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Testing 1% Transformers

Methodology and Motivation

7/22/2025

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Agenda

- Terminology
- Why
- CT Testing Overview
- Knopp True Primary Reference Comparison
- 1% CT Construction/Design
- What to Test and Why
- True Error, Knopp Testers
- Questions

Common Terms and Acronyms

- **Ref**: Reference Transformer
- **TUT**: Transformer Under Test
- **RCF**: Ratio Correction Factor
- **TCF**: Transformer Correction Factor
- **Minutes**: 1 degree = 60 minutes
- **RF**: Rating factor, sometimes expressed as a % (100% = 5A) or a number (4 = 20A), can be based on thermal rating
- **Accuracy Class (Acc)**: Percentage of allowed error, ex. 0.3Acc means +/- 0.3% accuracy
  - Knopp gives a measured accuracy class during test, this should be below the nameplate of CT. Ex. 0.21 shown, <0.3 so within spec

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Why?

- C57.13 does not spec below 5% but many manufactures are beginning to claim measurements down to 1%
  - *These claims need validation*
- Reduced inventory variety
  - *600:5 can go down to 6amps, rendering 100:5 and 50:5 less critical to have*
- Most of the present 1% CT’s are 0.15 Accuracy Class, so an upgrade of range is an upgrade in accuracy as well.
  - *When compared to 0.3, 0.6, and 1.2 accuracy class CT’s*

https://ritzusa.com/wp-content/uploads/2020/11/Low-Voltage-Extended-Range-Current-Transformers.pdf

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Background of Testing

Understanding the Parallelogram

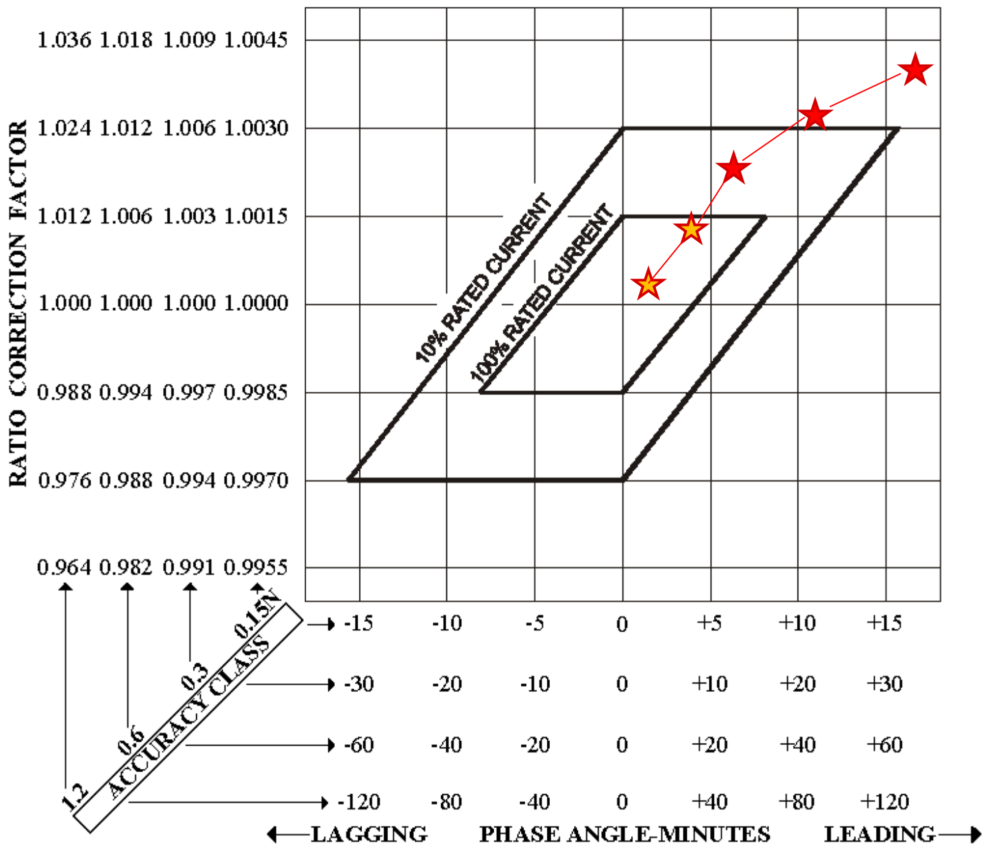


Figure 2, IEEE C57.13-2016

- Transformers when under test must comply within their respective class bounds for phase and ratio.
- The class they fit within also depends on the current value, all must match nameplate at 5amps, but some (0.3 in example) can double when below an RF of 1.0

Understanding Accuracy Class

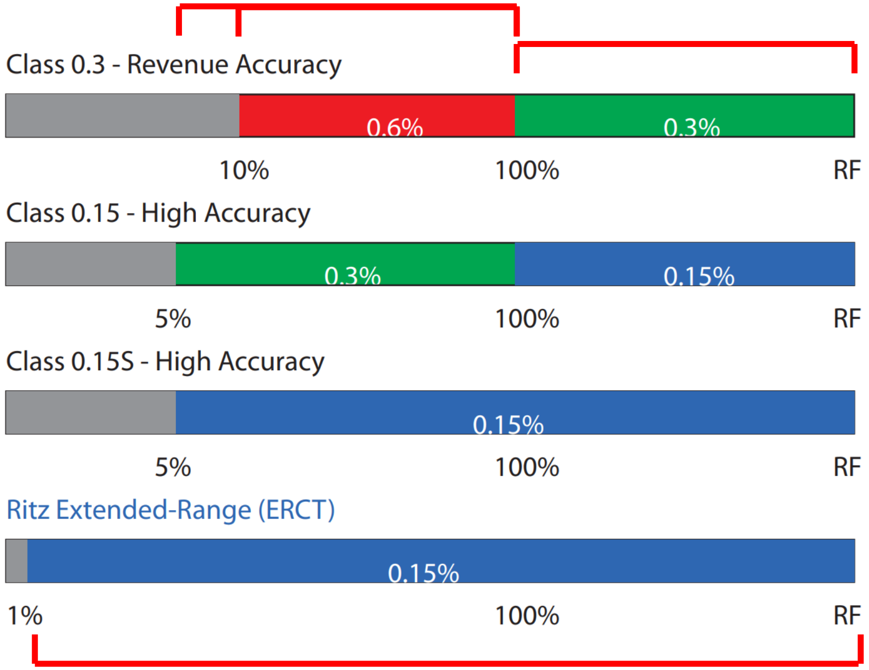
IEEE Std C57.13-2016
IEEE Standard for Requirements for Instrument Transformers

Table 8—Standard accuracy class for metering service and corresponding limits of transformer correction factor and ratio correction factor [0.6 to 1.0 power factor (lagging) of metered load][c]

Metering accuracy class	Voltage transformers (at 90% to 110% rated voltage)		Current transformers					
			At 100% rated current[a]		At 10% rated current		At 5% rated current	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
0.15S[b]	—	—	0.9985	1.0015	—	—	0.9985	1.0015
0.15[b]	0.9985	1.0015	0.9985	1.0015	—	—	0.9970	1.0030
0.15N	—	—	0.9985	1.0015	0.9970	1.0030	—	—
0.3S	—	—	0.9970	1.0030	—	—	0.9970	1.0030
0.3	0.9970	1.0030	0.9970	1.0030	0.9940	1.0060	—	—
0.6	0.9940	1.0060	0.9940	1.0060	0.9880	1.0120	—	—
1.2	0.9880	1.0120	0.9880	1.0120	0.9760	1.0240	—	—

[a] For current transformers, the 100% rated current limit also applies to the current corresponding to the continuous thermal current rating factor.
[b] Previously defined in IEEE Std C57.13.6.
[c] Other accuracy requirements may be specified and should be included on the nameplate.

Table 8, IEEE C57.13-2016



https://ritzusa.com/wp-content/uploads/2020/11/Low-Voltage-Extended-Range-Current-Transformers.pdf

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Accuracy Class Examples

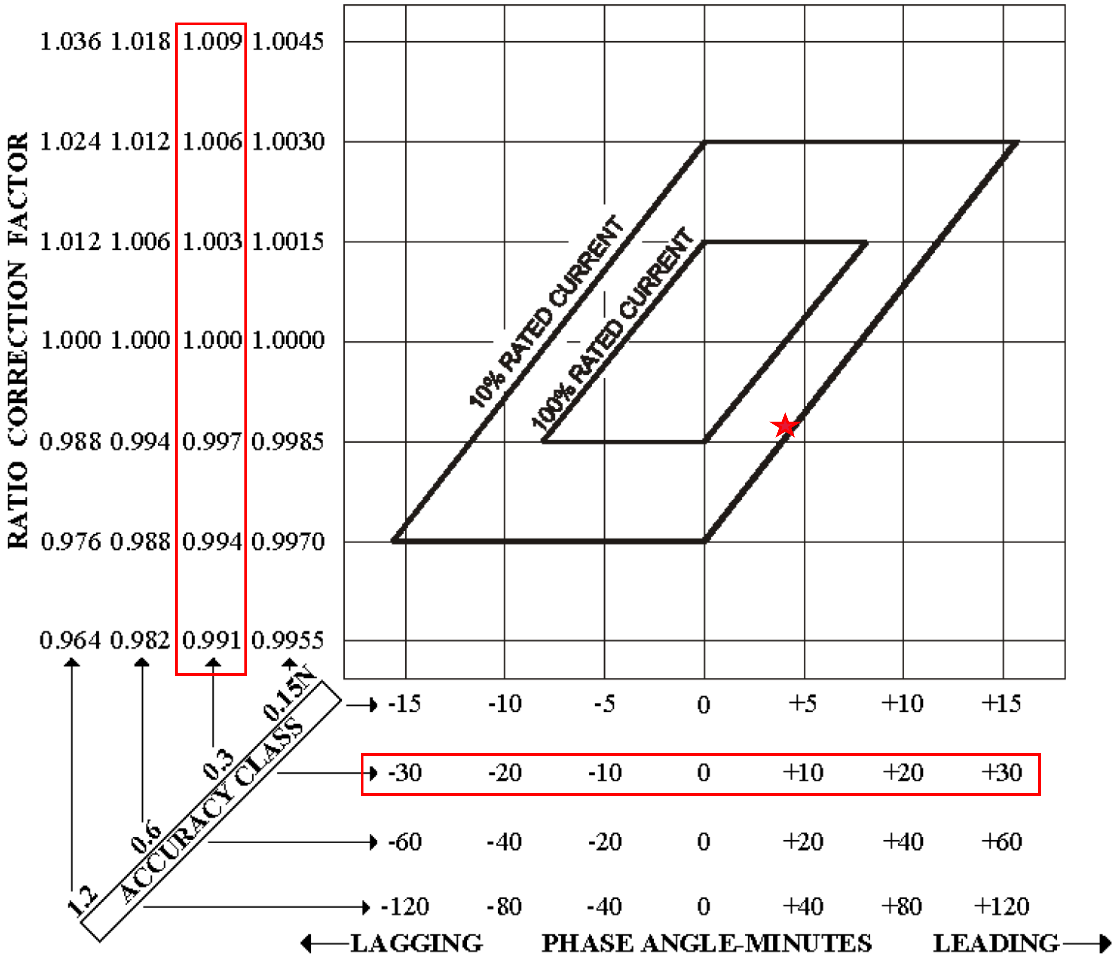
$$Acc = Greater\ of\ Acc1\ vs\ Acc2$$

$$Acc1 = |RCF - 1| \times 100$$

$$Acc2 = \left|RCF - 1 - \frac{\beta}{2600}\right| \times 100$$

$$\beta = Phase\ Difference\ in\ Minutes$$

- ***Given***: RCF 0.9975, Mins +8, Nameplate 0.3Acc
- Acc1 = 0.25 *Pass or Fail?*
- Acc2 = 0.558
- Accuracy Class = 0.558, *Pass or Fail?*
- *Fail @ 100%, Pass at 10%*



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CT Testing Methods

Secondary Injection

- Mobile, can be done in field
- Can determine other CT parameters for use diagnosing site issues
- Medium Accuracy

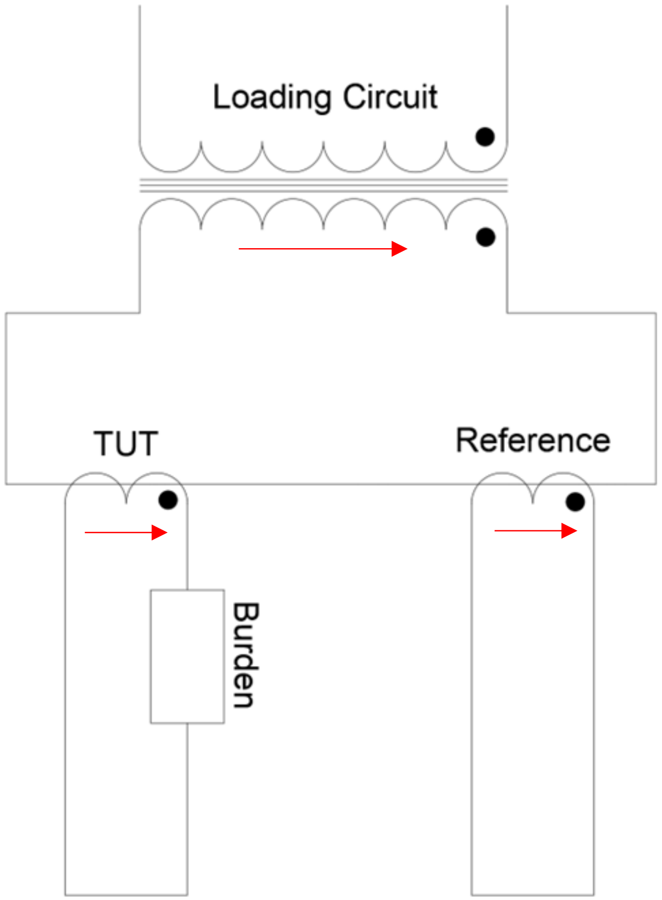
Direct Primary Measurement

- Mobile, can be done in field
- Testing can be done in conjunction with metering
- Medium-Low Accuracy

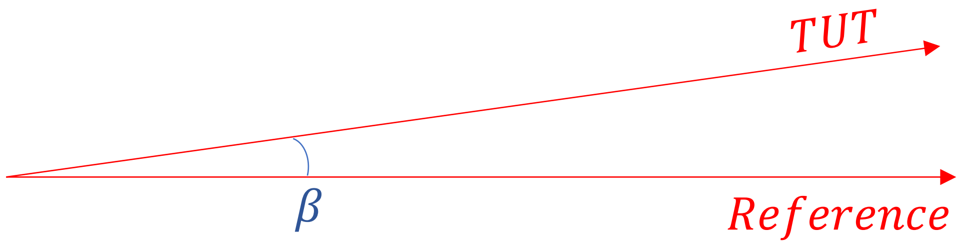
True Primary Reference Comparision

- Static, lab/truck based
- Testing with variety of parameters (purchasing/Eng.)
- High to Very High Accuracy

Understanding a True Primary Test



- A True Primary test, pushes the entire primary current through the CT to be tested, and a reference transformer.
- Both of these output their secondary current which are each read. The TUT must push its secondary Current through a Burden which will affect its output



Understanding a True Primary Test

TUT

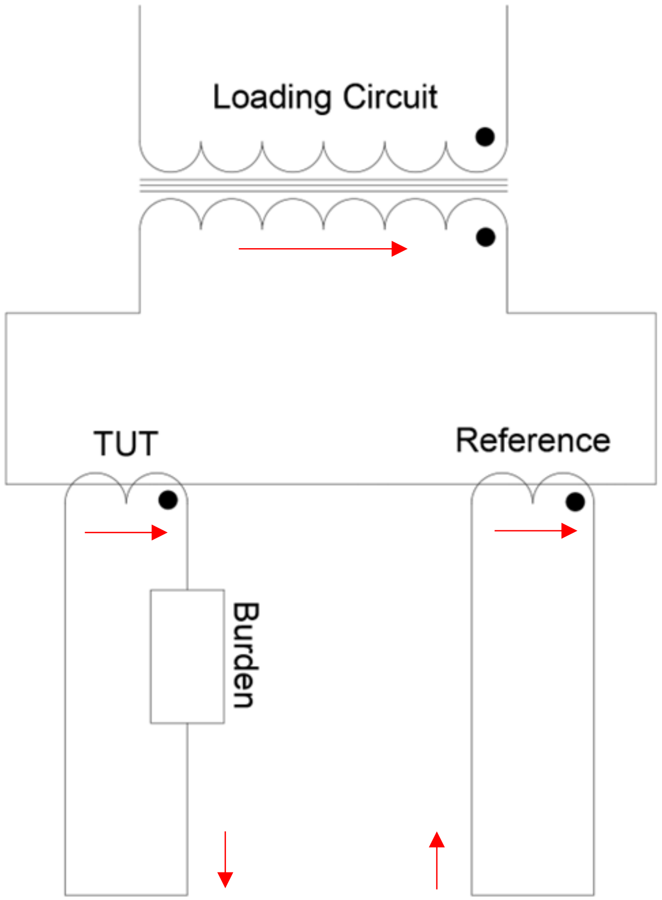
$Reference$

The difficulty without a trick…

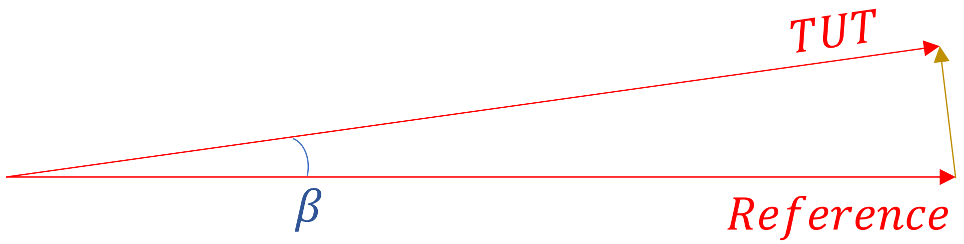
5.0000A vs 5.0200A

0.38Acc

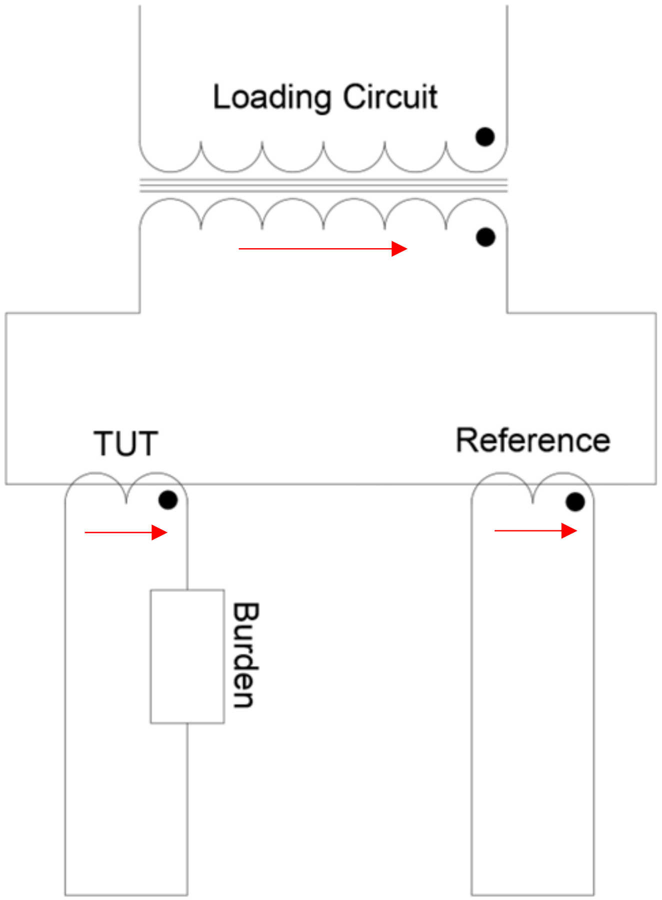
Understanding a True Primary Test



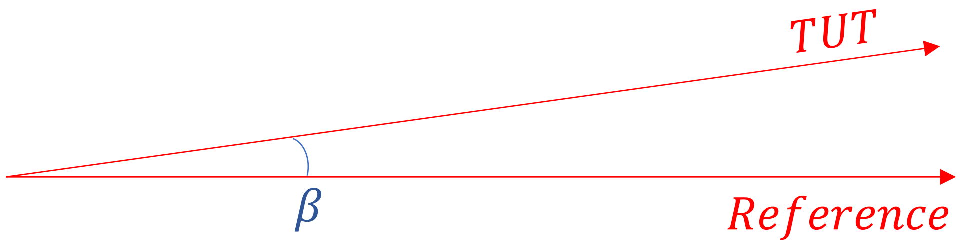
- Notice the Reference and TUT are opposing one another in the center…
- What happens to opposing currents in a branch?
- Summed Vector (opposite direction is subtractive)
  - *At Knopp, we call this the "Error" Vector*



Understanding a True Primary Test



- So, we have devised a test that tests a CT in the way that it will be used rather than secondary injection
- And, we have used "Electrical Trig" to increase the accuracy of the measurement vs measuring primary to secondary



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Understanding RCF: An Example

$$RCF = \frac{Reference\ Current}{TUT\ Current}$$

$$RCF = \frac{Measured\ Ratio}{Marked\ Ratio}$$

Take a 600:5 for example:

- Marked ratio: $\frac{600A}{5A} = 120$
- Primary Current = 600A
- Ref Current = 5.00A
- TUT Current = 4.99A

Calculate RCF by Current, and by Ratio

RCF by Current: $\frac{5.00A}{4.99A} = \mathbf{1.002}$

Ref Measured Ratio: $\frac{600A}{5A} = 120$

TUT Measured Ratio: $\frac{600A}{4.99A} = 120.24$

RCF by Ratio: $\frac{120.24}{120} = \mathbf{1.002}$

Understanding TCF: An Example

$$TCF = RCF - \frac{\beta}{2600}$$

From before, RCF = 0.9975, and phase = +8mins:

$$TCF = 0.9975 - \frac{8}{2600}$$

$$TCF = 0.9944$$

This is similar to RCF, but accounts for phase error as well and is what is typically used to correct for a CT's error if only one number can be given

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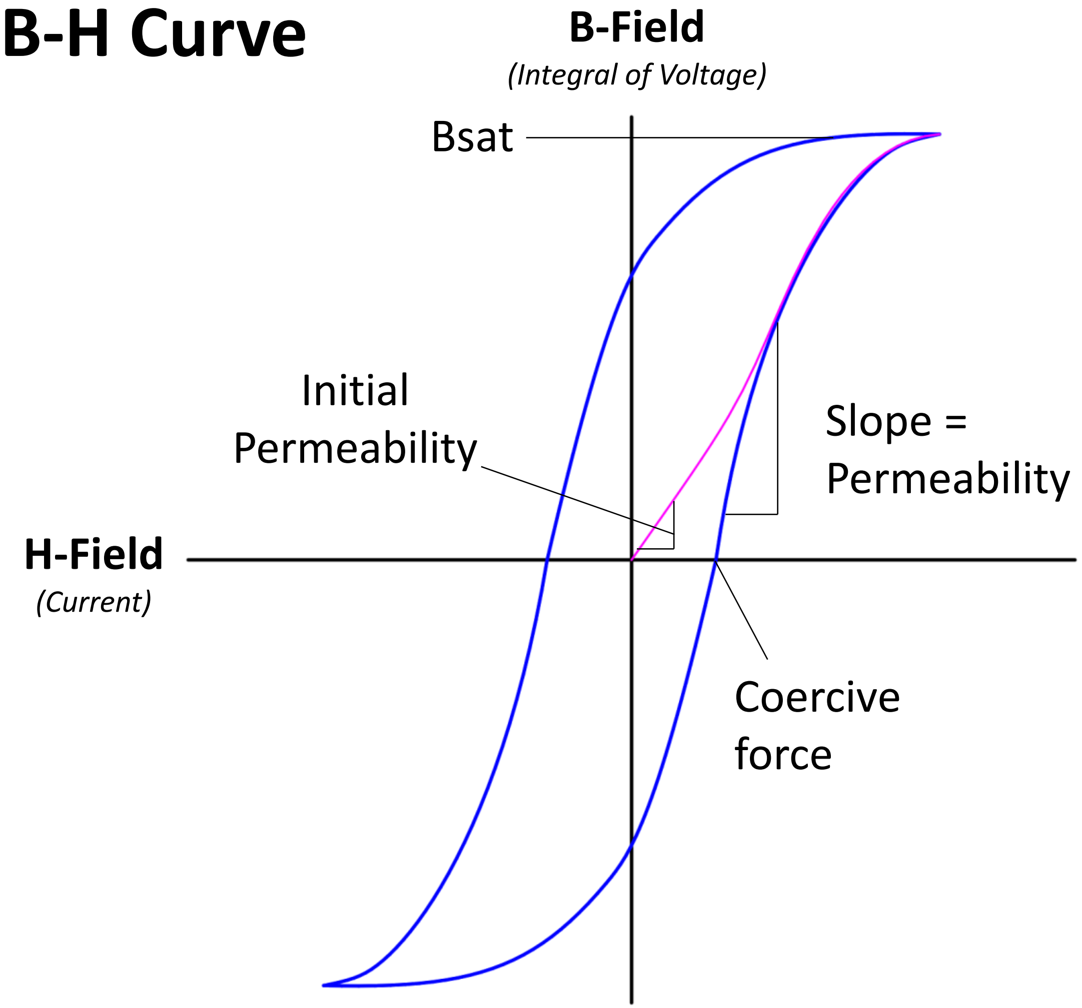
1% Contruction and Design

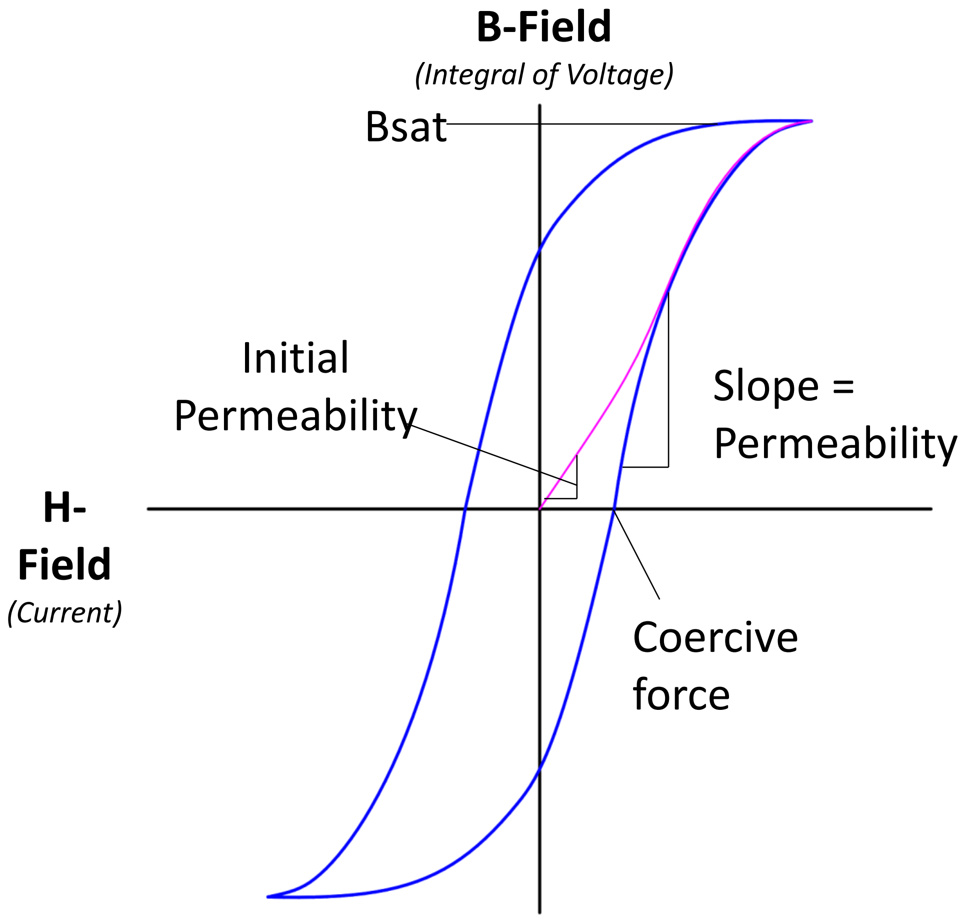
Transformer Magnetic Operation

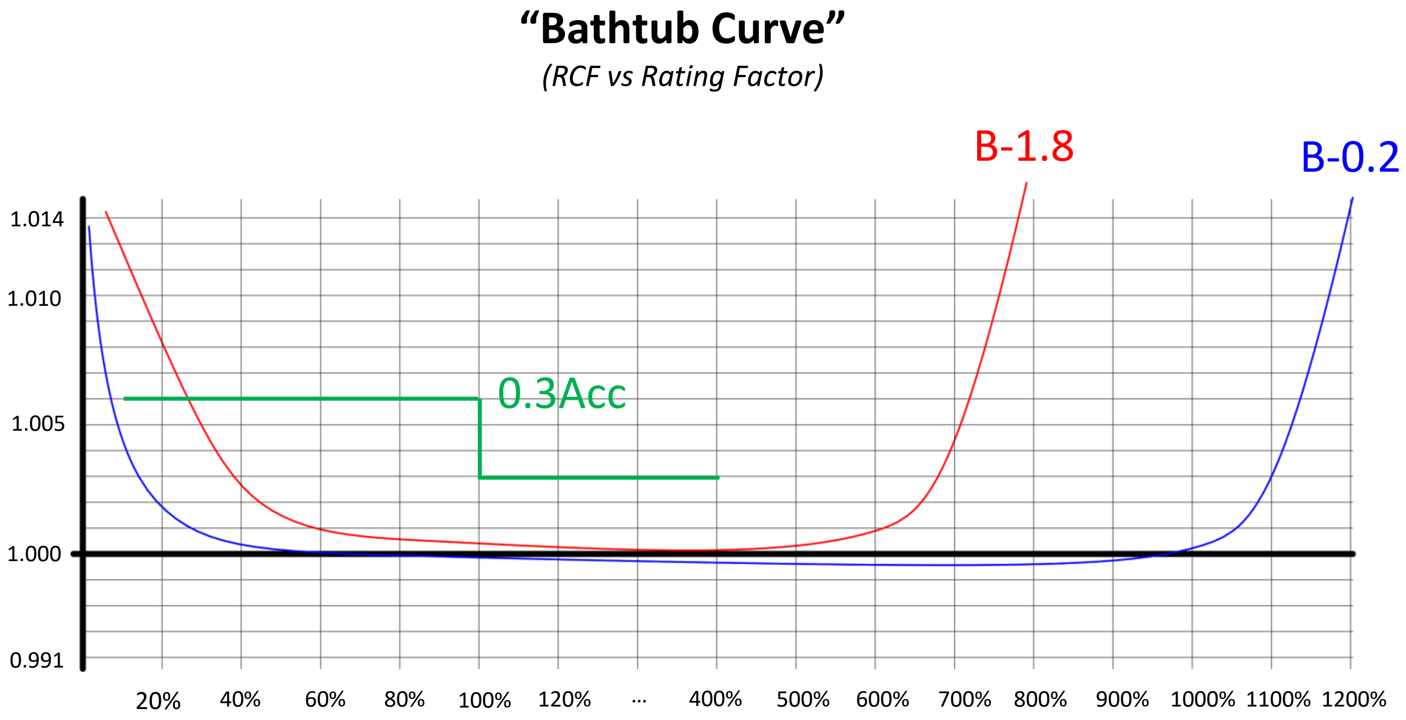
B-H Curve



- A Transformer is a magnetic device that reacts to current passing through a core
- The Core builds up a magnetic field
- In turn, the magnetic field creates a secondary current
- The Core can only contain so much field until it is saturated
- The area in graph is the CT core losses
- The consistency of the permeability slope yields a more linear transformer

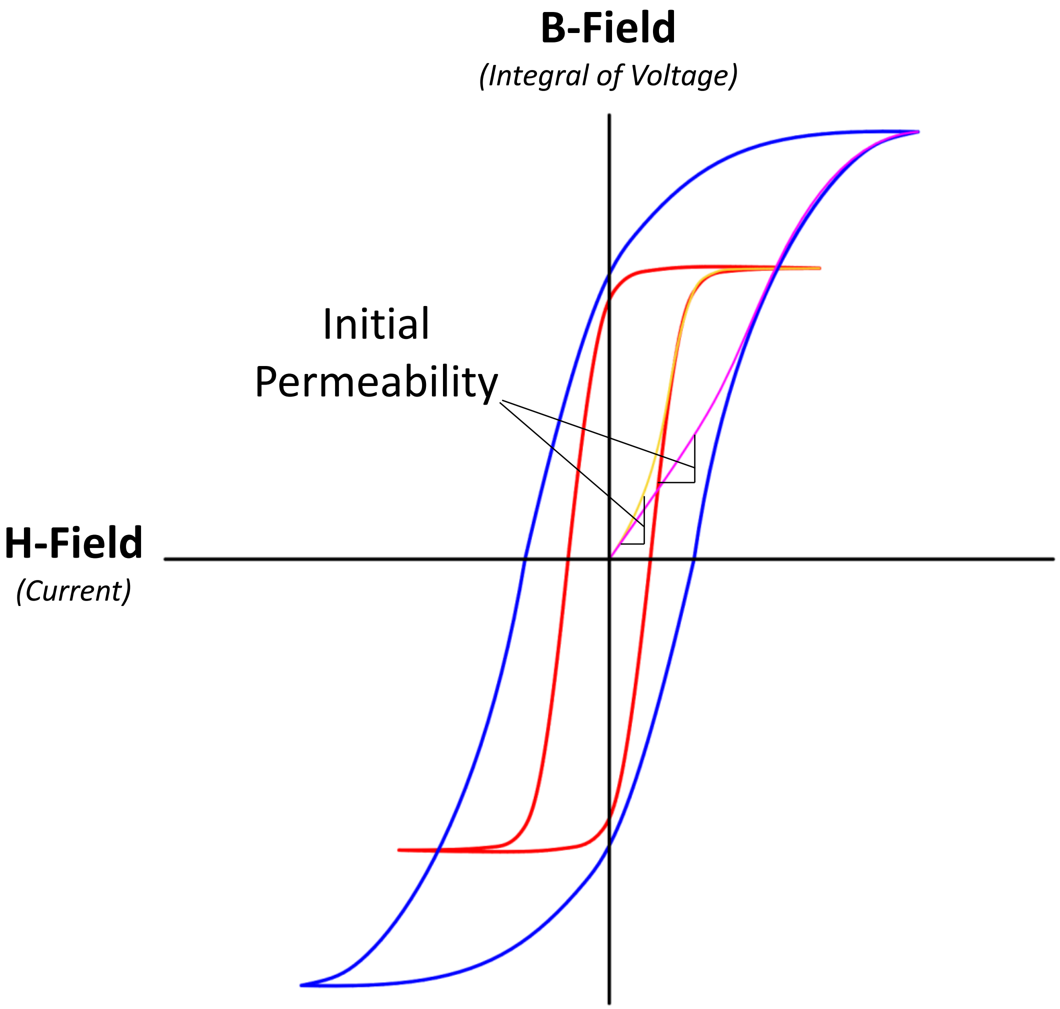
Transformer Magnetic Operation



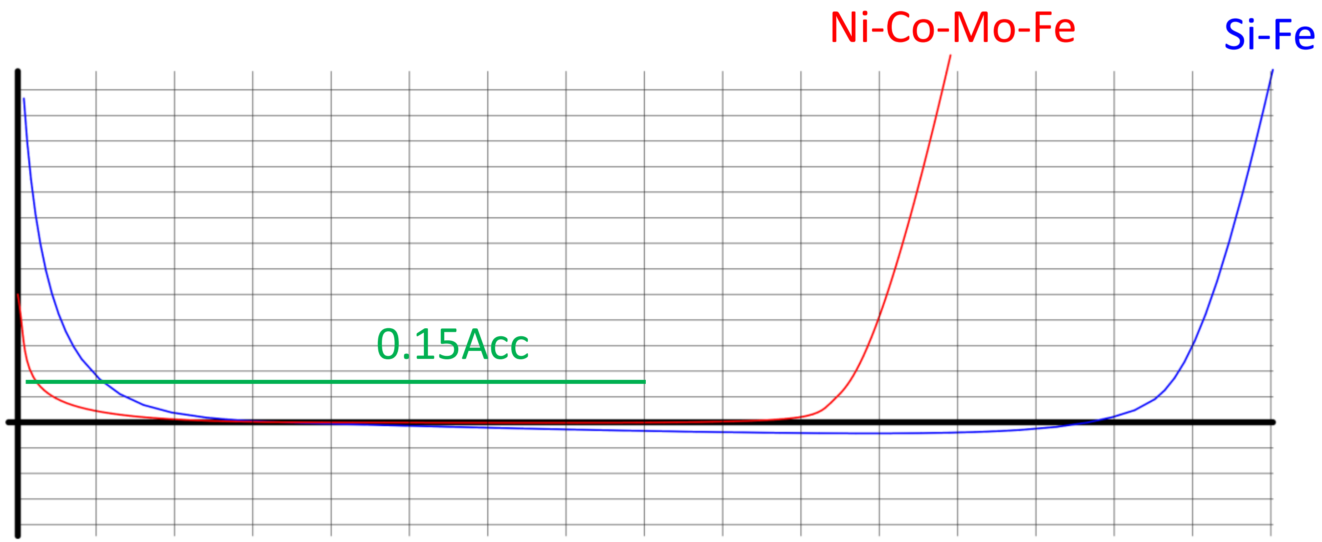


- Take note of initial perm and saturation
- Increased burden increases secondary voltage, hence Bsat is hit faster

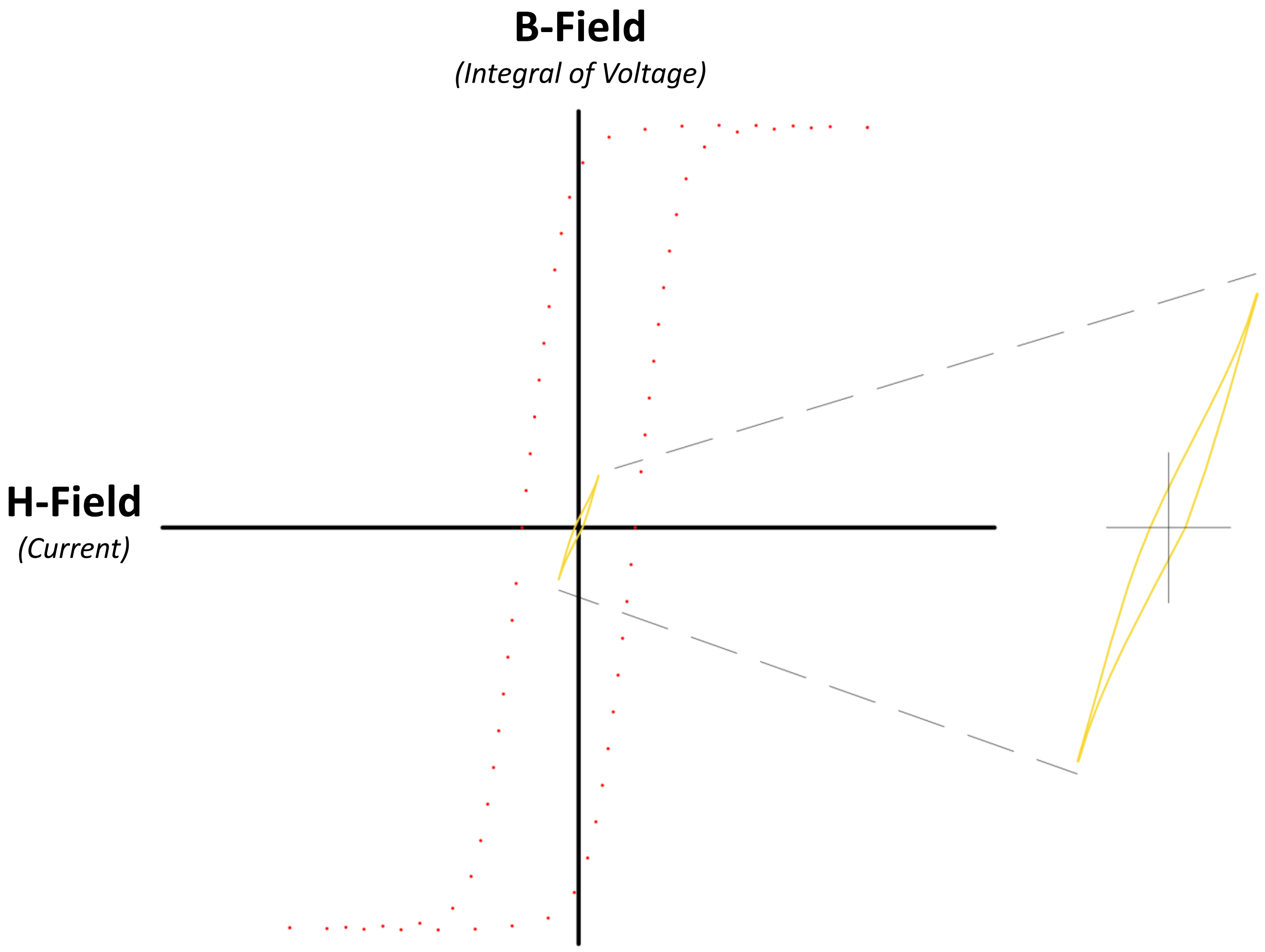
Material Selection



- In order to go lower, and be more accurate, more exotic materials were chosen.
    - Blue represents normal silicon steel, found in power transformers.
    - Red represents nickel and amorphous alloys
- Softer new materials have a lower saturation, but tend to be more linear and better low end
- Note the initial permeability slopes…



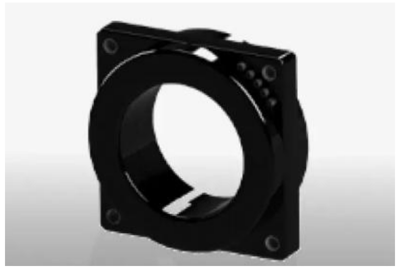
How CT’s Operate



- CT’s should never be run near saturation, they are a near zero flux device.
- If there was a true zero burden (including windings), no core losses, CTs would have almost no B-H curve as the ratio would be perfectly cancelled out
- This is why initial perm plays such a large role in material selection.
- Initial perm can be a bit erratic as its almost entirely material and material processing, so CT to CT can differ depending on process control.

Be sure to Test Upper and Lower

- Without tight enough Core material process control, CT's can have variability at the low end even with "higher end" Materials
- Shrinking the core can also improve the low end by shifting the bathtub to the left. This can result in the high end starting to come close to saturation on larger burdens
- Softer Cores also can be more sensitive to magnetization due to the reduced B scale



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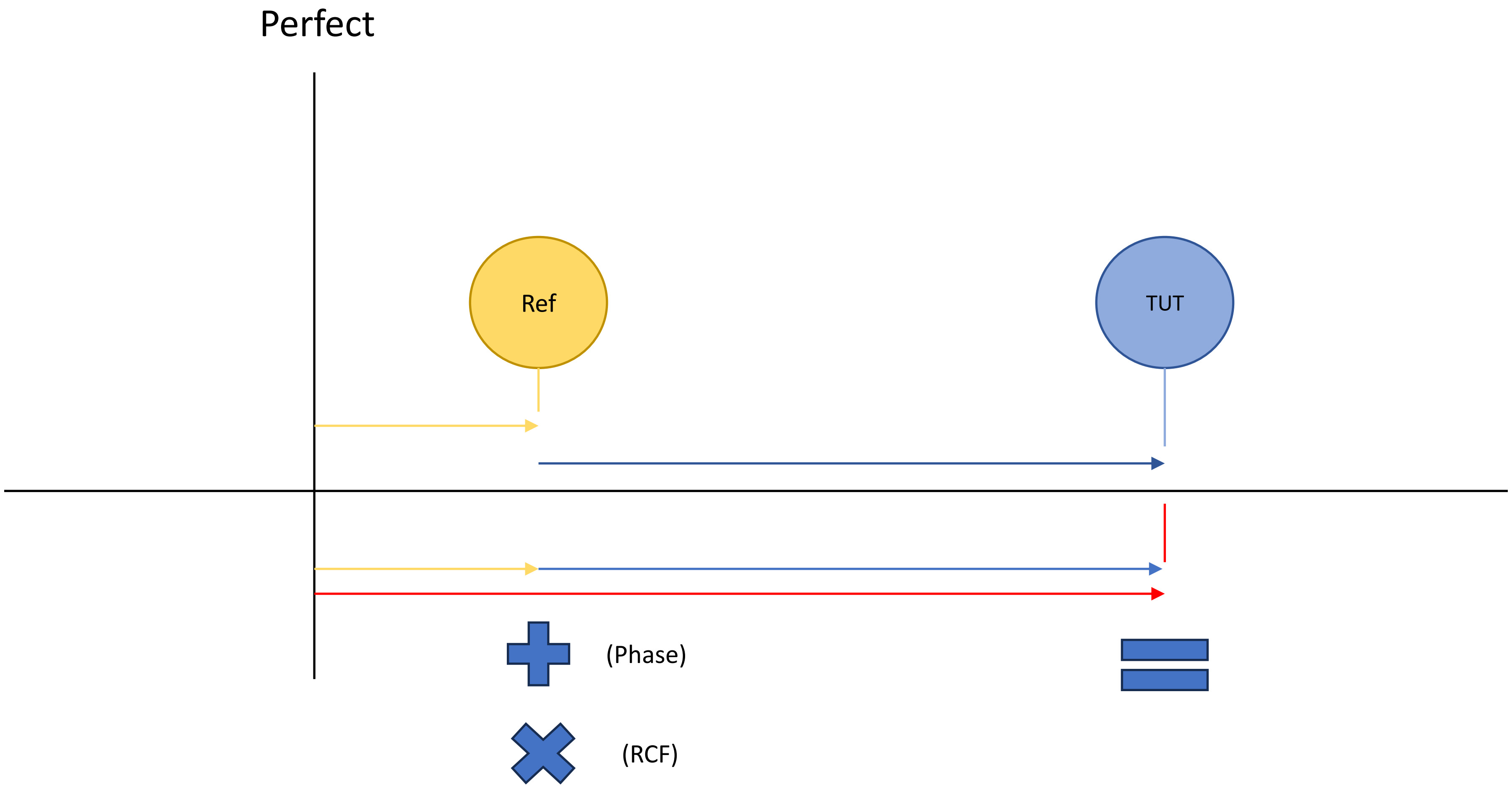
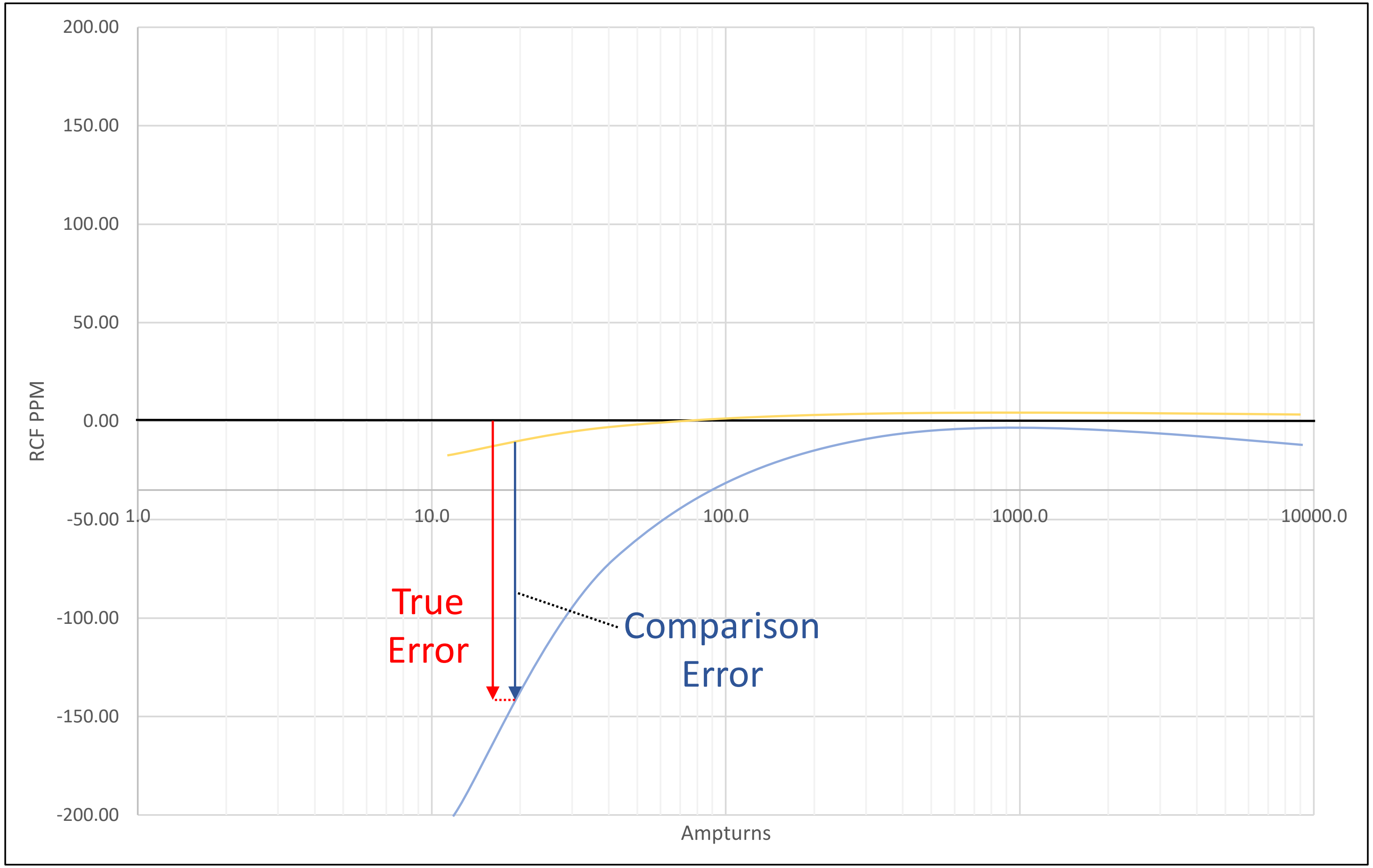
True Error



True Error


200.00
150.00
100.00
50.00
0.00
-50.00
-100.00
-150.00
-200.00
RCF PPM
1.0
10.0
100.0
1000.0
10000.0
Ampturns
True Error
Comparison Error

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Course Feedback

Please Take a Few Minutes To Provide Feeback About The Course & Instructor

Track 3 - Testing 1% Transformers
72225 8:45AM Ben Bollinger

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Questions?

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