# The ART and SCIENCE of TESTING

# RELAYING CURRENT TRANSFORMERS.

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## THE REQUIREMENTS.

Power system relaying systems must have accurate information if they are to operate properly under normal and system fault conditions. Such information is provided by voltage and current transformers (VTs, CTs). This means that the output signals from VTs & CTs must represent primary voltage and current values, as failure to do so may result in protective relays operating when they are not supposed to operate, or alternatively – they may fail to operate when they are required to operate. The characteristics and performance of CTs is much more important than VTs because the CTs are required to operate over a very large dynamic range. We are going to concentrate on the requirements of CTs for protection applications and on test methods suitable for verifying their performance.

## THE STANDARDS.

There are primarily two standards that are used to specify the performance of CTs for protection applications, namely the ANSI and the IEC. Although these two standards are describe the performance of the same product – the protection CT – their approach is somewhat different and may appear to be completely different to the inexperienced professional.

Here are some of the differences between the ANSI and the IEC standards for CTs as they relate to relaying performance:

* ANSI recognizes only one power frequency, namely 60 Hz, while IEC recognizes and is applicable all power frequencies, including: 16 2/3, 25, 50 60 Hz.
* ANSI recognizes only one Rated Secondary Current – namely 5 amperes, while IEC recognizes various values of Rated Secondary Current, including – 1, 2, 5 amperes.
* ANSI recognizes only one Accuracy Limiting Factor, namely 20, while IEC recognizes many Accuracy limiting Factors, including – 5, 10, 15 and 30.
* ANSI recognizes relaying burdens to be 0.5 power factor and having impedances of 0.5, 1, 2, 4 and 8 ohms (12.5, 25, 59, 100, 200 and 400 VA), while IEC recognizes burdens at 0.8 power factor and having a variety of ratings, with the preferred values being 5, 10, 15 and 30 VA.
* ANSI differentiates between relaying CTs that are of "low-impedance" (low leakage flux, CTs with toroidal cores & uniformly distributed windings) and those that are of "high-impedance" (high leakage flux, wound primary & wound secondary CTs).
* ANSI recognizes a 2.5% and a 10% Class of relaying CTs, while IEC recognizes a 5% and a 10% Class.
* IEC specifies "ratio error" and "phase displacement" limits for CTs at rated current and "composite current" over the specified range of Accuracy Limit Factor (5 . . . 30), while ANSI specifies the composite error only at the Accuracy Limit Factor of 20.

## ANSI SPECIFICATIONS & TESTS.

### Expression of Accuracy Class.

The ANSI accuracy class is expressed as: - 10C400, 2.5C800 or 10T200, where:

* The first number indicates the CT Accuracy Class – 2.5% or 10%.
* The letter "C" indicating a "low leakage", low-impedance CT, whose performance can be readily "C"alculated from excitation measurements. The letter "T" indicating a "high leakage", high-impedance CT, whose performance must be obtained from a full-power test.

- * The second number indication the burden rating of the CT. Here 0.5, 1, 2, 4, and 8 are represented by 50, 100, 200, 400 and 800. As the ANSI Accuracy Limit Current is always 100 amperes, this number approximately indicates the knee-point voltage of the CT.

### Tests Required to Determine Accuracy Class.

As the "T" class CTs must be determined only by means of a full-power test, we shall consider here only the "C" class CTs, whose performance can be calculated from low-power tests. The calculation of "C" class relaying CTs requires a knowledge of the:

1. Excitation characteristics.
2. Winding resistance.
3. Burden.

There are other tests, like polarity and insulation resistance, but these are not used to determine the relaying accuracy of the CT.

## IEC SPECIFICATIONS & TESTS.

### Expression of Accuracy Class.

The IEC accuracy class is expressed as: 10VA5P20, 30VA10P30, where:

- * The first number indicates the burden rating of the CT. The burden is 0.8 power factor and expressed in "VA".
- * The second number indicates the Accuracy Class – 5% or 10%.
- * The letter "P" indicating that it is a "Protection CT".
- * The third number indicates the Accuracy Limit Factor – 5, 10, 15, 20 or 30.

### Tests Required to Determine Accuracy Class.

The specification recognizes only CTs that are of low impedance ("low leakage") and whose protection class can be calculated from the measurement and knowledge of:

1. Excitation characteristics.
2. Winding resistance.
3. Burden.

Similarly to ANSI, there are other tests, like polarity and insulation resistance, but these are not used to determine the relaying accuracy of the CT.

## CTERP - 2000.

### General.

The CTER-2000 is an instrument especially designed for testing the characteristics of CTs for relaying performance. The CTERP's measurement technology departs from the typical "traditional" measurements of CTs as they may be described in electrical textbooks or standards. Nevertheless, the operation of the CTERP strictly adheres to all the electro-magnetic theory and principles and one will find its origins in papers and textbooks on electricity & magnetism.

Thus, for example, the CTERP is battery operated, applies no high voltage to the winding of the test CT, but produces excitation characteristics that are equal, or even superior, to those provided by "conventional test sets" that are ac-line powered. The reason the CTERP can do this is because it measures the magnetic characteristics of the core using the secondary winding, and then calculates the performance of the CT. As the measurements are conducted using dc, the results of the measurements can be calculated for any power frequency such as 50, 60, 25 or 16 2/3 Hz.

### Principle of Operation.

The CTERP-2000-5A operates and relies on fundamental physical principles. Measurements of the fundamental magnetic quantities of field strength and flux density allow the instrument to calculate and provide the desired results. It applies magnetic flux density, in volt-seconds, and measures the resulting magnetic field strength, in amperes. This process allows one to draw full hysteresis loops for the test specimen. Multiple hysteresis loops allows one to calculate the excitation characteristics for the test specimen.

In addition to the above, the CTERP uses a "modified test sequence". This modified test sequence uses "four-phases" of measurement (+; 0; --; 0) rather than the traditional two-phase measurement (+;--) and allows the separation of core loss into the "hysteresis" and "eddy-current" components.

Dealing with magnetism, we have the following basic units:

1. The Magnetomotive Force

   Ampere (A)

2. The Magnetic Flux

   Weber ($kg*m^2/A*s^2$) ($V*s$)

3. The Magnetic Field Strength (H)

   Ampere per meter (A/m)

4. The Magnetic Flux Density (B)

   Tesla ($kg/A*s^2$) ($V*s/m^2$)

The above indicates that the quantities that need to be measured are – current (A), voltage (V) and time (s). All the required AC characteristics can be calculated from the above three measurements.

**Measurements.**

The CTERP-2000 CT Analyzer primarily measures and displays the following:

1. Insulation resistance of the secondary winding.
2. Residual magnetism (remanence).
3. Ratio.
4. Polarity.
5. Winding resistance.
6. Maximum possible residual magnetism.
7. Volt-Ampere excitation characteristics – volts, amperes & watts.
8. Demagnetizes the CT.
9. Draws the excitation characteristics on a log-log graph.
10. Determines ANSI relaying CT Class or the IEC protection CT Class.

**Explanation of Measurements.**

The above tests are performed using the following methods:

1. Insulation resistance of the secondary winding is measured using a 500 volt insulation resistance tester.
2. Residual magnetism is measured by conducting a hysteresis loop test and calculating the “as found” residual magnetism (remanence).
3. Ratio is measured using the voltage injection method. A square wave voltage is applied to the secondary winding and the output is measured on the primary winding.
4. The polarity is measured by comparing the polarity of the square wave voltage applied to the secondary winding to the polarity of the voltage measured on the primary winding.
5. The winding resistance is measured by measuring the voltage drop across the secondary winding when a known current is flowing in the winding.
6, Maximum possible remanence is calculated from the hysteresis loop taken at the highest test current.
7. The excitation characteristics is required to be determined using a sinusoidal voltage of 60 Hz. The voltage is measured using a rms responding voltmeter and ammeter. Incase of distortion, a rms and an average (flux) responding voltmeters are required. The excitation characteristics also require the measurement of excitation power. As a suitable wattmeter are typically not available, this is usually not carried out.
8. Degaussing, or demagnetization is carried out by saturating the core and then applying a square wave voltage of gradually increasing frequency.
9. The excitation characteristics is calculated from an analysis of 40 – to – 80 hysteresis loops. The test starts at the largest loop (highest excitation current) and gradually reduces to a very small value.
10. The ANSI Accuracy Class is calculated based on the excitation voltage corresponding to a magnetizing current of 2.5 amperes rms and the winding resistance.
    The IEC Accuracy Class is calculated from the excitation characteristics, winding resistance and a knowledge of the burden.

As the CTERP traces hysteresis loops at various excitation field strengths, it can reproduce these loops on the screen and provide data about them in digital format. Similarly, the instrument measures the peak values of field strength, from which the rms values are calculated, it can display these instantaneous values in the Full Test sequence.

### Measurement Sequences.

The above 9 measurements are organized to provide four distinct test, namely the ANSI Test, the IEC Test, the Full Test and the Hysteresis Test. The first two tests (ANSI & IEC) are designed for shop or field application and intended to verify the performance of relaying CTs before these are placed in service. The second two tests (Full & Hysteresis Test) are intended to be used by professionals for studying core materials and troubleshooting problems on CTs.

## TYPICAL TEST RESULTS.

### ANSI Test.

The results obtained after conducting an ANSI test include:

1. ANSI Accuracy Class.
2. Voltage at 2.5 A Excitation (Vfl)
3. Excitation Current (Irms=2.5 A)
4. Winding resistance (Rw)
5. Ratio
6. Remanence (%)
7. Core Loss at 45 deg point (W)
8. Core Loss Power Factor at 45 deg point
9. Insulation Resistance (Mo)
10. Eddy-current Loss (%)

### IEC Test.

The results obtained after conducting the IEC Test include:

1. IEC Accuracy Class.
2. Kneepoint Voltage (Vfl)
3. Kneepoint Current (Irms)
4. Winding resistance (Rw)
5. Ratio
6. Remanence (%)
7. Core Loss (W)
8. Core Loss Power Factor
9. Insulation Resistance (Mo)
10. Eddy-current Loss (%)

### Full Test.

Whereas the ANSI and the IEC Tests test the CT over its normal operating range, the Full Test allows the operator to limit the magnetizing force and study the characteristics of the core material over a selected region. In addition to providing a graphical presentation of the excitation characteristics (log-log graph), the CTERP provides numerical values for the excitation loss and power factor at the selected magnetizing force. The graphical presentation can be for ac excitation at the selected frequency, or it may be for the INSTANTANEOUS values, where peak magnetizing field is plotted against flux density (in volt-seconds). The results include:

1. Kneepoint voltage (Vfl) – (Vsm)
2. Kneepoint Current (Irms) – (Im)
3. Winding resistance (Rw)
4. Ratio
5. Remanence (%)
6. Core Loss (W)
7. Core Loss Power Factor
8. Insulation Resistsance (Mo)
9. Eddycurrent Loss (%)

### Hysteresis Test.

The hysteresis test allows the operator to select the magnetizing field at which he wishes to study the core material. In addition to plotting the hysteresis loop for the selected magnetizing force, the CTERP provides numerical values of flux density, loss and power factor of the magnetizing force.

The hysteresis plot is done on an arbitrary scale, where the peak field (H) is equal to 100% and the peak induction (B) is 100%. The numerical values of field and induction are given in numerical form in a table. The table of results is as follows:

1. Peak Flux Density (Vsm in Vs)
2. Peak Magnetic Field (Im in A)
3. Winding resistance (Rw)
4. Ratio
5. Remanence (%)
6. Core Loss (W)
7. Core Loss Power Factor
8. Maximum Remanence (Vsr in %)
9. Coercive Force (Ic in A)

## DISCUSSION.

ANSI offers a “Testing Guide” for commissioning CTs into service, where in addition to the tests discussed here, they specify that one needs to measure the service burden and to check for “inter-core coupling” of multi-core CTs. As the burden measurement requires a source of ac current it is not possible to do it with the CTERP.

The inter-core coupling requires that one core out of an assembly be excited with power frequency voltage and that voltages on the windings of other cores be measured. This also is a test not suited for the CTERP as it requires a large source of ac power and is best done with a current injection set and a sensitive voltmeter.

The IEC does not offer a “CT Testing Guide”, thus many of the tests and tests methods are at the discretion of the individual. This means that all of the tests can be conducted in the same fashion as suggested by ANSI.

IEC does identify a particular value – the “Knee-Point” that is of interest. The IEC “Knee-Point” is that value on the excitation characteristics where a10% increase in applied voltage causes a 50% increase in excitation current. It should be noted that this point is where a 10/50 sloping line touches the excitation characteristics on a log-log graph paper. Note that the IEC knee-point is different from the point of “Maximum Permeability”. The point of maximum permeability is the point where a 45 degree sloping line touches the excitation characteristics on a log-log graph paper.

As may be obvious from information herein that the CTERP provides more information then is needed for checking CTs into service. In particular the CTERP is most suitable for detecting and tracking problems with CTs with respect to shorted turns or damaged cores. This ability is due to the instrument being capable of differentiating “eddy-current” loss from “hysteresis” loss in a CT. It should be remembered that eddy-current loss is caused by eddy-currents within the core structure or that caused by a shorted turn. Thus, when one CT out a batch shows higher loss, and especially higher eddy-current loss, then damage to the core or shorted turns should be suspected.

It should be remembered that the traditional “excitation test” was not only designed to determine the CT relaying accuracy, but also to sense shorted turns, as such turns would increase the excitation loss. It should be also pointed out that improvements to the excitation test required one to measure not only the excitation current, but also the excitation power. The reason for this is that the increase in excitation power was much more sensitive to shorted turns then the current (say 3 to 5 times more sensitive, depending on the core loss). As shorted turns cause eddy-current loss, thus a measure of the eddy-current loss is most sensitive to shorted turns, more sensitive than a power measurement and much more sensitive than an increase in excitation current.

## ITEMS THAT INFLUENCE THE PERFORMANCE OF A CT.

There are numerous factors that affect the performance of a CT. These include:

### Core Material Characterisitics.

Ideally the core material should have a very high permeability, Little or no losses and a very high saturation flux density. The permeability of available core materials varies from less than 100 to 1,000,000 but the actual core materials used for CT cores varies from about 500 to 50,000. The typical saturation flux densities of core materials varies from about 0.4 Tesla for the very high permeability materials to about 1.8 Tesla for materials of lesser permeability.

Metering CTs, that operate over a range of 5 . . . 120% current range, require high permeability core material to provide good accuracy. Protection CTs, that require to operate to with a large accuracy limit factor, require core material that exhibit high saturation flux density.

### Core Geometry.

Ideally, the core of a CT should be of toroidal construction. This geometry reduces flux leakage and CT impedance.

### Core Quantity.

Generally speaking, the more core material is used – the higher will be the winding knee-point voltage and the better will be the performance of the CT.

**Winding Arrangement.**

A uniform winding arrangement reduces flux leakage and CT impedance. All other winding arrangements increase leakage flux and reduce CT performance.

**Winding Resistance.**

The lower the winding resistance – the lower will be the internal burden of the CT – the better will be the performance of the CT. This indicates that it is advisable to use series-parallel connections when changing ratios on CTs.

**Ratio.**

The CT ratio determines, in part, the Accuracy Limit Factor and thus determines the amount of "overload" the CT can handle. The higher the ratio, the lower the Accuracy Limit Factor, and the more likely the CT will operate within its accuracy class.

**Burden.**

The higher the burden, the larger the will be the core requirement. This also means that it will be more difficult for the CT to meet its accuracy class. The resistive component of the burden is especially troublesome as it is the resistive component that causes the CT to loose performance under transient system fault conditions.

## TERMINOLOGY.

**Excitation Characteristics.**

A graphical representation of the voltage-current relationship of the secondary winding of a current transformer. Such characteristics are typically drawn on log-log graph paper. The characteristics depends on the frequency and the wave shape of the applied voltage. Such characteristics become wave shape independent if the voltage is measured using a "flux voltmeter" and the current is measured as "peak current".

**Ratio.**

Coefficient of transformation.

**Toroidal current transformer.**

A transformer whose core is the shape of a doughnut and the secondary winding is uniformly distributed about the circumference.

**Bushing current transformer.**

A transformer of toroidal shape, consisting only of a core and secondary winding and secondary insulation and designed to fit on the bushings of a power transformers or circuit breaker. The bushing provides the "one-turn" primary winding and the primary insulation.

**Wound Current transformer.**

A transformer consisting of a primary winding, primary insulation, a core, secondary insulation and a secondary winding.

**Remanence.**

Remanence or residual magnetism in the core. Closed-core CTs, such as bushing current transformers, may have large residual magnetism in the core. Such residual magnetism is caused by faults, especially by faults with transient components, and may be as large as 80% of saturation flux density. The relaying performance of a CT with large remanence may be compromised, thus it is desirable to "demagnetize" or "de-gauss" CTs after severe faults. Metering CTs are always tested in the "demagnetized" condition, as residual magnetism increases the CT errors.

**Low Remanence Current Transformers.**

Protective current transformers whose remanence it typically less than 10% of Saturation flux density. Such CTs typically have galled toroidal cores, larger excitation current and are used on extra high-voltage networks.

**Flux Density.**

"Magnetic Flux Density" or Induction, is the magnetic field within the CT core. It is measured in Gauss or Tesla. Typical Electrical steels support a flux density of about 1.7 Tesla, low-loss nickel steels support density of about 0.7

Tesla, while amorphous materials support a magnetic field in the range of 0.4 . . . 2 Tesla.

**Magnetizing Force.**

The current that is required to achieve a particular flux density in the CT core. The force is measured in “amperes” or “ampere turns” and represents the loss in the transformation of current from the primary to the secondary winding.

**Accuracy Class.**

A method of grading the accuracy of a CT. There are basically two types of accuracy classes recognized by standards – the “Metering Class” and the “Relaying Class”.

The metering class applies to the performance of the CT over the normal operating current range, say 5% . . . 120% of rated, while the relaying class applies over the fault current range of the CT, say 100% . . . 2,000% of rated. The accuracy of the CT depends greatly on the loading of the CT – or the “burden” that is connected to its secondary winding.

There are primarily two systems of grading the accuracy of CTs, namely the IEC (International Electrotechnical Commission) and the ANSI (American National Standards Institute) methods.

**Composite Error.**

For relaying CTs, the rms value of the difference between instantaneous primary current and instantaneous secondary current multiplied by the rated transformation ratio.

For metering CTs - composite error is the square-root of the sum of the squares of the ratio error plus the phase error.

**Ratio Error.**

It is the in-phase component of the error exhibited by a CT.

**Phase Error.**

Is the quadrature component (out-of phase error) of the error exhibited by a CT.

**IEC Knee Point.**

It is a point on the CT excitation characteristics where a 10% increase in voltage causes a 50% increase in excitation current. It is a 10/50 (V/I, B/H) slope on the log-log graph of the CT excitation characteristics. It is typically considered that the CT has reached the limit of its performance.

**Point of Maximum Permeability.**

It is the point on the CT excitation characteristics that represents the highest magnetizing impedance. It is represented by a line sloped at 45-degrees on the log-log graph of the CT excitation characteristics.

**Rated Instrument Limiting Primary Current (IPL).**

The value of the primary current at which the composite error is equal to 10%.

**Instrument Security Factor (SF).**

Ratio of the IPL to rated primary current.

**Secondary Limiting emf.**

The product of SF rated secondary current and the vectorial sum of rated burden plus impedance of secondary winding.

**Exciting Current.**

The rms value of current drawn by the secondary winding of a transformer when a sinusoidal voltage of rated frequency is applied.

**Rated Accuracy Limit Primary Current.**

The primary current to which the CT complies with composite error.

**Accuracy Limit Factor.**

The ratio of Rated Accuracy Limit Primary Current to the Rated primary current.

**Internal Burden.**

Typically the winding resistance of a low-leakage CT. Typically the winding resistance plus the leakage inductance of a wound CT.

**Toroid.**

The doughnut-shaped object enclosed by a torus.

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# CTERP-2000 comparison with ANSI C57.13.1

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This document compares the IEEE Guide for Field Testing of Relaying Current Transformers with the performance and features of the Relaying CT Analyzer, Model CTERP-2000.

## 1. Introduction.

The purpose of the guide is to assure that the current transformers are connected properly, are of marked ratio and polarity, and are in condition to perform as designed.

***The CTERP-2000 has been designed to assist technicians to accomplish this task.***

## 2. Consideration of American National Standards Institute (ANSI) Accuracy Classes.

*The CTERP-2000 recognizes the ANSI relaying accuracy classes (C10, 20, 50, 100, 200, 400, 800) and test the CT for compliance. In addition to this the instrument can perform test to IEC specifications as well as other tests.*

## 3. Safety Considerations in Field Testing Current Transformers.

*Yes, testing of CTs should be done by experienced personnel familiar with any peculiarities of danger that may exist. However, as the CTERP-2000 applies a voltage of only 12 Vdc for testing the performance of the CT and 500V DC for measuring the insulation, it is considerably safer to use than other conventional test equipment used for this application.*

## 4. Current Transformer Types, Construction, Effect On Test Methods.

### 4.1 Bushing, Window, or Bar-Type Current Transformers.

*Yes, the CTERP-2000 is designed to test CTs built with "uniformly distributed windings" as covered by this part (4.1).*

### 4.2 Wound Current Transformers.

*Yes, wound-type CTs with uniformly distributed secondary windings can be tested with the CTERP-2000 as describ4ed in the standard.*

### 4.3 Consideration of Remanence.

*The CTERP-2000 measures the remanence (residual magnetism) of the test CT as well as demagnetizes the test CT, leaving a magnetic field within 3% of the saturation flux density. The demagnetization is automatic when conducting the ANSI, IEC or the FULL TEST.*

***This is the only instrument known to perform a measurement of remanence and to automatically demagnetize the test CT.***

## 5. Insulation Resistance Tests.

*Yes, the CTERP-2000 measures the resistance of the secondary winding with respect to ground using a 500 volt, two terminal measurement (no guard).*

## 6. Ratio Tests.

### 6.1 Voltage Method.

*Yes, the CTERP-2000 measures the ratio of the CT using square wave excitation of 12 volts. The range of the measurement is 5 . . . 1,000 to 1 amperes.*

### 6.2 Current Method.

*No, the CTERP-2000 uses the "Voltage Method" of CT excitation.*

## 7. Polarity Check.

### 7.1 DC Voltage Test.

*No, the CTERP-2000 uses the AC voltage test.*

### 7.2 AC Voltage Test.

*Yes, the CTERP-2000 uses the AC voltage test to determine the polarity of the test CT windings.*

### 7.3 Current Method.

*No, the CTERP-2000 uses the AC voltage test.*

## 8. Winding and Lead Resistance.

*Yes, the CTERP-2000 measures resistance in the range of 0 . . . >100 ohms using a four-terminal connection. Depending on the connection, it will measure the test CT secondary winding resistance, or the total secondary circuit resistance.*

## 9. Excitation Test.

*The excitation test that the CTERP-2000 conducts is different from the conventional method of applying power frequency (50, 60 Hz) voltage to the test CT winding and then measuring the resulting current. For the excitation test, the CTERP-2000 conducts a measurement that is identical to the basic magnetic measurement conducted on magnetic materials using an Epstein Frame. The CTERP-2000 applies a dc voltage, measures the applied voltage and the resulting current, both with respect to time. A series of such measurements allows the instrument to calculate the excitation characteristics for the CT for any frequency* (50, 60 Hz).

*For the magnetic flux density (B) the instrument measures "volt-seconds". Once converted to a voltage at the power frequency, this reading is identical to the "average responding voltmeter" specified in the standards. This voltage is plotted on the vertical axis.*

*For the magnetic force (H) the instrument measures instantaneous current. As the current is measured with respect to time, its "rms" value can be calculated and plotted on the horizontal axis.*

*In summary, the plotted excitation characteristics, as well as the numerical values quoted in the results, are the same as would be obtained during a "conventional" excitation test.*

## 10. Burden Measurements.

*The CTERP-2000 will measure the resistance of the burden connected to the test CT. The preferred method of measuring the burden resistance is to subtract the winding resistance from the total resistance.*

## 11. Special Situations.

*All of the discussions in this section apply equally to the CTERP-2000 as they do to more conventional test methods.*

## ADDITIONAL INFORMATION.

*The CTERP-2000 conducts more tests then are specified by C57.13.1-1981, most of these are useful in searching for problems in test CTs.*

*The important measurement performed by the CTERP-2000 and not specified or even mentioned in the standard is the measurement of core loss and core loss power factor. This is done during the excitation test and is a valuable tool in spotting shorted turns or damaged cores. Even though the losses and their power factor will vary between manufacturers and between types of CTs, there are at least three CTs in a protection system, thus one can compare these against each other. The CT with a shorted turn will be easily identified by the higher core loss and/or power factor.*

*The above is infinitely more sensitive for finding CT problems then that suggested in the standard, Clause 9, which is:* **"deviation of the excitation curve for the test CT from curves of similar CTs should be investigated".**

*Some of the less important measurements include the measurement and plotting of the hysteresis curve and the plotting of the excitation characteristics on a >peak – vs - peak< graph as well as on the more traditional >average volts – vs - rms current< scales.*

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# CTERP -2000 – Some Questions and Answers

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## I) *Measurement of Core loss and Core Loss PF*

Q- The losses in a CT will vary between manufacturer to manufacturer and for different type of CTs .

**Ans- YES .That is correct. The loss is dependent on the quality and quantity of core material in the CT.**

Q- Core Loss PF – The higher the Core Loss PF (i.e nearer to unity) it is more likely that there are shorted turns on the CT core –which reflects in the higher PF.

**Ans- The typical "Core Loss Power Factor" should be in the range of 0.05. . 0.3. High quality (nickel steels) will have a low power factor, while grain oriented silicon steel will have power factors in the range of – 0.15. . 0.3. Power factors higher than this would typically indicate other problems with the core or the windings. Problems with the core would be shorted laminations, problems with winding - shorted turns.**

Q- Why is the core loss PF different when we test the same CT for different type of tests .i.e IEC Test and ANSI Tests.

**Ans- The core loss does vary as the square of the magnetizing current or the square of the voltage (volt-seconds). The loss is presented at the highest test current, which may not be the same for all tests (the test is NOT CONTINUOUS as the readings are taken at some pre-scribed internals – like 100 microseconds) as it is impossible to take readings at exactly the prescribed current value (the reading at 0.1234 seconds is too low a reading at 0.1235 seconds which is too high).**

**The POWER FACTOR typically should not vary very much with small changes in the test current. The CTERP converts values to 50 or to 60 Hz, regardless of the test - IEC – ANSI. It does a 50Hz ANSI test**.

Q- Eddy Current Loss – You have indicated that Eddy Currents are caused due to shorted turns on the winding or shorted turns due to defects in mounting.

**Ans- Shorted turns can be caused by - actual shorting of the turns, . . . by shorting of laminations due to poor coating on laminations, . . or by shorting of mounting clamps – such as used on bushing CTs**. **BUT as you typically have three or more samples, and if one sample reads high on eddy-current loss, then you should have a strong suspicion about shorter turns .**

Q- Shorted turns may arise over a period of time due to various reasons

**Ans- YES .**

Q- Defective mounting – When the CTs are already mounted inside equipment, how can this happen ?

**Ans- This typically refers to CTs mounted on bushings. Such mounting arrangements typically involve flanges and mounting bolts that are insulated from each other. If this insulation fails - it will cause a one-turn short of the CT.**

Q- As indicated in the various write-ups and ANSI Std., the accuracy class in ANSI is specified as 2.5C400 , 10C400 etc . ANSI Std. has only one ALF – i.e 20 ( The second term in ANSI Acc class - indicates the sec voltage that can be delivered by the winding at 20 times rated sec current w/o exceeding 10% ratio correction).

**Ans- Close - but not a thumb rule . The term after the "C" (Calculated) refers to the voltage developed across the "rated burden". The CTERP identifies only the 2.5% class of CTs. The reason for this is that there is hardly any difference between the 2.5% class and the 10% class, as the CT is already operating above the "knee-point". Typically there are hardly any "10C" CTs produced, except those of very low ratios.**

Q- In our CTERP ANSI Test, the ANSI Acc. Class is always calculated based on excitation voltage when the CT draws 2.5A excitation Current ?

**Ans- YES, that is correct. This is what the standard calls for. You determine the voltage @ 2.5 amperes excitation, and calculate back what burden this will support at 100 amperes secondary current.**

Q- Why this 2.5A ? Is this given anywhere in the ANSI Std. ?
**Ans- Because 2.5% of 100 amperes is 2.5 amperes.**

Q- Irms value displayed during ANSI test is not varying on different CTs ?

**Ans- NO, this is not a variable . ANSI identifies secondary current as 5 amperes, a overload factor of 20 times, this gives a secondary current of 100 amperes, and 2.5% of 100 amperes - gives 2.5 amperes .**

Q- In the FULL Test, we have indicated that it allows the operator to limit the magnetizing force & study the core characteristics over a selected region ?

**Ans- YES, the operator can set different values of "peak excitation" current to study the core material and so on .**

Q- The Full Test provides data for the excitation loss and PF at a selected mag.Force (i.e at a particular current ) – How is this helpful for a CT manufacturer ??
**Ans- It provides numeric values for the core material at the "peak excitation" current. The manufacturer can study and plot loss curves for the core material he is using. It provides the "rms"characteristics(ac characteristics) & the "peak" characteristics (dc characteristics).**

Q- How is the above data /readings helpful to CT designers ?
**Ans-** ***One has to "know CTs" for this to be helpful to a user .One can write a whole chapter on this !***

Q - Protection CTs that operate at large Accuracy Limiting Factor (ALF) require core material that exhibit high saturation flux density ?
**Ans- Designers are typically limited to "Grain Oriented Silicon Steel" - or GOSS . . .**

Q- Rms Current – 15A (in CTERP-5A ) and upto 5A (CTERP-1A) . Why is this difference ?

**Ans- The CTERP-5A is set for a maximum peak current of about 15 amperes and excites the CT @ 12 volts. The CTERP-1A is set for a maximum excitation current of about 5 amperes and excites the core with 24 volts.**

Q- Current Peak – 15A ( in CTERP-5A ) and upto 10A (CTERP-1A) – Why ?

**Ans- We do not need 15 amperes to excite a 1 ampere CT. Also you can not push 15 amperes trough a winding that may be 20 ohms ! The CTERP-5A is set for a maximum peak current of about 15 amperes and excites the CT @ 12 volts.** ***Different CT requirements*** **dictate a differences in the power supplies for the CTERPs.**

Q- Why are the secondary leads of a much higher gauge than the primary leads ?
**Ans– The CTERP measures the secondary characteristics of the CT. The primary leads are only used to measure the ratio and are not needed to be used if ratio measurement is not required . The secondary leads are used to excite the CT core and carry out the measurement of the Winding Resistance, Insulation resistance and other parameters. These are rated for upto 15A current and so are of a larger cross-section than the primary leads.**

Q-Why are the core loss values different when the CTERP conducts various Tests on the same CT ?

**Ans- As explained earlier, the core loss does vary as the square of the magnetizing current or the square of the voltage (volt-seconds). So for each test , since the Core Loss is calculated at a different current value , the results are different . The points at which the Core loss is calculated by the CTERP-2000 for the various tests is given below:**

1. IEC Test - The core loss and power factor is for the IEC Knee-Point.
2. ANSI Test - The core loss and power factor is for the 2.5 ampere (2.5%) excitation test point.
3. Hysteresis Test - The core loss and power factor is for the excitation current (peak, Im) entered prior to beginning the testing.
4. Full Test - Core loss and power factor is for the highest current in the test sequence (current value entered before commencing the test).

Q- How can we improve the Ratio measurement accuracy under interference conditions?

**Ans- To improve the stability of the Ratio reading under interference conditions, please try to bring out the COMMON of the CTERP-2000 Test Set and Ground this for the measurement. The PRIMARY of the test CT is to be also grounded on one side. This is a very important point that will definitely result in better measurement accuracies for Ratio measurements**.

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# MODERN METHODS of TESTING RELAYING CTs.

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**RESUME:**

The principles of a test set operating on direct current and providing information on the alternating current performance of relaying current transformers is described. The portable test set operates according to traditional physical principles of electricity and magnetism. The unique feature of the test set is its ability to separate the eddy current losses from the hysteresis losses, thus being extra sensitive to CT problems, such as shorted turns.

## INTRODUCTION.

The reliability of the electric power system depends, in part, on the proper operation of the protective relay systems. The proper operation of any relaying scheme, in turn, relies on the proper voltage and current signals applied to it. This paper discusses the test that should be carried out on current transformers in order to verify their performance and assure the proper operation of the protection relaying scheme.

Unlike metering current transformers that operate over a specified range of current and can be readily tested for their accuracy, relaying current transformers operate in the current overload range and cannot be readily tested for their performance. As the test set up for testing of relaying current transformers is very extensive it is practical only in factories or test laboratories. The testing of relaying CTs at site, prior to commissioning of any protective relaying system must rely on other than over current test which will lead one to believe that the CT is of desired characteristics and in good operating condition.

Test that have been used for this application include: ratio, polarity, secondary winding resistance, excitation current and loss and insulation resistance. A normal procedure would also require the CT to be demagnetized prior to being connected into service.

## REASONS for TESTING.

The reasons for testing the CTs should be obvious. Reviewing some of the reasons we have:

**The ratio** - if the ratio of the CT is not correct in a differential protection scheme then the scheme will be tripping incorrectly. If it is used in a line protection scheme then the reach of the relay will not be shorter or longer than what is expected.

**The polarity** – if connected with incorrect polarity, the protection scheme will trip immediately upon energization. In a line protection scheme, the protection will be looking in the opposite direction than expected.

**The secondary winding resistance -** is part of the burden on the CT. By measuring it, we not only determine the internal burden of the CT, but are also checking the continuity of the circuitry. A CT with inadequate accuracy, or one that is overburdened, will not be able to drive the secondary current through the relays of the protection scheme. The same applies to a damaged core or shorted turns.

**Insulation resistance** – checks that there are no unwanted grounds on the CT and that its winding and wiring insulation is adequate to withstand the voltage that may be developed across the winding during a fault condition.

**Excitation current and power loss** – allows one to determine the relaying accuracy of the CT as well as to check for any problems with the CT, such as shorted turns, damaged core and the like.

## TRADITIONAL INSTRUMENTATION.

The traditional instrumentation for conducting all of these tests consisted of many individual pieces of equipment.

For determining the ratio and polarity – a ratio meter of some description would be used. For measuring the continuity and winding resistance – a bridge of some description, or a low resistance ohmmeter would be used.

The excitation test is the most complex one as it requires a variable source of voltage capable of delivering substantial current (VA), a voltmeter, an ammeter and a wattmeter of suitable range. This instrumentation was especially cumbersome as ranges of current from milliamperes to amperes and voltages from a few volts to hundreds of volts had to be accommodated.

A 500/1000-volt insulation tester was required to measure the insulation resistance of the CT secondary winding.

The demagnetizing would be typically carried out as part of the excitation test, using the same equipment.

The advent of modern digital test equipment reduced the number of individual instruments as a digital voltmeter or ammeter would cover a wide range, thus multiple voltmeters and ammeters would not be required.

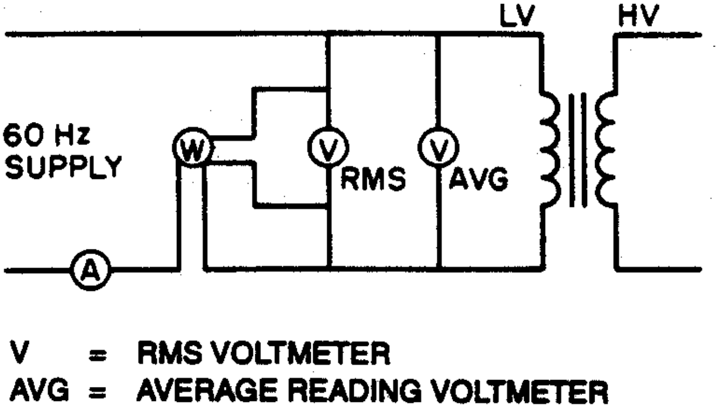

Figure 1. Setup for measuring excitation characteristics of CTs according to ANSI C57.13.

## THE TESING PROCEDURE.

Traditionally, the resistance is conducted first, then the ratio and polarity test, followed by the excitation test. The reason for this particular sequence is that the resistance test would magnetize the core of the CT while the excitation test would demagnetize the core.

The testing usually does not present much of a problem except for the excitation test. Here one experiences a lack of appropriate instrumentation – such a "flux voltmeters" as well as low current and low voltage wattmeter. As the CT contains a magnetic core, the test is subject to influences that will depend on the test frequency and the harmonic distortion of the test voltage. As the magnetic core is not linear, the test results will also depend on the excitation source, especially on its output impedance.

The result of all of this is that it is rather difficult to conduct an excitation test over the required range and then to compare it to previous tests, such as those from the factory. As the excitation sources are different and the instrumentation is not identical, the results are typically not comparable but questionable.

## ALTERNATE TEST METHODS.

Perhaps the main problem with testing the relaying performance of a CT is the lack of appropriate instrumentation for testing the characteristics of the magnetic core of the CT. The typical tests with rms responding voltmeters and ammeters is accurate only under sinusoidal excitation conditions. It can be shown that if the excitation testing was done using a “flux voltmeter” and a “peak reading” ammeter, then the test results would be independent of harmonic distortion in the excitation source, thus they would always be comparable – as long as the test frequency would be maintained. As neither flux voltmeters nor peak reading ammeters are readily available, they are not specified in typical standards or test guides.

Realizing that we have a non-linear magnetic element in the CT, we should tailor the test method to deal properly with the magnetic element, especially with its non-linearity. The test method presented here plays special attention to the characteristics of the magnetic core. The method determines the characteristics of the CT core using direct current and then converts this characteristics to current and voltage values.

## THE THEORY.

Going back to physics and lessons in electricity and magnetism in particular, we know that the voltage developed in a coil is proportional to the “rate of change of magnetic flux”, or $e = d\hat{O}/dt$.

Intergrating both sides of this equation with respect to time, we have the integral of ‘e’ being proportional to ‘Ô’, the flux in the core. The integral of ‘e’ is the area under the excitation voltage curve. With the vertical dimension being voltage and the horizontal dimension being time, the unit of flux (Ô) becomes “volt-seconds”. Herein lies the problem with the repeatability of typical excitation tests, as it is not the test voltage, but the “integral” of the test voltage that is proportional to magnetic flux (also the magnetizing current).

Knowing that the application of “volt-seconds” to the magnetic structure of the CT will result in a flux (Ô) in the core and a certain magnetizing current to be drawn, we can chose to apply these “volt-seconds” by other means than a voltage at the power frequency of 50 or 60 Hertz. A test at 50 Hz applies many repetitive cycles of relatively high voltage (V) but applies them for a very short time – namely 10 milliseconds. One could choose to test the CT at one-tenth the frequency (5 Hz) by applying only one-tenth the voltage (V/10), wherein the “volt-seconds” would be applied over a period of 100 milliseconds. One could even chose to test the CT at one-hundredth the frequency (0.5 Hz), by applying one-hundredth the voltage (V/100), wherein the “volt-seconds” would be applied over a 1 second period. One could even apply a DC voltage “V” for a period of time “s”, which would apply the required “volt-seconds” (Vs) for testing the CT.

The above justification indicates that one does not need to apply a power frequency voltage to test the performance of a relaying current transformer. With appropriate instrumentation the test could be performed using direct current excitation of the CT.

## THE MODERN TEST EQUIPMENT.

The aim of the development of modern test equipment for relaying CTs has been to design a piece of test equipment that would provide reliable and repeatable test results for all the required quantities. This meant that the equipment's test results must not only be repeatable but also should not be affected by line frequency or distortion. The test results must be but also comparable to the test results using "ideal test equipment".

It was realized very early in the development that to make it reliable and repeatable, the test would have to be conducted using direct current excitation, as alternating current excitation was subject to errors due to frequency and waveform distortion (harmonic distortion). Furthermore, it was very apparent from the beginning that power requirement for testing with direct current was very low, say 1 to 10 watts, whereas testing with alternating current required power in the vicinity of 1kVA. This reduction of power requirement makes it possible to make the relaying CT test set portable. A further advantage of direct current excitation is its safety. A CT with a knee-point of thousands of volts can be safely tested using low voltage.

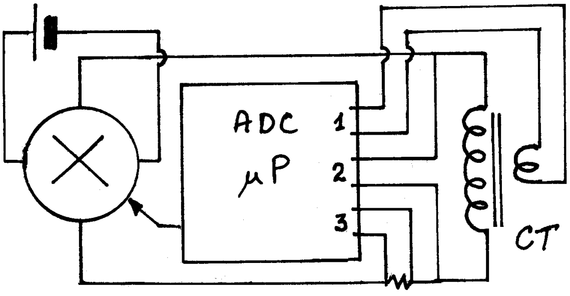

Figure 2. Basic diagram of the Relaying CT Test Set.

Thus, a CT Saturation Test Set was designed using a microprocessor, a multi-chanel analog to digital converter, some controls and an operator interface. The excitation test was programmed as per the outline under the "excitation tests', below. In addition to the excitation test, the microprocessor was programmed to conduct the following tests:

**The ratio and polarity** of the CT would be made be exciting the secondary of the CT with a square waveform of 12 volts peak. The frequency of this waveform would be variable, so that even CTs with very low knee-point voltages could be tested. By measuring the applied voltage and the polarity and magnitude of the voltage induced on the primary, the ratio and polarity of the CT would be accurately determined.

**The secondary winding resistance** would be measured once the CT was saturated and drawing current. By measuring the voltage drop across the secondary winding and knowing the test current, the secondary winding resistance would be determined.

**The insulation resistance** of the winding would be determined by applying a test voltage of 500 volts and the winding's leakage current to ground would be measured.

**The excitation current and power loss** would be measured by conducting a series of tests on the CT that are similar to the "Epstein Frame Test". As the core in the CT is not a "sample", but is typically a complete toroid, it does not require an Epstein Frame arrangement, but can be tested using a test popularly referred to as the "Rowland Ring Test".

The conventional method of conducting the Rowland Ring Test is identical to that of the Epstein Frame Test, namely a known current is applied to the test winding while the voltage across the winding is integrated using a ballistic galvanometer. As the ballistic galvanometer integrates the applied voltage, its calibration is in volt-seconds or similar units. In the modified Rowland Ring Test used in the test set, a fixed voltage is applied to the winding while the voltage across the winding and the current through the winding are measured at precise intervals. The measuring intervals are very short, typically in the microsecond range. By integrating the applied voltage during the saturation process the magnetic flux in the core can be calculated. By using proper scaling factors, the magnetic field can be converted to voltage and then plotted against exciting current. Two graphs can be plotted from the results. One graph would be that of rms voltage at a frequency "f" (assuming sinusoidal excitation) against rms current. The other graph would be of flux voltage against peak current. The second graph is actually a plot of many "end points" of individual hysteresis loops. A more precise explanation of the process is provided below.

## THE EXCITATION TEST.

The excitation characteristics curve is plotted using anywhere from 20 to 40 points. Each point on the curve is the result of calculations based on one "hysteresis loop".

Thus, to accomplish this, 20 to 40 hysteresis loops, each consisting of 200 to 800 readings of excitation voltage and current are taken. The voltage readings are integrated over the test period to provide a measure of voltage, while an rms calculation is performed of the current readings to provide an rms value of the excitation current. The same 200 to 800 readings are used to calculate the excitation volt amperes, power loss and excitation power factor for each hysteresis loop.

The excitation test is conducted starting with the largest hysteresis loop, the loop using the highest current. The applied volt-seconds and thus the excitation current are slowly decreased for each successive hysteresis loop until the applied volt-seconds are only a few percent of the saturation volt-seconds.

Conducting the hysteresis loop test with direct current allows one to calculate the residual magnetism in the core. This measurement can be conducted ONLY ONCE, as the core is demagnetized during the test.

It should be noted that this process not only provides the 20 to 40 points for the excitation curve, but at the same time the CT core is demagnetized, leaving typically less than 3% remanence.

Thus the excitation test is conducted with direct current using an automated Rowland Ring Method, and the results are used to calculate the rms voltage and rms current at any prescribed frequency. These dc test results can be converted into ac excitation values for frequencies of 25, 50, 60 Hz or other frequencies.

## INTERESTING MODIFICATIONS.

Most professionals dealing with electricity and magnetism know that losses in magnetic materials comprise of two components, namely “Hysteresis Loss” and “Eddy Current Loss”. Once the discussed test equipment was operational, it was soon realized that by modifying the Rowland Ring Test sequence, it would be as possible to measure these two loss components separately. As is known, this is the first time that separate measurements of hysteresis losses and eddy current losses have been possible by any instrument.

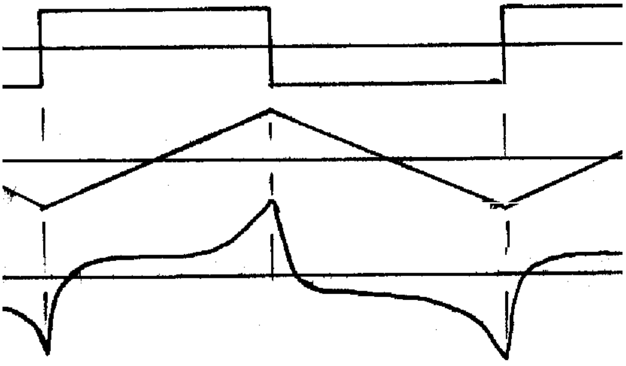

Figure 3. Conventional method of conducting a Rowland Ring Test.

Top – applied voltage – (+) & (—).
Center – Flux in CT core (volt-seconds).
Bottom - Exciting current.

The separate measurements of hysteresis and eddy current losses are important as they can identify problems with current transformers. Whereas hysteresis and eddy current losses are characteristics of the core material, an increase in eddy current losses are indicative of shorts on the core including shorted turns on the winding or shorted turns due to defective mounting arrangements.

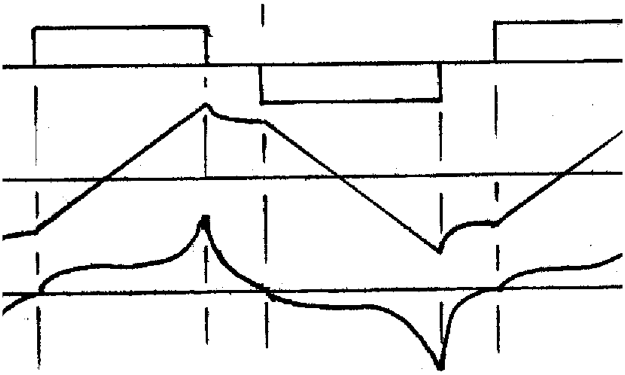

**Figure 4. Modified method of conducting a Rowland Ring Test.**
Top - Applied voltage – (+), (0), (—), (0).
Center - Flux in CT core (volt-seconds).
Bottom – Exciting current.

## CONCLUSIONS

A project to develop a "relaying CT test set" resulted in not only a test set that provides all the measurements required by typical standards, such as ANSI C57.13, but also provides valuable addition information. The instrument provides a measure of residual magnetism in the CT core, automatically demagnetizes the core and can distinguish between hysteresis and eddy current losses in the transformer. Although applied to current transformers, the principles employed here can be equally applied to large power transformers.

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