10.5.5. Means to reduce Errors in Current Transformers. It is clear from Eqs. 10.22 and 10.23 that for usual types of burdens, the difference between actual transformation ratio and the turns ratio depends largely on the loss component $I_L$ and the transformer phase angle depends largely on magnetizing current $I_m$. It is obvious that if the ratio has to be close to the turns ratio and the phase angle is to be small, $I_L$ and $I_m$ must be small as compared to $I_p$.

There are some design features which help us to minimize the errors and they are discussed below:

### Design Features of Current Transformers

1. **Core.** In order to minimize the errors the magnetizing current $I_m$ and loss component $I_L$ must be kept to a low value. This means that the core must have a low reluctance and a low core loss. The reduction of reluctance of flux path can be brought about by using materials of high permeability, short magnetic paths, large cross-section of core and a low value of flux density. The current transformers are, in fact, designed for much lower flux densities than that are used for power transformers. This is especially important for current transformers used for protective relays which are frequently required to have a fair accuracy at currents many times the rated current (20 to 30 times the rated value), in order that the relay operation may be correct in the event of a short circuit or a fault on the system, particularly when differential relaying schemes are used.

The number of joints in building up cores should be minimum a far as possible because joints produce air gaps which offer paths of high reluctance for the flux. The mmf consumed by joints can be reduced by properly lapping the joints and tightly binding the core. The core loss is reduced by choosing materials having low hysteresis and low eddy current losses, and by working the core at low flux densities.

Present-day magnetic materials used in current transformers are divided into three categories:

(i) hot rolled silicon steel; (ii) cold rolled grain oriented silicon steel; and (iii) nickel iron alloys.

In current transformer practice hot rolled silicon steels (4% silicon) are used in a variety of forms. For ring type current transformers “ring” stampings are commonly used. For wound type, T-U, L or E and I stampings are used. In the highest grades of transformers, the core is built of ring shaped stampings stacked in cylindrical form as shown in Fig. 10.10. An alternative method employs cores that are made of strip wound in spiral form like a clock spring (Fig. 10.11). These are called toroidal cores. The latter method is much to be preferred when grain oriented magnetic materials are being used as it ensures that the flux path is always along the grains and hence there is minimum reluctance. Another advantage of spiral type of cores is that the joints are entirely eliminated.

![Fig. 10.10 Ring type core.](image)

![Fig. 10.11. Spiral type core.](image)

High permeability nickel iron cores are used for high precision current transformers. Mumetal (76% Ni) cores are very common as it has the property of high permeability, low loss and small retentivity — all of which are advantageous in current transformer work. But its maximum relative permeability (90,000) occurs with a flux density of only 0.35 Wb/m² as compared with maximum relative permeability of silicon steel (4500) occurring at a flux density of about 0.5 Wb/m². Thus Mumetal saturates at a low flux density and is, therefore, not useful for protective current transformers like those used for overload relays etc. Also Mumetal (and also other nickel iron alloys) are costlier.

Permendur (49% Co and 49% Fe) has the advantage of a very high saturation density of 2 to 4 Wb/m² as compared with 0.7 to 0.8 Wb/m² of other high permeability alloys.

Hipernik (50% Fe and 50% Ni) has high permeability at low flux densities and reasonable high saturation density and therefore it is frequently used for current transformers.

2. **Primary Winding Current Ratings.** Whatever equipment a C.T. is feeding, it is desirable that the ratio of exciting current to primary current should be small. This means that the ratio of excitation mmf
primary winding mmf should be low. It is difficult to achieve this condition if the latter quantity (primary winding current or mmf) is small and an improvement in performance is always obtained by increasing the primary winding mmf. Satisfactory results can usually be achieved if the total primary winding mmf at rated current is 500 A. Thus transformers with a rated current of 500 A or more are provided with a single turn primary. Transformers for ratings below 500 A are where possible, provided with multiturn windings, if this enables the core size to be reduced.

With the advent of improved magnetic materials and the development of methods for biasing the core to improve permeability, single turn primary winding can be used for even 100 A primary winding current.

3. Leakage Reactance. Leakage reactance tends to increase ratio error. Therefore, the two windings, primary and secondary should be close together to reduce the secondary winding leakage reactance. Use of ring shaped cores around which toroidal windings are uniformly distributed also leads to low values of leakage reactance.

4. Turns Compensation. We have, actual transformation ratio:

\[ R = n + \frac{I_s}{I_s} \]  

(Eqn. 10.20)

Thus if we make the “nominal ratio” equal to the turns ratio the actual transformation ratio becomes more than the nominal ratio. Now if we reduce the turns ratio and keep the nominal ratio equal to the earlier value, the actual transformation ratio will be reduced. This would make actual transformation ratio nearly equal to the nominal ratio. Let us make it clear with the help of an example.

Let us consider a 1000/5 A current transformer with loss component equal to 0.6 percent of primary winding current.

Its nominal ratio \( K_n = 1000/5 = 200 \). Loss component \( I_s = (0.6/100) \times 1000 = 6 \) A.

Let the number of primary turns \( N_p = 1 \).

If the turns ratio is equal to the nominal ratio, we have \( n = 200 \).

\( \therefore \) Secondary winding turns \( N_s = nN_p = 200 \times 1 = 200 \).

Actual ratio \( R = n + \frac{I_s}{I_s} = 200 + \frac{6}{5} = 201.2 \).

Now suppose we do not use 200 turns for the secondary winding and instead use 199 turns.

Actual transformation ratio with turns compensation \( R = n + \frac{I_s}{I_s} = 199 + \frac{6}{5} = 200.2 \).

Thus we find that by reducing the secondary winding turns slightly, the actual transformation ratio is made nearly equal to the nominal ratio.

Usually the best number of secondary winding turns is one or two less than the number which would make actual transformation ratio equal to nominal ratio of the transformer. The phase angle error is effected very little by a change of one or two turns in the secondary winding.

The correction by reduction in secondary winding turns, is exact only for a particular value of current and burden impedance. The C.T. in this case may be called “compensated”.

The errors can also be reduced by:

5. Use of Shunts. If the secondary winding current is too large, it may be reduced by a shunt placed across the primary or the secondary winding. This method makes an exact correction only for a particular value and type of burden. It also reduces phase angle error.

6. Wilson Compensation Method. Reduction of one or two turns of the secondary winding, no doubt, reduces the ratio error, but it has no effect on the phase angle error. Also this method is too coarse a method for ratio adjustment and therefore we must use a method which exercises a finer control, say which is equivalent to reduction to a fraction of a turn. A compensated type of design was given by S. Wilson of the General Electric Company (Fig. 10.12). This method gives finer adjustments.

It employs a few turns of wire called auxiliary secondary turns passed through a hole in the core and connected in series with the secondary winding. A short-circuited turn is placed around one position of core to improve the phase relationships.

The auxiliary turns are connected to magnetize in the same direction around the core as the main secondary winding and thus their effect opposes the flux set up by the primary winding. The auxiliary turns, tend to set up a circulating flux around the hole as indicated by the dotted line in Fig. 10.12 (b). The two
fluxws are additive in the section A of the core and subtractive in section B. At low flux densities the addition in flux is equal to the subtraction in flux. However, as the flux densities increase (with larger currents $I_p$ and $I_s$) section A tends to saturate, so that the flux in section A is no longer linearly proportional to the current and the increase in flux in this portion is less than linear proportional to the current. The action is equivalent to transforming some of the core flux to section B of the core, where it links with the auxiliary turns and gives the effect of increased secondary winding turns. An increase of secondary turns means a reduction of $I_s$, as compared with an uncompensated transformer causing an increase in ratio $R$. This action is needed to flatten the curves relating the ratio and phase angle with secondary current (Figs. 10.8 and 10.9) are flattened out so that the errors are practically constant (and of course known over a wide range of secondary winding current). This is the greatest advantage of this method. The curves can be lowered or raised by adjusting the number of auxiliary turns.

The shorted turns around part of the core makes the flux in that part lag in phase behind the main flux. The action of this turn is like that of a shading band. The small lag effect produced on secondary winding current $I_s$ brings it closer to primary current $I_p$ and thus phase angle errors are reduced.

![Diagram of Wilson compensation method](image)

**(a)** Prim.  
Sec.  

**(b)** Sec.  
Prim  

**Fig. 10.12. Wilson compensation method**

7. **Two Stage Design.** This design utilizes a second current transformer to correct the error in secondary current of first transformer. This method in general is applicable to an energy meter because a second coil is needed in the meter to carry the error-correcting current, unless an auxiliary transformer is used.

**10.5.6. Construction of Current Transformers.** The current transformers may be classified as:

(i) **Wound type.** A current transformer having a primary winding of more than one full turn wound on core.

(ii) **Bar type.** A current transformer in which the primary winding consists of a bar of suitable size and material forming an integral part of transformer.

Figs. 10.13 and 10.14 show wound type and bar type transformers respectively.