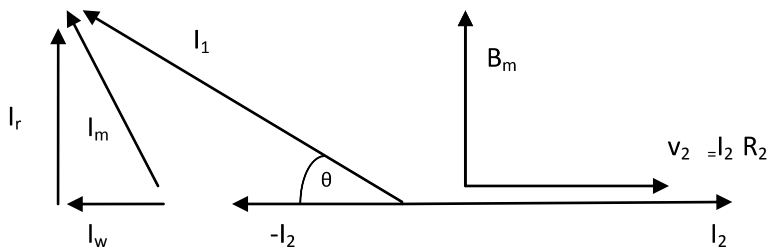
Current Transformer Design Guide

An effective design of a Ring Type C.T. may be produced first time using the following procedure, without any previous experience.

Principles

In operation the C.T. will induce current in its secondary winding and burden which serves to completely oppose the magnetising effect of the primary current, except for that small proportion required to magnetise the core. This core magnetising component will then be the only source of error if the secondary current is to be used as a measure of the primary current.

Making two assumptions i.e. that the CT has no leakage reactance and that its burden is purely resistive, the vector diagram for a one-to one ration CT will look like this;



N_2 = No. of secondary turns
V_2 =Secondary Voltage
R_b = Burden Resistance
I_1 = Primary Current
I_2 = Secondary Current
I_m = Excitation current
I_r = Reactive component of I_m
I_w = Watt loss of component I_m
e = Ratio Error

From this diagram, the primary current I_1 differs from the secondary I_2 in magnitude and phase angle. The angle error θ is $\sin^{-1} I_r/I_1$ and the magnitude of $I_1 = [(I_2 N_2 + I_w)^2 + I_r^2]^{½}$

In practice, the angle θ is so small as to allow the approximations $I_1 N_2 + I_w$ and $\theta = I_r / I_1$ radians, i.e. the current error is due to the watt loss component of the excitation current and the phase error is proportional to the reactive component I_r . The ratio error can be corrected by an amendment to the turns ratio, the secondary winding being reduced by several turns or fractions of a turn. Because of the non - linearity of the excitation characteristics, such corrections do not maintain accuracy as the current changes, and a choice must be made which gives good balance over the whole range of current. Cores can be supplied with drilled holes, enabling the fractions of a turn to be wound.

The phase angle error, on the other hand, cannot be corrected , being a function of the reactive component of the excitation characteristics which vary widely over the current range and must take priority in the design of the transformer and choice of core.

The procedure is best described by considering an example, as follows:

1. Transformer Specification
   Ratio 150/1
   50Hz. Burden 2.5Va at Power Factor =1.0
   Accuracy BS.3938, Class 0.5
   Insulation Level – 11 Kv.

   Maximum Permissable Error

From 10% to 20% of rated current	Ratio error Phase displacement	1% 60 minutes
From 20% to 100% of rated current	Ratio error Phase displacement	0.75% 45 minutes
From 100% to 120% of rated current	Ratio error Phase displacement	0.5% 30 minutes

2. Internal Diameter
   The I.D. of the core is fixed by physical consideration of the primary conductor and insulation, plus allowance for the secondary winding and core insulation. The main insulation is invariably placed on the primary conductor so that a 20 mm dia. conductor insulated for 11 Kv will have an overall diameter of about 40mm. The Secondary winding and core insulation for a nominal 660 volts lead to the choice of core I.D. of 60mm. Assuming a maximum O.D. of 110mm, the mean path length will then be $\pi\left(\frac{60+110}{2}\right) = 267$mm.

3. Flux Density
   The requirements of phase displacement and angle error limit the working flux density of the core. An estimate of the flux density can be made by considering one working condition, preferably one likely to be most stringent. So, considering the phase displacement at the 20% full load condition –
   $\mathrm{I}_1 = 30$ amps $\quad\quad \theta = 45'$

   From phase diagram, $\quad$ Sin $\theta = \frac{\mathrm{I_r}}{\mathrm{I_1}}$

   $$\therefore \mathrm{I}_{\mathrm{r}=\mathrm{I}_1}\ Sin\ \theta = 30\ \mathrm{x}\ .013$$

   $$= 0.4\mathrm{A}$$

   $$\mathrm{H_r} = \frac{\mathrm{I_r}}{\mathrm{L_m}} = \frac{.4}{0267}$$

   $$= 1.5\mathrm{A/M}$$

   By inspection of resolved component curves for TS grade core material
   - $\mathrm{H_r} = 1.5$ when $\mathbf{B_m}$**= 60mT.**

   If the flux density at 20% F. L condition is chosen at 60mT, it will rise to 300mT at full load, add other points pro-rata which can now be checked for error. If for any condition the phase displacement is excessive, a lower flux density must be chosen.

Condition (%Full Load)	120%	100%	20%	10%
Primary current I_1 (amps)	180	150	30	15
Bmax (mT)	360	300	60	30
H_r (from curves) A/m	4.5	4.0	1.5	0.95
I_r (H_r x 0.267	1.2	1.068	0.4	0.307
θ(Sin^{-1} $I_r/I_{1)}$	23'	24'	45'	58.5'
H_w (from curves) A/m	5.2	4.5	1.05	0.6
I_w (H_w x 0.267)	1.39	1.20	0.28	0.16
E(^{I}w/I_1 x100) %	0.77	0.80	0.94	1.07
1 turn compensation %	- 0.67	- 0.67	- 0.67	- 0.67
Compensation error e_1 %	0.1	0.13	0.27	0.4

4. Compensation
   Assuming the phase angle displacements are within allowable limits, the ratio error is calculated for each condition as shown above, and a turns ratio correction is chosen which will make then acceptable. In this case, 1 turn correction is made by reducing the secondary winding to 149 turns.

5. Cross Sectional Area
   Having chosen the working flux density at full load the required cross sectional area is calculated thus:-

   Voltage across Burden at full load =2.5 volts
   Allowing secondary winding resistance 0.1 ohms
   Then additional voltage for internal burden = 0.1 Volts
   Total secondary E.M.F. = 2.6 volts
   For 149 turn secondary
   Volts/Turns =$\frac{2.6}{149}$ = 0.0175 Volts
   At rated condition B_m = 0.3 Tesla
   By transformer equation $\frac{V}{T} = .0222 \text{ x } B_m \text{ x Afe}$

   $\therefore$ Nett C.S.A. Afe $= \frac{.0175}{.0222 \times 0.3} = 2.63 cm^2$

   Allowing 0.95 space factor, Gross C.S.A. = 2.77 cm^2

6. Final Dimensions
   Before fixing the final dimensions, take account of possible core degradation during winding. If protected by a case, this will be small, but it is prudent to allow 20% extra area for a core taped, wound and impregnated.
   In this example, a strip width of 20 mm with a build up of 17 mm gives a final core dimension of
   I.D. – 60 mm
   O.D. – 94 mm
   Length – 200 mm