

PRECISION CURRENT TRANSFORMER CALIBRATIONS UP TO 10 000 AMPS AND BEYOND.

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Introduction: Current transformers are a key element in the measurement of electrical currents up to 10 000 amperes and beyond in the electrical supply industry. Measurements need to be made at the point of generation, by the twelve electricity supply companies and at the points of distribution to the whole range of users from major industries to domestic premises. An overall limit of error of 0.5 % is set by the industry on the measuring equipment for electric power. This is made up of 0.2 % for voltage transformers, 0.2 % for the measurement system and 0.1 % for current transformers. In fact the limit of error for current transformers is more severe than at first sight since they have a wide dynamic range from approximately 5 % to 120 % of rated current.

For convenience, when current transformers having errors of one tenth, or less, of the permitted error are used no correction for their current or phase angle errors is normally made. As a consequence laboratory standard transformers are designed to have current errors no greater than 0.01% and phase angle errors of less than 0.01 centiradian. Other measurement transformers may have errors up to ten times these levels, depending on their application. Calibration methods have been developed at NPL to meet these requirements and have been updated to enable current error measurements to be made down to 1 ppm and below in order to calibrate high precision current comparators and transformer test sets. In addition methods for on site measurements at currents above 10 000 amperes have been successfully developed.

Resistance bridge method: The basic method of determining the current error is by comparison with resistance standards. A resistor R_p is connected in series with the primary winding of the current transformer under test and a second resistor R_s is connected in series with the secondary winding as shown in figure 1.

The nominal ratio R_s/R_p of the resistance standards is chosen to be the same as the nominal ratio of the transformer under test. The primary current is adjusted to the desired value and the bridge is balanced by shunting R_p or R_s with resistance r and capacitance C adjusted as required. The current and phase errors can be calculated from the measured values of the shunts used.

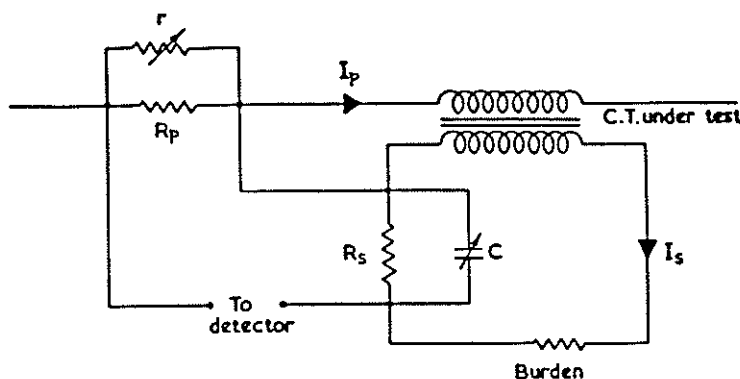


Figure 1: Circuit for the resistance bridge method.

To a close approximation:-

$$\text{Current Error \%} = \pm (R/r) \times 100$$

and

$$\text{Phase Error} = \pm 2 \pi f C R \text{ microradians}$$

where:

C is the shunt capacitance in microfarads,

f is the supply frequency in hertz,

R is either R_p or R_s , in ohms, dependent on the position of the shunt resistor r in ohms,

the signs of the errors are derived from the composition of the bridge arms.

This method has significant disadvantages. Firstly, the values of the resistances and capacitances must be known with an uncertainty of 10 ppm if an uncertainty of 30 ppm is required on the calibration of the transformer. This usually necessitates the measurement of these components immediately prior to the transformer calibration. Secondly, high current carrying, low value resistance shunts are required for high primary currents and their resistance errors vary with air temperature and load current. Thirdly the sensitivity of the bridge is low. For these reasons the use of the resistance bridge is usually restricted to the calibration of the NPL standard transformers for ratios unobtainable on the current comparators mainly used nowadays and for some types of current transformer test set and transformers where there are problems caused by interwinding capacitance.

Testing by comparison with a standard transformer: By careful choice of core material and winding techniques, it is possible to produce standard transformers having ratios from 5/5 A up to 20 000/5 A with current errors of the order of 10 ppm and correspondingly low phase angle errors. With care, these can be calibrated as described in the previous section and then used in a method developed at NPL by Arnold¹ to calibrate other current transformers with an uncertainty of the current error of 20 ppm. The basic circuit, known as the Arnold bridge, is shown in figure 2. The standard transformer is chosen to have the same nominal ratio as the test transformer.

The primaries of the standard and test transformers are connected in series and the secondaries also connected in series, then a current equal to the difference between the standard and test secondary currents will flow through resistor R. This difference current is determined in magnitude and phase using an a.c. potentiometer to measure the voltage drop across resistor R. Resistor R_t is a non-inductive resistor forming the test burden and A is an ammeter for monitoring the secondary current. The components r and m of the a.c. potentiometer are supplied by a 5/5 isolating transformer connected in the secondary circuit of the standard transformer.

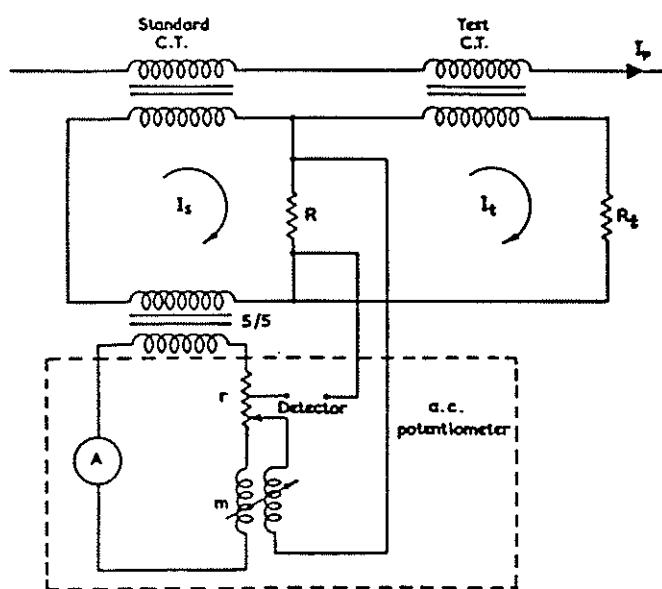


Figure 2: Circuit of the Arnold bridge.

The variable mutual inductor, m , has a value ± 2.4 microhenries and r is a centre-tapped slide resistor of value 500 microhms. At balance the difference in the current error between the standard and test transformers will closely approximate to the value $(r/R) \times 100\%$ and the difference in the phase angle error will approximate to $2\pi fm/(rR)$ microradians for m in microhenries, f in hertz and R, r in ohms. Corrections are then applied for the measured errors of the standard transformer. The method has a number of advantages over the resistance bridge. Once a standard transformer has been calibrated on a resistance bridge, it need only be re-checked at infrequent intervals since the errors of the NPL standard transformers are very stable. The sensitivity of the Arnold Bridge is ample for all but exceptional conditions. The standard transformer is not appreciably sensitive to temperature and has been calibrated over the working current range. A current range from 1 to 10 000 amperes can be covered using a small number of multi-ratio transformers. However, nowadays not all the required ratios can be realised in this way due to the limited range of standard transformers.

The compensated current comparator method: The compensated current comparator designed by Kusters and Moore^{2,3} forms the basis of a precision reference standard for current transformer calibration. Figure 3 shows the construction of the comparator and figure 4 shows the circuit. With the balance control set to zero, the compensating winding, which has the same number of turns as the secondary winding, will carry a current which is the difference between the comparator secondary winding current and the test transformer secondary current.

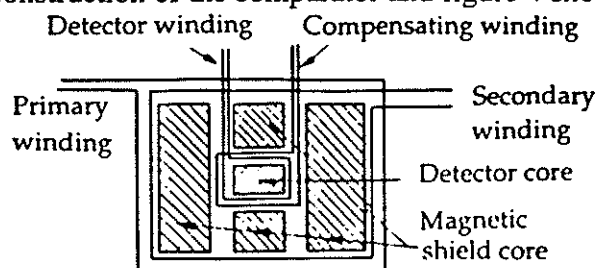


Figure 3: Comparator construction.

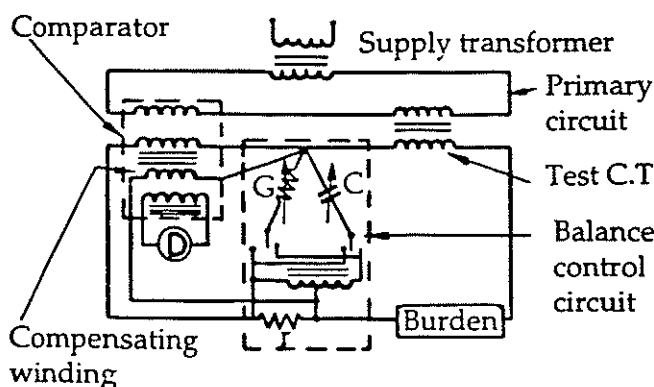


Figure 4: Comparator circuit.

If i is the nominal secondary current and α and β are respectively the errors of the comparator and the test transformer secondary currents, the compensating winding current is $(i + \alpha) - (i + \beta)$ which is equal to $(\alpha + \beta)$. In linking the detector core, the compensating winding ampere turns due to α will subtract from those of $(i + \alpha)$ due to the secondary winding, giving a resultant due to i , which exactly cancels the primary ampere turns. The detector core is

therefore magnetized only by a current β , the error of the test current transformer. An equal and opposite current from the balance control circuit is injected into the compensating winding to give null deflection of the detector. The error β is then given by $i r (G + j\omega C)$.

Inherent errors arise from imperfections of the linkages of all the windings on the detector core. With care these errors can be made exceedingly small. With zero burden they are less than 0.1 ppm and 0.1 microradian. Even with a burden of 750 VA the residual error in the measurement is less than 3 ppm and 3 microradians. At NPL we have two commercially produced current comparator systems, one for ratios from 4/5 A up to 1200/5 A and the other having over 2500 ratios in the range 5/5 A up to 12 000/5 A. Both can be used with secondary

currents of 1 A with ampere turn ratios corresponding to those using a 5 A secondary current.

Electronically aided compensated current comparators: The original design of comparator has been modified by the addition of a tertiary winding on the core of a standard transformer³. A servo circuit and detection system control the current in this winding at a level which compensates for the errors in the standard transformer. An auto balancing test set measures the magnitude and phase of the difference current between the compensated standard transformer and the test current transformer. The range of this type of compensated current comparator is from 5/5 A up to 5000/5 A and the uncertainty of the measurement system is of the order of 10 ppm and 10 microradians. Many intermediate ratios between those provided by the current comparator can be obtained using a range extender which provides a range of 40 % to 149 % of a nominal ratio. The auto balancing test sets can also be used with the range of non-compensated NPL standard transformers, calibrated using either a resistance bridge or one of the compensated current comparators.

Measurements above 10 000 A: At currents above 5000 A, aperture type NPL standard transformers can be calibrated using multiple primary turns to achieve ratios up to 20 000/5 A. These transformers can then be used for calibrating test current transformers up to ratios of 20 000/5 A. Unfortunately, a practical difficulty arises in that the inductance of the loop of the primary circuit is appreciable due to the need to space the return conductor of the loop at sufficient distance (up to 3 or 4 metres) from the centre of the test transformer since the latter usually is constructed without shielded windings. The available VA from the NPL generator set and supply transformer limits in house measurements to about 12 000 A. However, measurements of ratios up to 20 000/5 A, which require currents of up to 24 000 A to achieve the necessary upper condition of 120 % of rated current, have been successfully carried out on site using customer's own high current supplies.

Uncertainties: Whilst the inherent uncertainties of the current transformer calibration systems in use at NPL at present are between 0.1 ppm and 10 ppm for current error and between 0.1 and 10 microradians for phase error, there are significant additional contributions to the overall measurement uncertainty due to the state of the magnetic core of the test transformer, its shielding (or lack of) and interaction between the primary circuit loop and other parts of the measurement system. The total uncertainties in the measurement of current transformers are usually in the range 30 to 100 ppm for current error with corresponding values in the range 30 to 100 microradians for the phase error. With continued improvements in the NPL current transformer calibration facility these uncertainties have been reduced to 10 ppm and 10 microradians for the calibration of compensated current comparators and current transformer test sets now commercially available.

References:

1. Arnold, A.H.M., Current transformer testing, JIEE, 1934 pp 424-437.
2. Kusters, N.L. and Moore, W.J.M., The compensated current comparator: a new reference standard for current transformer calibrations in industry, IEEE Transactions on Instrumentation and Measurement, vol. IM-13 (2-3), June-September 1964 pp 107-114.
3. Moore, W.J.M. and Miljanic, P.N., The Current Comparator, IEE Electrical Measurement Series 4, Peter Peregrinus Ltd, London, 1988, ISBN 0 86341 112 6.