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MAGNETIC PERFORMANCES AND THE TYPES OF CURRENT TRANSFORMERS FOR HV SWITCHING EQUIPMENT IN SMART GRID METERING APPLICATIONS

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Abstract:

Current Transformers (CT) is used for the measurement of current. CT reduces current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instrument. CT also isolates metering-protection circuits from high voltage lines. CT is commonly used in metering and protective relays in the electrical power industry.

Magnetic core is one of the most important part of CT. Core material must be tested before production of the core.

BUSHING TYPE CT's are used in gas insulated systems (GIS), in power transformers and in other switching equipment , which are in center simple insulated bear as primary winding.

Keywords:

Current transformers (CT), CT for gas insulated systems (GIS), Bushing type CT for HV Power transformers, magnetic cores, Single sheet test, Epstein test, Franklin test, online tests for surface condition, metering classes, protection classes, test of CT's.

1. INTRODUCTION

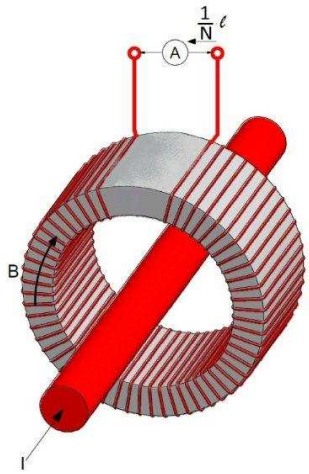
HV CT is used extensively for measuring current and monitoring the operation of the power grid, [1]… [6].

The magnetic circuit of a CT is one of the most important and complicated part. Accuracy classes depend on magnetic core specification. We concentrate in the magnetic circuit and the quality of magnetic materials first. Cold rolled grain oriented (CRGO) silicon steels are the most used materials to produce of magnetic cores. Nickel alloys and nano crystallines are used for high accuracy classes only.

It is very important that the quality test according international standards must be realized before using the core materials, [7], [8]. We give some detail information about testing of CRGO materials.

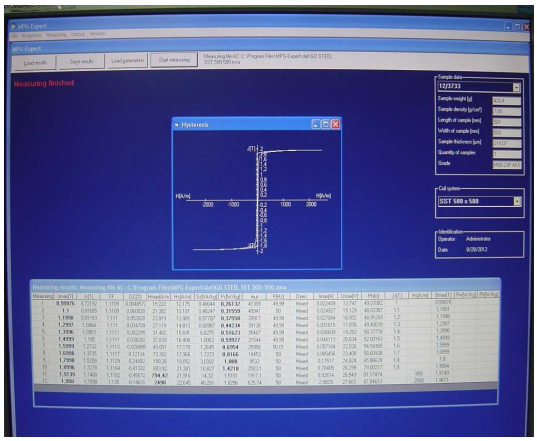
2. QUALITY CONTROL OF CRGO ELECTRICAL STEEL

Let's start to study the quality from CRGO silicon steels which are used to produce magnetic circuit in type of WOUND CORES (TOROIDAL CORES). It will be a risk to produce wound core without performing below tests. [9], [10]



A. Specific total loss (single sheet test) [7],[8]

Specific Total Loss for **Stacked Core application**, shall be controlled by Single Sheet Tester
according to IEC60404-3.

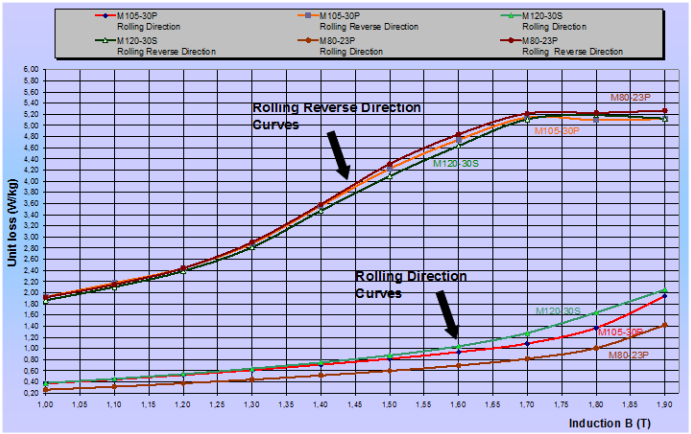


- SST is used for measure magnetic values of all type Grain Oriented and Non- Oriented Electrical Silicon Steel
- Especially, Domain Refined (example: EN 10107 M85-23 Pb) Electrical Steels' magnetic values shall be controlled by SST

- Due to Step-lap Core, Stacked Core and Shunt Reactor Core are used without Stress Relief Annealing, SST must be used to measure Magnetic values of Grain Oriented and Non- Oriented Electrical Silicon Steel

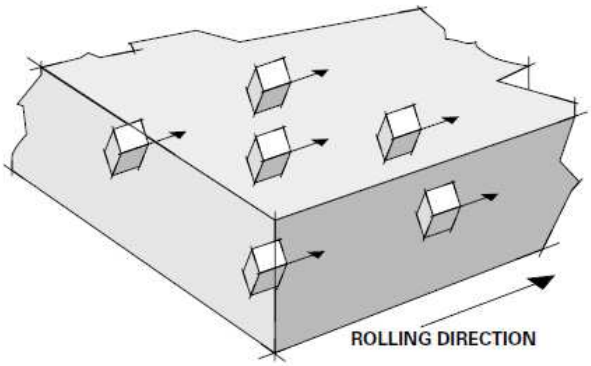
Rolling direction is important to measure magnetic values of Grain Oriented Electrical Steel.

For Grain Oriented Electrical Steel
If the Test Samples are taken Perpendicular Rolling Direction, High Iron Losses are had according to IEC 60404-8-7

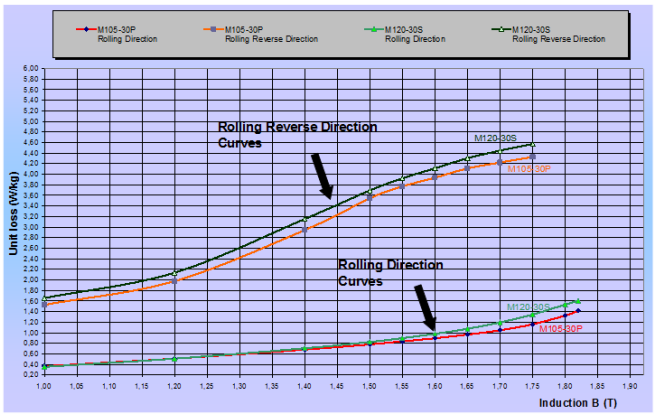


B- Specific total loss (EPSTEIN TEST)

Wound Core application, Grain Oriented Electrical Steel is determined by Epstein Frame according to IEC60404-2 Due to Working at Low Induction which is not determined on IEC 60404-8-7, [7], [8].

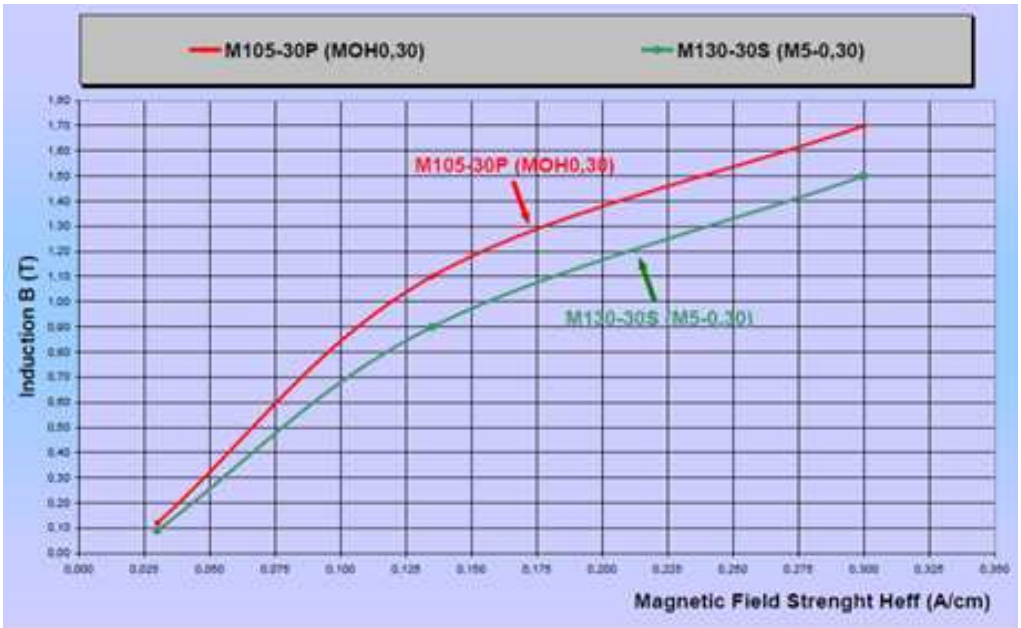


- All the Test strips shall be cut parallel to the direction of Rolling. Before the measurements, the test strips shall be subjected to a stress relief heat treatment.
- For Grain Oriented Electrical Steel, Specific Values such as Bmax (T) – H (A/m) and Iron Loss can be measured correctly if the Samples are taken Rolling Direction.
- Specific Values and Iron Loss cannot be measured correctly if the Samples are taken Perpendicular Rolling Direction.
- Epstein Testing is not applicable to Domain Refined Steel since the domain refinement treatment is eradicated upon annealing at high temperatures.



C-Magnetic Polarization (Epstein Test) IEC 60404-2

Bmax - Heff Curves for Wound Core application



ENPAY Standard Values for Wound Cores

M105-30P(MOH0,30)		M130-30S(M5-0,30)	
Heff(A/cm)	Bmax(T)	Heff(A/cm)	Bmax(T)
0,030	0,120	0,030	0,090
0,135	1,110	0,135	0,900
0,300	1,700	0,300	1,500

The relationship between measurement methods of magnetic losses;

There are two measurement methods to be used in accordance with International Standards to detect the magnetic losses.

1- Single Sheet Test Method IEC60404-3
2- Epstein Frame Test Method IEC60404-2

Measurement of magnetic losses with Single Sheet Test Method provides the results which are closer to the actual values. Precision of this measurement is about +2%.

During Epstein Frame Method, lower values up to about -8% are detected due to the voltage removal annealing process to be made at $800^{\pm 20}$ ℃.

In this case, whereas the value of Magnetic Sheet sets out better values with Epstein measurement method, SST measurement method gives the results closer to the actual values than Epstein. IEC60404-3 Page 21 Annex C indicates the relationship on this issue.

D- Surface Insulation Resistance (Franklin Test), [7],[8]

Surface Insulation Resistance (Franklin Test) are controlled according to IEC60404-11 Mode A

Surface Insulation Resistance Test Report
By Franklin Test Method

Report No:	120616/01
Date :	16.06.2012
Project :	-

Obtain Values of Coils

No	Sample Number	Surface Number	Surface Insulation Resistance [ohm.cm²] 1. Meas.	2. Meas.	3. Meas.	4. Meas.	5. Meas.	Avg.	Avg.
1	Sheet: M0H0,30 Supplier: XXXXXX Pallet No: 12/3477 Coil No: A534593AA	Top	14,38	10,79	20,65	9,54	11,02	12,47	9,56
		Bottom	9,11	12,10	6,44	5,99	6,29	7,56	
2	Sheet: M0H0,30 Supplier: XXXXXX Pallet No: 12/3477 Coil No: AF534593C	Top	13,33	18,06	32246,78	10,46	12,20	17,16	26,06
		Bottom	34,85	25,80	204,84	115,34	41,94	48,81	
3	Sheet: M0H0,30 Supplier: XXXXXX Pallet No: 12/3469 Coil No: AB534225D	Top	13,74	16,21	12,80	10,91	9,70	12,36	9,84
		Bottom	4,73	8,91	7,67	12,94	8,83	8,02	
4	Sheet: M0H0,30 Supplier: XXXXXX Pallet No: 12/3469 Coil No: BA534225F	Top	3221,78	3221,78	641,78	35,87	41,94	96,99	62,08
		Bottom	399,90	33,30	31,34	38,23	46,01	45,21	
5	Sheet: M0H0,30 Supplier: XXXXXX Pallet No: 12/3464 Coil No: CA534104A	Top	24,53	12,78	7,89	15,67	16,89	13,95	9,95
		Bottom	10,35	7,42	6,60	7,26	6,44	7,46	
6	Sheet: M0H0,30 Supplier: XXXXXX Pallet No: 12/3464 Coil No: AB534104B	Top	103,56	3221,78	641,78	355,11	125,78	226,48	60,15
		Bottom	93,62	44,98	99,81	16,25	19,55	33,53	

Incoming Coil	Measured Coil	Product Type
6	6	LAMINASYON

Revision (Explanations):

Surface Insulation Resistance Test By Franklin Test according to IEC 60404-11 Method-A and Alstom Grid DH-4-C-1-100 - Rev02
Test Equipment: Brockhaus Messtechnik -Franklin Sensor: S/N: BM 04 39 01 03686 -Franklin Tester: S/N BM 04 39 02 03679

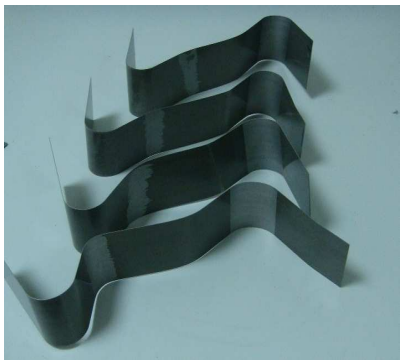
Calibration Date: 01.02.2012
Next Calibration Date: 01.02.2015

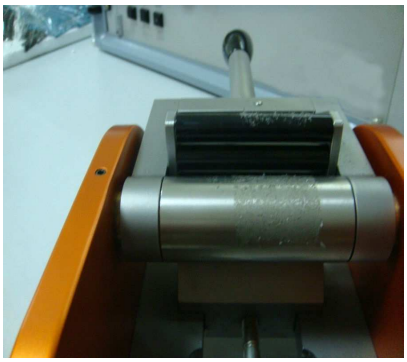
Controlled by O.K

Approved by O.K

E- Adhesion Test

Adhesion Test are controlled according to IEC60404-12





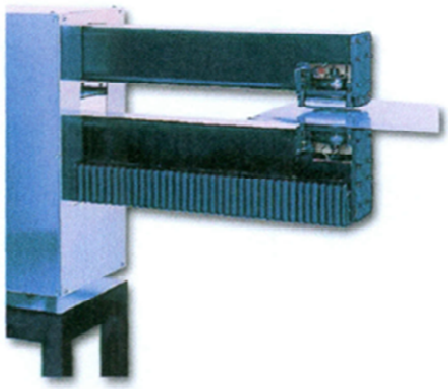
F. Online Continuous Measuring Surface Condition

Surface Condition are controlled according to IEC60404-8-7 / 6.4

G- Online Continuous Thickness Measuring

Material Thickness is measured by online and continuous measuring gauge during the Slitting process.

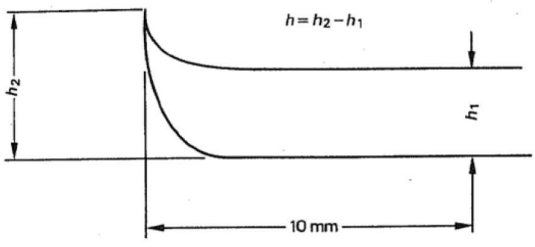
Measuring Capability; Repeatability better 0, 1 % and Resolution 1 µm



H- BURR HEIGHT MEASURING

The measured burr height shall not exceed 0,025 mm according to IEC60404-8-7 and EN10107.

But, the burr height value is applied max. 0.010 mm by ENPAY.



Burr height (h).

Without realization of the tests **A-G** it cannot be quality guaranty.

Because the quality certificate from the mills shows not clear all that points. But CT quality depends on the result of those tests.

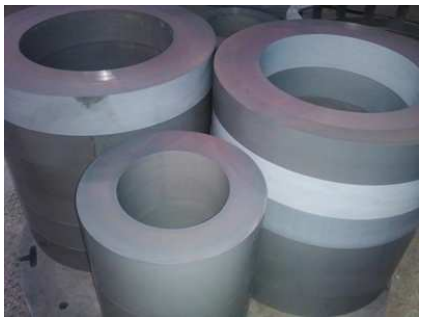
Slitting machine, equipped with:

1. online thickness measuring
2. online grain and tool mark (chip mark) detection

Slitting of the band, step-lap with the cutting-out system of defect parts.

Grain surface, as well as surfaces with thickness difference will be cut.

3. CORE TYPE OF CURRENT TRANSFORMERS

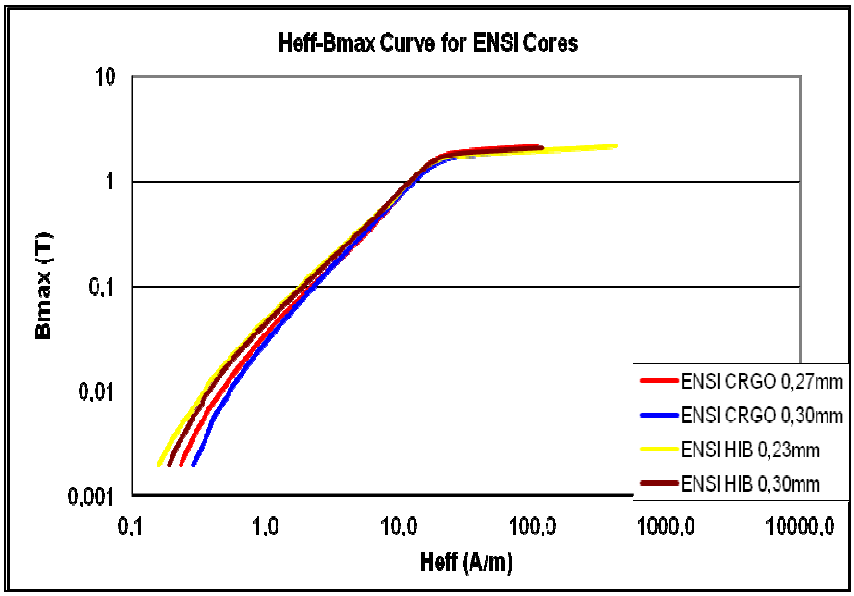


Group of toroidal cores for CT's made from silicone steel(ENSI®)

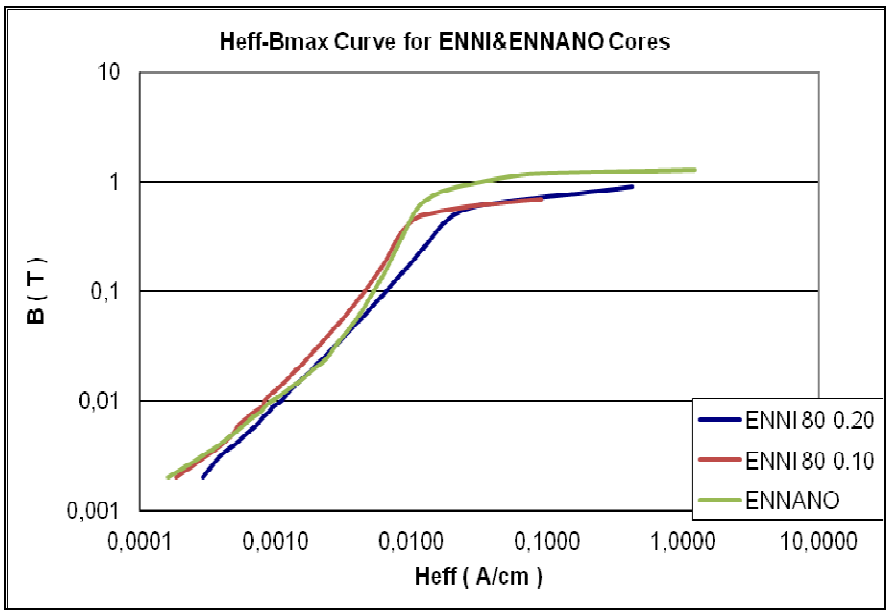
Toroidal linear cores for TPY,TPX,TPZ class CT's made from silicone steel (ENSI®)

Group of toroidal cores for CT's made from Nıckelalloys (ENNI®) and Nanocrystallin (ENNANO®)

ENSI® cores are mostly used at protection type CTs because of it's high saturation. The B-H curve of these has been given below.



In order to obtain high accuracy, ENNI®80 0,20mm and 0,10mm thickness and ENNANO® cores are used at metering type CTs because of high magnetic permeabilities. The B-H curve of these has been given below, [11].



In the last decade, due to developments on magnetic materials, nanocrystalline core is used instead of Nickel alloys at some classes of metering type CTs because of its advantages as higher saturation point, less density and stacking factor, less weight.

4. CURRENT TRANSFORMERS, [13], [14], [15]

The current transformers are mainly used in multi purposes in energy transmission and distribution where;

A. Metering Type
B. Protection Type

The general classes in international standards and the application of CT's are given at below.

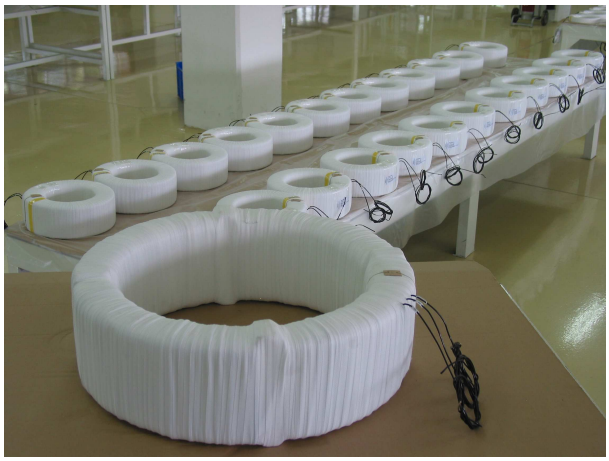
IEC 60044-1 & -6 / GOST 7746		
Type	Class	Application
Measuring	0,1	Precision Laboratuary metering
	0,2	Precision revenue metering
	0,2S	Precision revenue metering
	0,5	Standart revenue metering
	0,5S	Precision revenue metering
	1	Industrial Grade metering
	3	Instruments
	5	Instruments
	10*	Instruments
Protection	5P	Protection
	5PR**	Protection
	10P	Protection
	10PR**	Protection
	PX	Protection
	TPS***	Protection
	TPX***	Protection
	TPY***	Protection
	TPZ***	Protection

IEEE C57.13		
Type	Class	Application
Measuring	0,15	Precision revenue metering
	0,3	Standart revenue metering
	0,6	Metering
	1,2	Metering
Protection	C100	Protection
	C200	Protection
	C400	Protection
	C800	Protection

* Only in GOST 7746

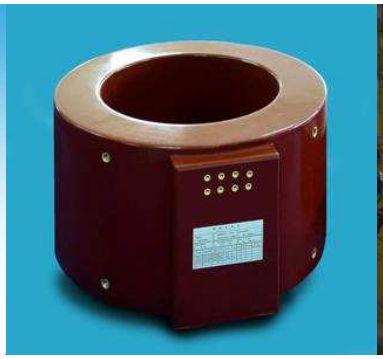
** Only in IEC60044-1

*** Only in IEC60044-6



Special application in order to protect CTs against dust and all kinds of particules.

Group of Bushing Type CTs for Gas Insulated System



Group of Bushing Type CTs for HV Power Transformers

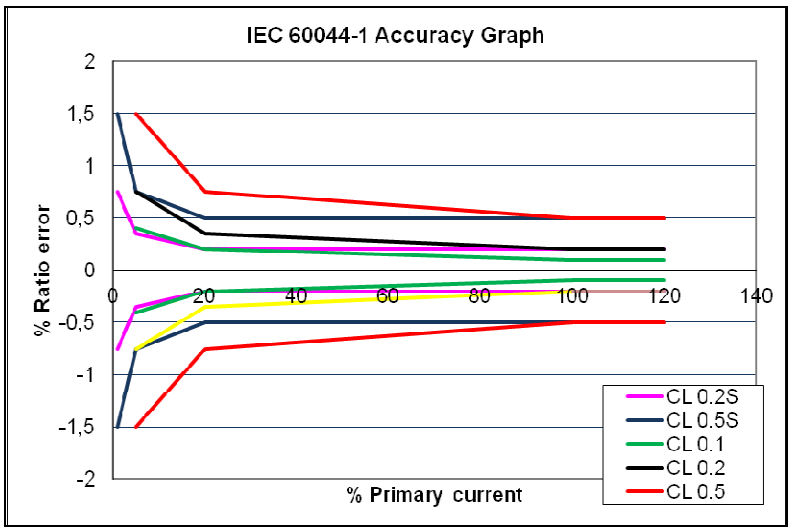
A. Metering Types, [16], [17]

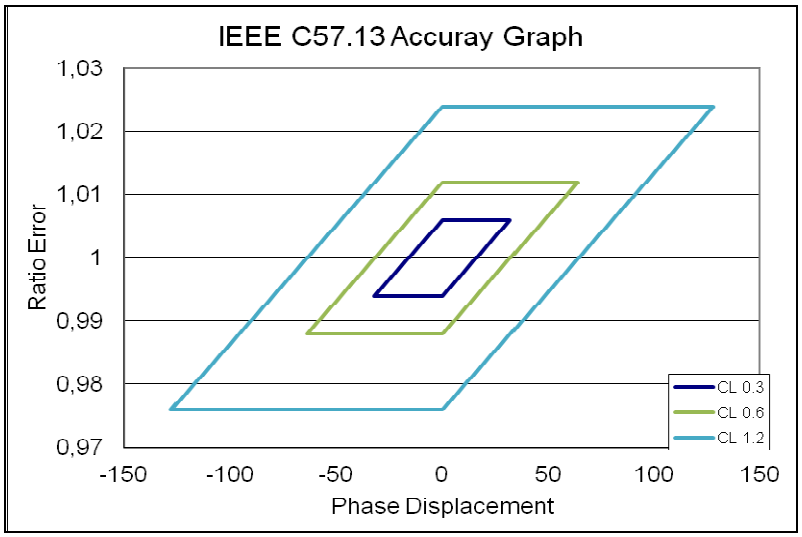
As all standard, for the IEC standard, accuracy classes for various types of measurement are set out in IEC 60044-1, Classes 0.1, 0.2s, 0.2, 0.5, 0.5s, 1, and 3. The class designation is an approximate measure of the CT's accuracy. The ratio (primary to secondary current) error of a Class 1 CT is 1% at rated current; the ratio error of a Class 0.5 CT is 0.5% or less. The errors in phase are also important in power measuring circuits and each class has an allowable maximum phase error for specified load impedance.

Mostly used metering type classes are given in below table

MEASURING-METERING TYPE		
GOST 7746	IEC 60044-1	IEEE C57.13
0,1	0,1	0,15
0,2	0,2	0,15S
0,2S	0,2S	0,3
0,5	0,5	0,6
0,5S	0,5S	1,2
1	1	
3	3	
5	5	
10		

The accuracy of CTs at IEC 60044-1 and IEEE C57.13 have been given at below 2 graphs, for instance. (The accuracy of IEC and GOST are equivalent)





The accuracy of phase displacement against ratio error for metering type CTs in IEEE C 57.13 should be within above parabola for each class.

In order to obtain necessary accuracy for metering type CTs, high permeability materials like ENNI® and ENNANO® should be used.

B. Protection Types, [12], [15], [16]

Current transformers used for protective relaying also have accuracy requirements at overload currents in excess of the normal rating to ensure accurate performance of relays during system faults.[12]

Mostly used protection type classes are given in below table.

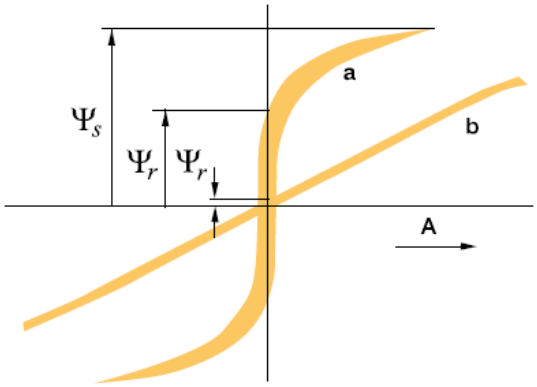
PROTECTION-RELAY TYPE			
GOST 7746	IEC 60044-1	IEC 60044-6	IEEE C57.13
5P	5P	TPS	C10
10P	10P	TPX	C20
	5PR	TPY	C50
	10PR	TPZ	C100
	PX		C200
			C400
			C800

The cores made by cold rolled grain oriented (CRGO) silicon steels, are used in this type of CTs since the accuracy of the CTs is not sensitive like metering. But the saturation of the core should be as high as possible because the CTs should be accurate in case of any failure which causes high primary currents on power transformer. So, ENSI® cores which has 2 Tesla saturation point are mostly used instead of ENNI® or ENNANO® which have high permeability and low saturation (respectively 0,8 and 1,2Tesla).

For the classes 5P and 10P in IEC 60044-1 and all C classes in IEEE C57.13, CRGO cores are preferred but for PX and TPS classes HIB cores where you need low excitation current and high knee point is preferred.

In addition to above classes, TPX, TPY, TPZ in IEC60044-6 and 5PR and 10PR in IEC60044-1 are also available.

A normal protective core in a current transformer will saturate very rapidly due to high currents and remanent flux. After saturation occurs, the current transformer output will be distorted and the performance of the relay protection system will be affected. Saturation of the core in protection type CTs should be as late as possible so in some special application, an air-gap is used for this purpose, [13], [14].



Hysteresis curves of a current transformer

a) without air-gap b) with air-gap

- TPX cores have no requirements for remanence flux and have no air gaps. High remanence CT. In this type of transformers the remanence can be up to around 80 % of the saturation flux.

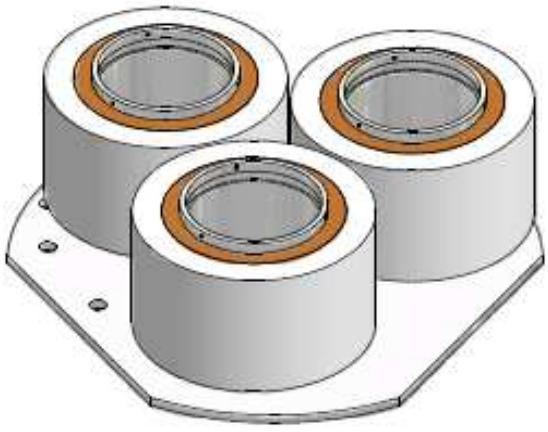
- TPY cores have requirements for remanence flux and are provided with small air gaps. Low remanence CT. This CT is made with a small air gap to reduce the remanence to a level that does not exceed 10 % of the saturation flux. The small air gap has only very limited influence on the other properties of the CT.

- TPZ cores have specific requirements for phase displacement and the air gaps will be large. Non remanence CT. This type of CT has relatively big air gaps in order to reduce the remanence to practically zero level. In the same time, these air gaps reduce the influence of the DC-component from the primary fault current. The air gaps will also decrease the measuring accuracy in the non-saturated region of operation.

Remanence factor (Kr) requirement plays an important role to specify current transformers for transient performance. If there are requirements regarding the remanence factor (usually *Kr* <10%) it is clear that the core must have air-gaps. If there is no requirement for low remanence we would probably choose a TPX-core. With a remanence factor of less than 10% the choice stands between class TPY and TPZ as they are both designed with air-gaps.

The difference between the two classes is that the TPZ core cannot accurately reproduce the d.c. component in the short-circuit current, and therefore the instantaneous current error can only take the alternating current component into account. The TPY-core has a smaller air-gap and it is possible to have a criterion for the total instantaneous error current

EXCITATION CURRENT OF CT's IN 3-PHASE SYSTEMS



Current Transformers in 3-Phase System

The performance of a protection function depends on the quality of the measured current signal. Saturation of the current transformer (CT) causes distortion of the current signal. Some failures may occur during operations Saturation of CT may cause unwanted operations of some functions. Consequently, CT saturation can have an influence on both the dependability and the security of the protection.

Excitation current in transformer protection and design of current transformer is a very critical parameter since it effects system protection even if CT is a very small part of the system. Meanwhile, it is preferred that the excitation current of the CT's to be placed in each phase of system are close to each other at three phase system. Numerically, it is approximately 10 percent for the CT's produced by ENPAY.

The required excitation current (Ie / Imag / Ial) of CT's for class PX, PS and TPS that are mentioned in IEC 60044-1, IEC 60044-6 and IS 2705 standards preferably should be close to each other at 3-phase system. We provide that the differences of measured current value between each other less than 10% if it's defined at an inquiry.

In the mean time, the excitation current is important to define CE (composite error) value for P and C protection classes in IEC 60044-1 & IEEE C 57.13 standards. CE value is a critical parameter for these type protection classes. We also provide that the differences of calculated CE value between each other less than 10% if it's defined at an inquiry.

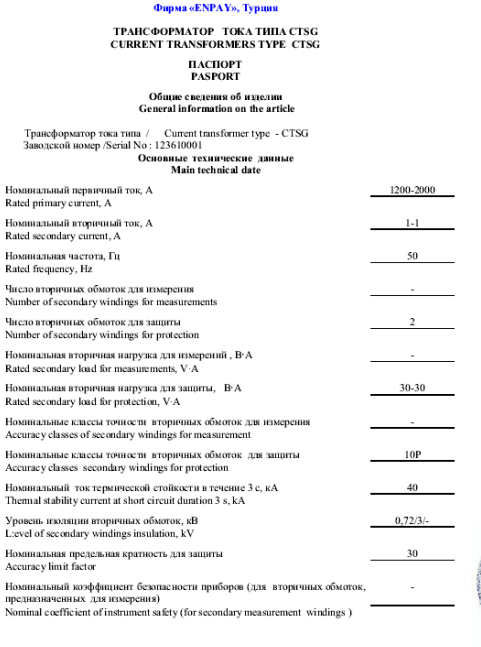
The Tests of CT

ENPAY has an international accredited CT test laboratory according to ISO/EN/IEC 17025. ENPAY also have pattern approval certificate for measuring equipments and authorized to issue verification certificate and CT passport by RUSSIAN METROLOGY INSTITUE (GOST). All below tests can be performed in our accredited laboratory. Many of approvals (TYPE TESTS) from different type of CT realized in international labs. like KEMA and CESI.

Standard	Tests
IEC 60044-1 /GOST 7746	Verification of terminal markings Power frequency withstand test İnter-turn overvoltage test Determination of errors Determination of remanence factor Determination of secondary loop time constant Determination of secondary winding resistance
IEC 60044-6	Turns ratio error Steady state ratio error and phase displacement Rct Excitation characteristic Determination of remanence factor Determination of secondary loop time constant
IEEE C57.13	Applied voltage dielectric test Induced voltage test Accuracy test Polarity test

Here below you can find the approvals that ENPAY has from various international authorities.

Upon request we can prepare calibration certificate or passports.



Фирма «ENPAY», Турция

ТРАНСФОРМАТОР ТОКА ТИПА CTSG
CURRENT TRANSFORMERS TYPE CTSG

ПАСПОРТ
PASPORT

Общие сведения об изделии
General information on the article

Трансформатор тока типа / Current transformer type - CTSG
Заводской номер /Serial No : 123610001

Основные технические данные
Main technical date

Номинальный первичный ток, А Rated primary current, A	1200-2000
Номинальный вторичный ток, А Rated secondary current, A	1-1
Номинальная частота, Гц Rated frequency, Hz	50
Число вторичных обмоток для измерения Number of secondary windings for measurements	-
Число вторичных обмоток для защиты Number of secondary windings for protection	2
Номинальная вторичная нагрузка для измерений , В·А Rated secondary load for measurements, V·A	-
Номинальная вторичная нагрузка для защиты, В·А Rated secondary load for protection, V·A	30-30
Номинальные классы точности вторичных обмоток для измерения Accuracy classes of secondary windings for measurement	-
Номинальные классы точности вторичных обмоток для защиты Accuracy classes secondary windings for protection	10P
Номинальный ток термической стойкости в течение 3 с, кА Thermal stability current at short circuit duration 3 s, kA	40
Уровень изоляции вторичных обмоток, кВ Level of secondary windings insulation, kV	0,72/3/-
Номинальная предельная кратность для защиты Accuracy limit factor	30
Номинальный коэффициент безопасности приборов (для вторичных обмоток, предназначенных для измерения) Nominal coefficient of instrument safety (for secondary measurement windings)	-

Комплектность
Complete set

В комплект поставки входят:
Delivery complete set include

- трансформатор тока / current transformer - 1 шт. / 1 st.
- паспорт / certificate - 1экз. / 1 copy
- техническое описание и инструкция по монтажу и эксплуатации / installation and service manual - 1 экз. на партию трансформаторов / 1 copy for a batch of transformers

Требования безопасности/ SAFETY REQUESTS

Особые условия и меры безопасности при эксплуатации трансформатора в соответствии «Руководства по эксплуатации» / The Conditions and activity of safety in during operation of transformer in accordance with Operation manual

Срок службы и гарантии изготовителя\ SERVICE LIFE AND GUARANTEE

Срок службы до списания/Service life -30 лет/ 30 years.
Гарантийный срок эксплуатации трансформатора – три года / Guarantee – 3 years

Свидетельство о приемке
Acceptance certificate

Трансформатор тока соответствует требованиям ГОСТ 7746-2001 и признан годным для эксплуатации.
Current transformer complies with the requirements of GOST 7746-2001 and is found fit for service.

Сертификат соответствия № РОСС TR.AB67.B01222
Certificate of conformance № РОСС

Зарегистрирован в Госреестре средств измерений под № 46666-11
Registered with number № 46666-11

Сертификат об утверждении средств измерений TR.C.34.004.A №42462
Pattern approval certificate of measuring instruments TR.C.34.004.A №42462

Прошел первичную поверку в лаборатории ENPAY
Primary checking of the transformer has been passed in laboratories ENPAY

М.П.
Place for stamp

Дата выпуска 10 / 09 / 2012
Date, manufactured
Подпись
Signature

ПОВЕРОЧНАЯ ЛАБОРАТОРИЯ
CALIBRATION LABORATOTY
фирмы «ENPAY», Турция

СВИДЕТЕЛЬСТВО
CALIBRATION CERTIFICATE

О ПОВЕРКЕ

№ 123116

Действительно до 24.08.2015
Valid 24.08.2015 г.

" 24 " 08 2012 г.

Средство измерений Трансформатор тока СТВ
Measuring Instrument Current Transformer СТВ

2000/5 A/A 40 VA 10P20 50 Hz

заводской № 123116001
Serial #

принадлежащее
Belongs to

поверено и на основании результатов первичной поверки признано годным к применению.
Calibrated and accepted suitable for use

Знак поверки
Verification Stamp

Yunus Sert
Responsible of Laboratory

Поверитель
Operator Ertan AKINCI

" 24 " 08 2012 г.

Safety precautions

Care must be taken that the secondary of a current transformer is not disconnected from its load while current is flowing in the primary, as the transformer secondary will attempt to continue driving current across the effectively infinite impedance. This will produce a high voltage across the open secondary (into the range of several kilovolts in some cases), which may cause arcing. The high voltage produced will compromise operator and equipment safety and permanently affect the accuracy of the transformer.

5. CONCLUSION

Current transformers are metering type - protection type and occur from 3 main parts. (Magnetic part, conductor and insulation). The magnetic part of current transformers is the most important and complicated part since, almost all accuracy is provided by core and additional process should be applied to core to gain necessary magnetic properties.

The most used core materials are cold rolled grain oriented (CRGO) silicone steel, nickel alloys and nano crystalline depends on the class of CT, all kind of materials have different annealing process which is done under different gasses and they should be respected for necessary properties.

Before using of CRGO materials at least, specific total loss (Single Sheet Test), Epstein tests must be performed and Surface Insulation Resistance (Franklin Test), Surface Condition Thickness, Burr height must be checked in order to obtain satisfied core quality. Otherwise a big risk occurs.

The design of CT’s are obtained from magnetic curves and these curves are obtained from Epstein test so this test is the most important to check point for design to avoid re-produce and material- time waste.

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