of the nickel-alloy cores in the production of same type of current transformer, core dimensions and section will be lower, core weight will be lower due to the high saturation magnetic flux density. Also weight of the wire used will be less due to the smaller core dimensions. Even though nickel-alloy core dimensions are equal to the nanocrystalline core's, the nanocrystalline core weight will be 30% less than the weight of nickel-alloy core as a result of the core density and stacking factor. In some cases, the current transformers can only be designed with nanocrystalline core due to some restrictions which is not possible to design with nickel-alloy cores.

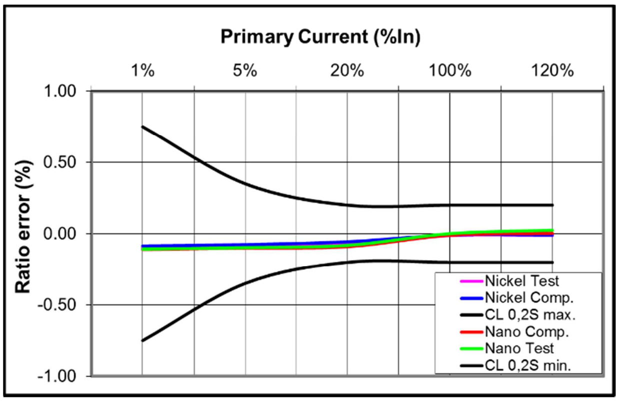

Figure 2: Computation and test results (RE) of Nanocrystalline and Nickel-alloy project

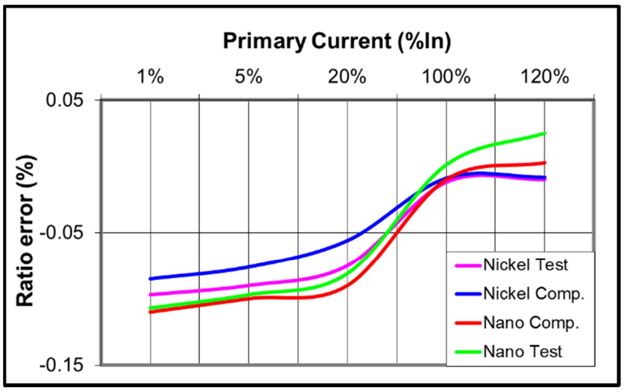

Figure 3: Magnified version of Figure 2

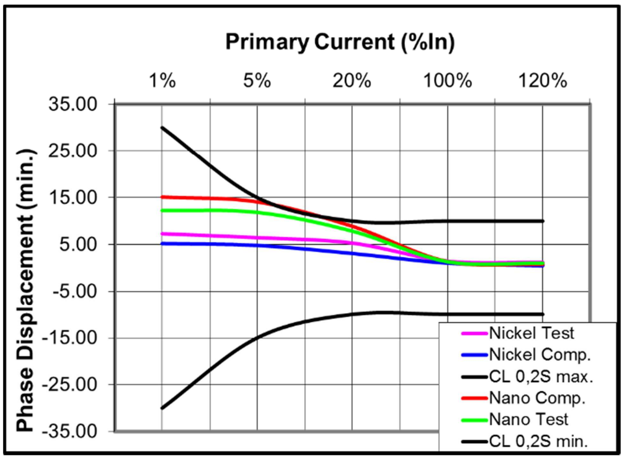

Figure 4: Computation and test results (PE) of Nanocrystalline and Nickel-alloy project

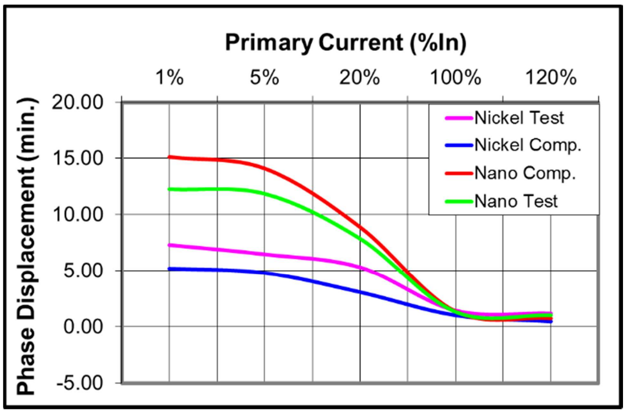

Figure 5: Magnified version of Figure 4

3.2 Ageing Tests

In this study, 3 pcs of Nickel-alloy core and 3 pcs of Nanocrystalline core (equal size) were subjected to ageing test. Ageing test was performed on each cores at ~100℃ for 600 hrs. This test was not carried out in transformer oil. Temperature was controlled daily. B-H properties are measured after doing ageing test. As you can see that, the deviation of B-H curve of Nanocrystalline core is less than Nickel-alloy core between before and after ageing tests.

The deviation of two types of material are shown at Figure 6 and Figure 7.

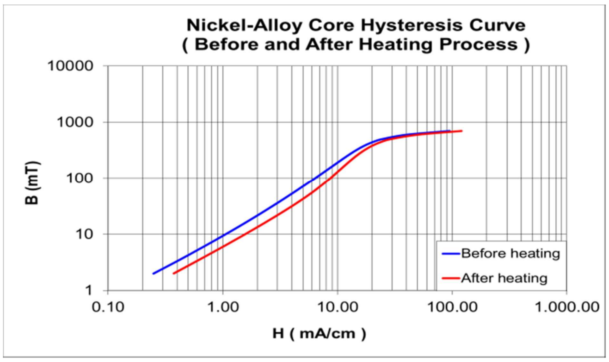

Figure 6: Ageing test results comparison for Nickel-alloy core.

Table 2: Test results of Nano core after ageing test

After Aging Test	Ip / Ipn	1%	5%	20%	100%	120%
NANO Material	RE (%)	-0.05	-0.04	-0.03	0.01	0.033
	PE (min.)	9.71	9.49	7.54	1.91	1.52

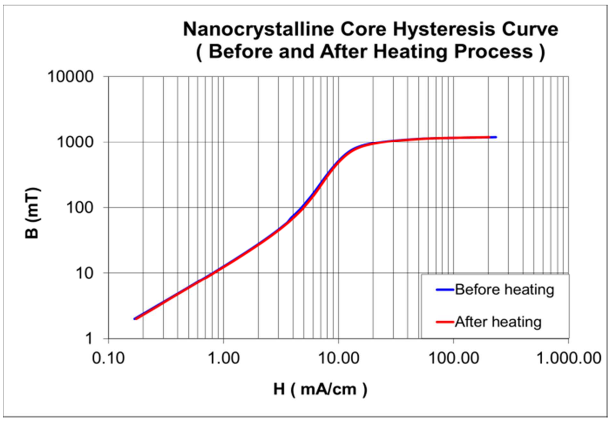

Figure 7: Ageing test results comparison for Nanocrystalline core.

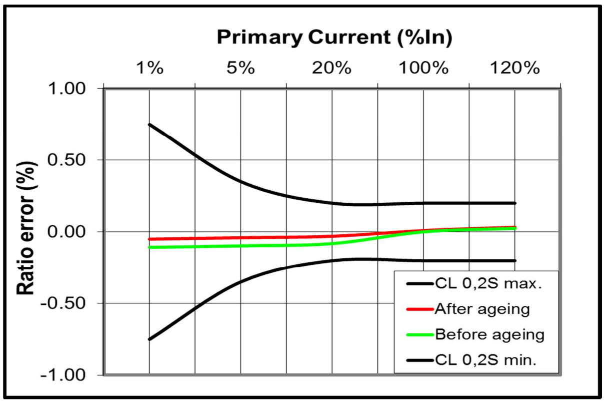

Figure 8: Nanocrystalline – RE test results before and after ageing test

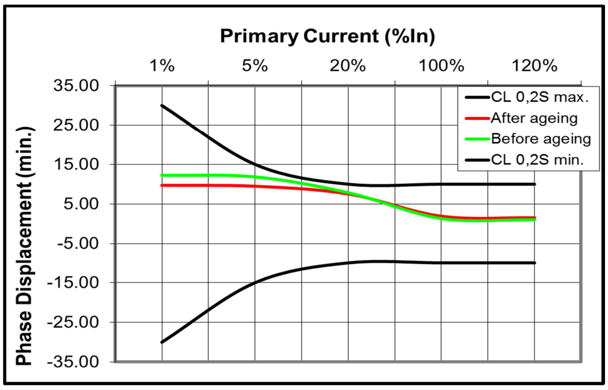

Figure 9: Nanocrystalline – PE test results before and after ageing test

4 CONCLUSION

As can be seen, on all the calculation tables and test results, in case of using a nanocrystalline alloy in current transformer cores instead of nickel alloy core can reduce the core weight (approx. %65), in addition, due to the reduction on core-section verify %30 saving at copper wire. This difference can be changed between %30 and %70 according to technical parameters of CTs.

In addition, accuracy values (ratio error and phase error) of CT's are measured after ageing treatment. As can be seen that on Table 4 and Graph-6&7, these values are within the limits and there is no big deviation between before and after the ageing tests.

This results reinforce the hypothesis that the use of nanocrystalline alloy more useful than nickel alloy.

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