

## A WIDE RANGE CURRENT COMPARATOR SYSTEM FOR CALIBRATING CURRENT TRANSFORMERS

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## ABSTRACT

This paper describes a new measurement system for the calibration of current transformers at 60 Hz for all ratios up to 10 000/5 and higher and at four times rated current. For ratios up to 1200/5, a reference transformer is needed and the system is accurate to five parts per million (ppm). Most higher ratios can be measured using only one reference transformer. Included is an example of how a laboratory could use such a system to measure all ratios up to 8000/5, requiring a calibration of only one reference transformer on one ratio (4000/5).

## INTRODUCTION

Extension of the a-c current scale from approximately five amperes to several thousand amperes is achieved through magnetically coupled ratio networks. Traditionally, these have been in the form of current transformers whose most extensive and perhaps most important application has been in the measurement of power and energy at or near 60 Hz. Introduction of the current transformer as part of a measuring system requires that it be calibrated and its errors in ratio and phase angle be determined to the accuracy prescribed by the measurement process.

Until fairly recently, the accuracy requirement has been a moderate one. The recent need for a markedly improved accuracy in the measurement of power and energy creates a need for a corresponding improvement in the accuracy of calibration of current transformers. The introduction and development of the compensated current comparator and its associated calibration circuits at the National Research Council of Canada has given the necessary impetus to the solution of this problem. (1) Also, as a result of this work, a test set for the more accurate measurement of current ratios up to 1200/5 is commercially available.

There are strong indications of a similar need at higher ratios to about 10 000/5. Furthermore, in the precise metering of electrical energy, some watt-hour meters now accept and are used under relatively high overload conditions. On a commercial basis, simple extension of the established current comparator measurement system to accommodate these recent requirements appears impractical.

In response to this need for a versatile, accurate and wide-range current transformer calibration method, a new measurement system with an uncompensated current comparator as the principal element has been developed.

## PRINCIPLE OF OPERATION

## The Current Comparator

The comparator is a four-winding, passive magnetic device. (2) In operation, zero voltage appearing at the terminals of one winding (identified as the detection winding) indicates zero flux in the magnetic core and correspondingly zero net magnetomotive force

(mmf) imposed on the core by the currents in the other three windings. Two of the remaining three windings, called collectively the ratio windings, carry the opposing currents to be compared, i.e., two currents of nearly equal mmf. The third winding (identified as the error winding) carries the small error current necessary to establish an ampere-turn balance.

## Calibration Circuits

This comparator design permits operation in two different circuit modes which together span the entire range of ratios normally encountered in current transformer calibration. In mode A (Fig. 1a), the comparator is used with an auxiliary power source (typically a current transformer of the same nominal ratio), the combination resulting in a burden compensated current comparator capable of measuring accurately all current transformer ratios up to 1200/5. (1) It can be seen that functionally, this composite comparator (comparator and auxiliary) is similar to the compensated current comparator as described by Kusters, et. al. and indicated in Fig. 1b. The excited magnetic shield (SH) of the Kusters design (permitting the transfer of power) is replaced by an external transformer (auxiliary transformer) to achieve the same purpose. The nominal function of the magnetic shield is retained in the present design by placing a light magnetic shield below the ratio and error windings. In this mode of operation, the current comparator governs the measuring accuracy; the auxiliary transformer is required only to supply power to the current comparator secondary circuit and need not be more accurate than about one percent. This being assured, no calibration of the auxiliary transformer is necessary. The blocks labeled "measuring circuit" in Figs. 1a and 1b represent networks for measuring and injecting a current equal to the test transformer error current into node M, thus balancing the comparator.

Separation of the excited shield from the comparator itself was employed for greater comparator flexibility. Hence, the passive comparator can be used in another circuit (mode B) in which a transformer under test is calibrated against a reference transformer. This circuit satisfies the need for accurate measurements under overload conditions and at ratios higher than the 1200/5 limit of the previous circuit. (3) Fig. 2 illustrates how the comparator can be used in mode B to compare a transformer under test with a standard transformer having a close, but not necessarily identical, nominal ratio. In this arrangement the primary and secondary windings of the comparator of  $n_x$  and  $n_s$  turns, respectively, are connected in series with the secondary winding of the corresponding X and S transformers. Thus, with flexibility provided in the  $n_x$  and  $n_s$  turns, a one-to-one correspondence between the nominal ratios of X and S is not required. If  $N/1$  and  $N \cdot A/1$  are the nominal ratios of the test and standard transformers, respectively, then a comparator ratio of  $A/1$ , i.e.,  $n_s/n_x$ , is needed. This arrangement makes it possible to calibrate transformers of higher ratio, e.g., 2000/1. Also it is possible to extend the calibration of a current transformer up to four times rated current using a standard operating at currents not exceeding rated. (An example is given in the appendix on how a laboratory using both modes of operation could calibrate through its entire range of transformer ratios by a "step-up" technique with minimum recourse to the facility of a national laboratory.)

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## WORKING MODEL OF SYSTEM

## Design of Comparator

Flexibility, both in terms of available ratios and operating currents, was a primary design consideration for the current comparator. Twelve independent sections of twenty turns each along with one of ten turns comprise the internal ratio windings. The sections are designed to carry twenty amperes and are used in series combinations to provide both the primary and secondary windings. A large window provides for feedthrough primary windings. The error winding is a tapped winding of the same number of turns per section as the ratio windings. With these windings, all normally encountered ratios from 0.05/5 to 1250/5 are available.

The detection core, tape-wound from high initial permeability magnetic material, has a cross sectional area of 1.6 cm<sup>2</sup> with outside and inside diameters of 25.4 and 22.9 cm respectively. With a detection winding of approximately 2,000 turns, the core has a characteristic detection sensitivity of 12 volts per ampere-turn at 60 Hz.

## Functional Modification of Comparator

In the final design, the circuits of Figs. 1 and 2 were modified so that the current comparator could be used as a self-balancing element. (4) Fig. 3 illustrates the modification of mode A. As the name implies, a self-balancing current comparator is one in which a feedback amplifier circuit maintains a condition of ampere-turn balance. By using the composite comparator circuit, advantage is again gained from the power transferred by the auxiliary transformer (or excited shield in the Kusters design); namely, the feedback circuit need only supply a small error current at low power to the error winding, and consequently low amplifier gain can be used. The resulting combination of auxiliary transformer and current comparator with feedback behaves essentially like a perfect transformer, and can be used as such. Accordingly, the resulting instrument in Fig. 3 is equivalent to a highly accurate standard transformer, being used in a comparison-type transformer calibration circuit. It can be used equally well with other measuring circuits and can be used in other high-accuracy current transformer applications.

As Fig. 4 illustrates, the self-balancing technique has been extended to mode B operation. In this circuit, the amplifier-driven error current is injected into the low impedance measuring circuit. As indicated earlier, the current comparator is a highly accurate range extender for the standard transformer, hence the measuring circuit measures only the error difference between the standard and test transformers.

A few practical limitations to this mode should be made clear. First, the current comparator imposes a burden on both the standard and test transformers. In general, this burden will be largely resistive and less than 0.1 ohm. Second, the maximum ratio difference between the standard and test transformers is limited by the maximum and minimum currents for which the standard is designed to operate accurately. These limits are generally 10 and 0.25 secondary amperes, respectively. Finally, a calibration is required for the standard transformer.

## Measuring Circuit

As was pointed out earlier, the self-balancing current comparator can be used with many conventional comparison-type transformer measuring circuits. In this model, the measuring network\* (as detailed in Fig. 5) is composed of a resistor ( $r$ ) and an adjustable branch containing a conductance ( $G$ ) and capacitance ( $C$ ) together with an ampere-turn-balance detector (ATB), a simple current comparator. An important function of the ATB is to facilitate the measurement of

relatively large errors without requiring the use of an excessively large value for resistor  $r$  or capacitance  $C$ . In effect, the difference current between the standard and test instruments is carried by a low impedance winding ( $w_p$ ) on a core. The  $r$ - $G$ - $C$  network supplies a balancing current to a second winding, tapped to provide for polarity selection. At ampere-turn balance, this current is equal to the difference current multiplied by the inverse turns ratio of the two windings. The balance equation is given by

$$\epsilon = \alpha + j\beta = rGA + jr\omega CB$$

where  $\epsilon$  is the difference between the complex ratio errors of the standard and test instruments

$\alpha$  and  $j\beta$  are the in-phase and quadrature (phase angle) components of  $\epsilon$

$$r = 0.05 \text{ ohm}$$

$G$  is the adjustable conductance in mhos

$C$  is the adjustable capacitance in farads

$A$  is the inverse turns ratio  $w_s/w_p$

$B$  is the inverse turns ratio  $w_s/w_p$

From the above formula, with the proper choice of constants  $A$  and  $B$ , the measuring circuit can be made direct reading at one frequency (in ppm and microradians, for example).

The ATB for such a measuring circuit is simple to construct since sufficient accuracy can be achieved without the use of magnetic shielding. Uniformly distributed windings and an electrostatic shield will assure a ratio accuracy of 0.1 percent, which is adequate, being of second order importance.

The flexibility of the measuring circuit is further enhanced by adding a fourth winding to the core. This winding makes possible a simple grounding network which does not require a separate balance. Referring to the simplified circuit of Fig. 6 the additional winding together with a fixed resistor of 10 ohms and an adjustable resistor  $R$  act as a current divider. Point  $G$  is essentially at ground potential since the voltage drop across the 10-ohm resistor is extremely small. Thus, corresponding terminals on the primary and secondary circuits ( $G$  and  $M$ ) are maintained at the same fixed potential. With this arrangement, capacitance currents from the primary circuit to ground (as shown) are directed into the current divider where a suitable portion, controlled by  $R$ , is made to pass through the comparator winding and link the core. Hence the measuring circuit compensates for the capacitance current that bypasses one or the other of the primary windings. The proper values for  $R$  can be readily calculated from the operating ratio. This circuit has been found to be virtually as effective as a balanced Wagner-grounding system, and is particularly useful when calibrating transformers at ratios less than unity.

## SOURCES OF ERROR

As pointed out earlier, only moderate accuracy is required for the simple comparator (ATB) in the measuring circuit. Thus an error produced in the calibration system from this cause can be made negligible. Errors attributed to the remaining portion of the measuring circuit and to the self-balancing feature are essentially the same as described in references (1) and (4). These can also be kept at an insignificant level. Sources of error associated with the current comparator have also been treated in the literature (1,6,7). However,

\*This is somewhat similar to the Petch-Elliott testing set.<sup>5</sup>

their influence is quite different in the measurement systems described here and will therefore be discussed.

Two principal sources of error exist which can cause a current comparator to deviate from a true ampere-turn-balance indicator. The first, which produces a magnetic error, is associated with the non-uniformity of permeability of the magnetic core. Zero voltage at the detection winding terminals is said to correspond to the null condition of the line integral of Ampere's circuital law

$$\oint \vec{H} \cdot d\vec{l} = \Sigma I. \quad (1)$$

In reality, a different but related line integral

$$\omega \frac{N}{L} \oint \varphi \, dl = V \quad (2)$$

is evaluated, assuming sinusoidal flux and uniform turns distribution, where

$$\varphi = \text{flux} = \int_S \mu \vec{H} \cdot d\vec{A}$$

$$\omega = \text{angular frequency}$$

$$V = \text{voltage of detection winding}$$

$$\frac{N}{L} = \text{turns of detection winding per unit length of core}$$

$$\mu = \text{relative permeability}$$

$$A = \text{cross sectional area of core.}$$

For a core of nonuniform permeability, leakage flux can induce a component of voltage in the detection winding that is unrelated to the net ampere-turns; hence, it is essential that all leakage and extraneous flux be restricted if equation (2) is to approach zero simultaneously with equation (1). This is achieved by providing a low reluctance shunt path of magnetic shielding material surrounding the detection winding. With proper shielding, magnetic errors can be reduced to one ppm or less, being extremely small when the leakage flux is initially low due to close coupling between the ratio windings.

The second source of comparator error arises from stray capacitance between and across windings as well as capacitance from windings to ground. These capacitances can be considered as one lumped capacitance shunting the secondary winding. Resulting errors are then proportional to the voltage across the secondary winding and to the capacitive admittance. For the passive current comparator (Figs. 1a and 2), the potential difference across any winding is largely due to the resistive voltage drop in that current-carrying winding since, ideally, no flux exists in the core and shield. (In actual practice, flux will exist in the shield inducing another small voltage. This effect will be discussed later.)

For an active (compensated) current comparator (Fig. 1b) in which shield excitation exists to support the secondary current, the source of secondary winding voltage is quite different. In this case, the resistive voltage drop across the winding, being opposed by an equal and opposite component of the induced voltage, has no effect. However, the induced voltage component that supports the current through the external burden is present.

When a passive comparator is used together with an auxiliary current transformer (Fig. 1a), the capacitive errors are still the errors of a passive comparator. Admittances across windings on the excited core (auxiliary transformer) cause no errors since they do not shunt

the detection core. By keeping the resistance of the ratio windings low, it is possible to keep the capacitive error below one or two ppm even at ratios up to 1200/5.

### EFFECTS OF LEAKAGE FLUX IN SHIELDS

Ideally, a passive current comparator has, at ampere-turn balance, no working flux in either the core or shield, and accordingly, no induced voltage in any winding. In the practical case, however, this condition is not completely realized except in that portion comprising the core and detection winding. This region is protected from the effects of leakage flux by the properly designed shield which encloses it. In contrast, the ideal condition is not satisfied with respect to that section containing the shield, ratio windings and error winding. The same condition that requires magnetic shielding of the core operates to produce induced voltages in the ratio and error windings. That is, leakage flux linking the shield induces voltage in the windings on the shield even though there is no working flux present. In terms of measurable quantities, the order of magnitude of this voltage can be expressed, for the secondary and error windings, as

$$E = Z_m \epsilon_m I$$

where  $E$  = induced voltage

$Z_m$  = magnetizing impedance associated with winding and shield

$\epsilon_m$  = magnetic error of the shield

=  $i/I$  where  $i$  = apparent current linking the shield at ampere-turn balance

$I$  = current in secondary winding

The effects of this induced voltage are threefold. First, in the composite comparator mode of operation (see Fig. 1a) this voltage, being induced in the error winding, can produce a significant voltage between point M and ground. Accordingly, the comparator-imposed burden ( $Z_B$ ) on the test transformer (which is given by  $Z_B = E/I$ ) will be significant. Second, if the comparator were used as in Fig. 1a, the accuracy of the measuring circuit, which depends upon point M being at ground potential, would be impaired. Third, the capacitive error will be increased due to the increased voltage across the comparator windings. For mode B operation, the effects are essentially the same.

Measurements on the comparator developed in this study indicate that effects of the induced voltage can be significant when feedthrough turns are used, i.e., when the leakage flux is highest. For example, the magnetic error of the shield,  $\epsilon_m$ , can range from a few ppm when closely coupled windings are used to nearly 1000 ppm when a single feedthrough turn, displaced to one side of the window, is employed for the primary winding. The magnetizing impedance,  $Z_m$ , is a function of the square of the number of turns, and for maximum secondary turns is approximately 300 ohms at 60 Hz.

It is felt that, in future comparator designs, this induced voltage could be reduced considerably by employing a more efficient magnetic shield to reduce  $Z_m$  and  $\epsilon_m$ .

Nevertheless, the problem has effectively been overcome in the present model by the use of the self-balancing feedback circuitry (see Fig. 3). Here, the feedback amplifier supplies the appropriate balancing current to the error winding regardless of induced voltage.

### CALIBRATION AND ACCURACY

As the previous discussion of errors implies, it is possible, from design considerations, to place a theoretical limit on the errors that

can be expected in the measurement system. Furthermore, actual measurements of the design parameters, i.e., winding capacitance, magnetic error, etc., add strength to these estimates. Such a process was employed in part to establish the accuracy of the system.

In addition, two calibrations of the comparator were performed, each using a compensated current comparator (Fig. 1b) as the standard.

The first calibration was performed with the passive current comparator and auxiliary transformer connected together in the composite comparator mode (Fig. 1a). Employing a comparison technique developed by Kusters (8), the composite comparator was compared with a compensated current comparator which in turn, had been calibrated at the Canadian national laboratory. Additional tests were conducted concerning the influence of stray capacitance and ratio error in the auxiliary transformer, confirming earlier statements made on these effects.

A second calibration was performed with the comparator and auxiliary transformer employed as a self-balancing current comparator (Fig. 3). This combination was treated as a test transformer and calibrated in a circuit identical to Fig. 1b. The standard employed was a compensated current comparator of the Kusters design.

Finally, the measuring circuit (as in Fig. 5) was compared with a previously calibrated measuring circuit of different design.

The results of these estimates and measurements indicate that the accuracy of the measuring system (not including the standard current transformer) is better than five ppm, both in ratio error and phase angle.

#### CONCLUSIONS

A calibration system for the calibration of current transformers at 60 Hz to an accuracy of 5 ppm (in its most accurate mode) or better has been described. The system, with two modes of operation, can cover transformer ratios up to 10 000/5 or higher and be used to calibrate transformers up to four times rated current. Its flexibility would provide a laboratory with a measurement capability whereby its dependence on the national laboratory is greatly reduced. Information accrued during its development indicates that its versatility can be further improved to meet other measurement needs.

#### APPENDIX

The following example offers a possible calibration plan requiring the calibration of a standard on only one ratio, whereby all normally encountered current transformer ratios up to 8000/5 can be measured.

All ratios up to 1200/5 can be measured using mode A provided the test ratio can be matched by an auxiliary transformer of moderate accuracy. If two transformers of the same ratio are to be tested, the two can be used in the auxiliary and test transformer positions, respectively, and then interchanged. Any transformer in this range can be tested at secondary currents up to 20 amperes, provided the auxiliary transformer can accommodate this current.

A transformer with a 1000/5 ratio, having been calibrated in mode A at currents up to twice rated, can then be used as a standard in mode B to measure ratios up to 2000/5.

Hence, transformer ratios of 1500/5 and 2000/5 can be tested at rated current.

If, then, a single 4000/5 ratio transformer is available with a calibration at secondary currents ranging from 0.25 to 10 amperes, the following additional tests are feasible:

- 1500/5 and 2000/5 ratios up to four times rated current,
- 3000/5 and 4000/5 ratios up to two times rated current,
- 5000/5 to 8000/5 ratios up to rated current.

#### ACKNOWLEDGMENTS

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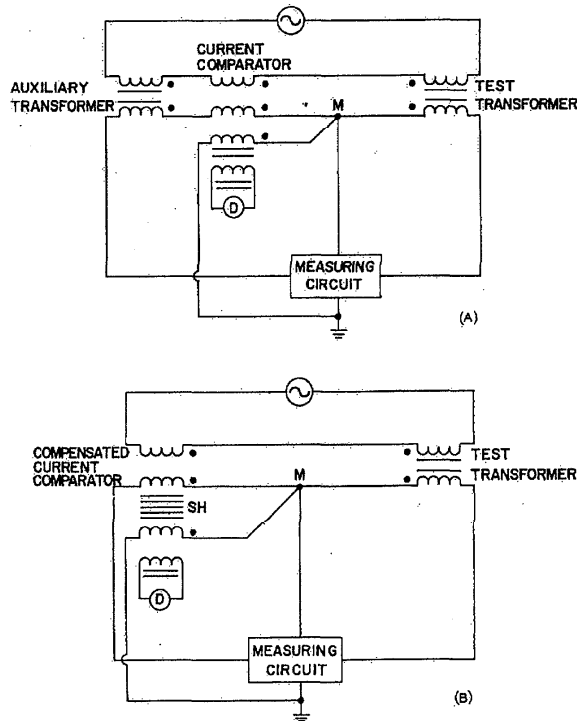


Fig. 1. Current transformer calibration circuits indicating the principles of operation

- (a) with the composite current comparator in mode A,
- (b) with a compensated current comparator.

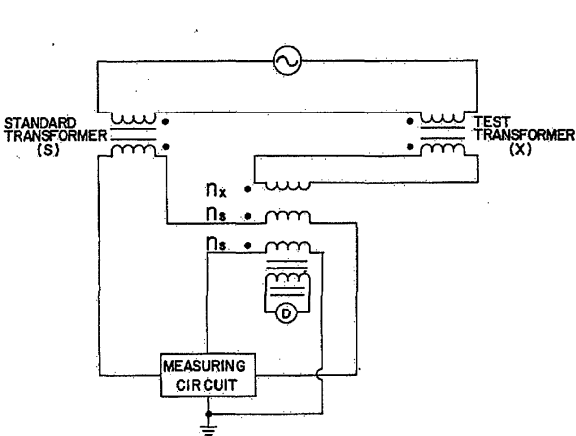


Fig. 2. Current transformer calibration circuit indicating principle of operation with the current comparator in mode B.

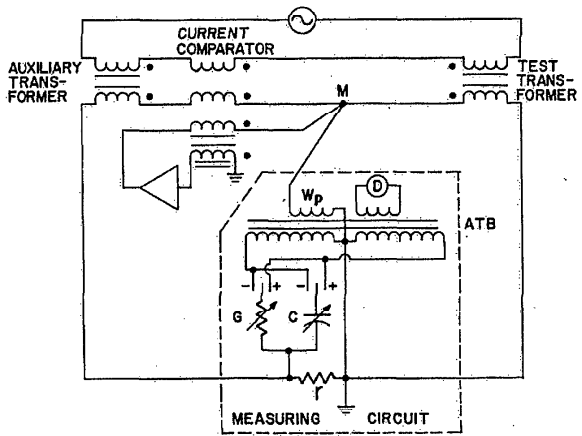


Fig. 3. Working model of the measurement system for mode A.

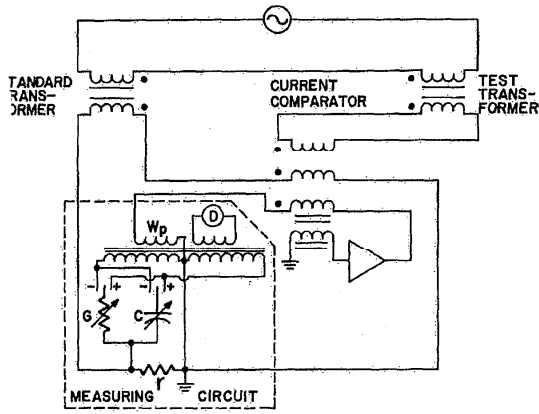


Fig. 4. Working model of the measurement system for mode B.

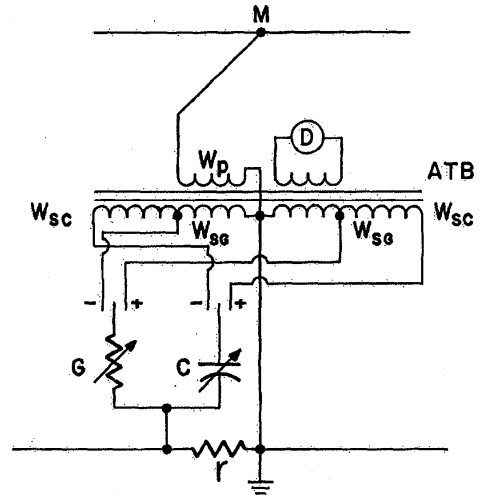


Fig. 5. Details of the measuring circuit.

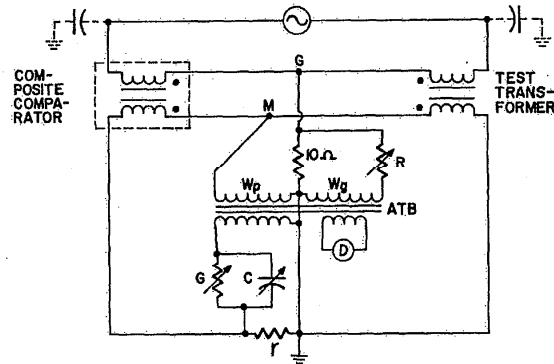


Fig. 6. Simplified diagram showing the grounding circuit.

## Discussion

W. J. M. Moore and N. L. Kusters (National Research Council of Canada, Ottawa, Ont., Canada): In the compensated current comparator, the main magnetic shield performs two functions. 1) It shields the compensation (or error) winding and the ampere-turn null detector from the leakage fluxes of the ratio windings. 2) It enables energy flow between the ratio windings. In Mr. Souders' proposal, the energy flow function has been transferred to an auxiliary current transformer, and the main magnetic shield has been eliminated, leaving only a much smaller shield between the error and detection windings. As a result, the current comparator itself can be somewhat reduced in size, weight, and complexity, and an existing investment in standard current transformers can still be utilized. No protection is now afforded to the error winding from the leakage fluxes of the ratio windings however, and the ensuing voltage drop in that winding inhibits its use in a passive mode. This difficulty could have been overcome by a modest amount of magnetic shielding or, indeed, by an Arnold type copper shield. Instead, an electronic amplifier has been used with the current comparator in a self-balancing mode, but now the equipment resembles more correctly a very accurate current transformer capable of supporting a burden, rather than a current comparator for detecting an ampere-turn balance. The advantage of this arrangement is that the equipment can be used in any of the various current transformer calibration circuits and, in particular, in the circuit shown in the paper which is well suited to the measurement of large error currents.

The amplifier must supply the error current of the auxiliary transformer in mode A and the difference between the error currents of the reference and unknown transformer in mode B. Direct current coupling into the current transformers themselves is to be avoided as this would cause drifts in these errors. More details on the amplifier, particularly a circuit diagram, would therefore be appreciated.

In the Section *Effects of Leakage Flux in Shields*, the use of a more efficient magnetic shield in future designs is proposed. It is not clear what is meant by this. More shielding, or the use of a higher permeability material, would presumably increase rather than decrease  $Z_m$ . Perhaps the use of an eddy-current shield of heavy gauge copper would be more productive.

Finally, it is stated in the paper that extension of the compensated current comparator technique to higher ratios and currents appears to be commercially impractical. While this is probably true in terms of a single device, extension in ratio up to 36000/5 A has been demonstrated by operating a current comparator with a two-stage current transformer in cascade [9], and a similar technique could probably be used to meet the overcurrent requirement.

## REFERENCES

- [9] P. N. Miljanic, N. L. Kusters, and W. J. M. Moore, "The application of current comparators to the calibration of current transformers at ratios up to 30000/5 amperes," *IEEE Trans. Instrum. Meas.*, vol. IM-17, pp. 196-203, September 1968.

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J. R. Barnwell (Tennessee Valley Authority, Chattanooga, Tenn.): The author and those who worked with him are to be congratulated in grasping the overall picture of instrument transformer testing.

With the advent of current transformers which are used to measure large blocks of power it becomes imperative to know the errors of current transformers rated 2000-5000 A and above. This paper presents the most reasonable approach to date.

There remains only the practical problem of providing these thousands of amperes in one bus bar under field conditions. Can the

author now suggest a method of establishing current transformer errors by measuring ratio and losses in the circuit using secondary voltage only? A temporary primary could be used in the case of through-type current transformers.

T. Michael Souders: The author first wishes to express his appreciation to Mr. Moore, Mr. Kusters, and Mr. Barnwell for offering these discussions. Several pertinent questions deserving further attention have been raised.

The first comment by Mr. Moore and Mr. Kusters concerns the use of shielding to reduce the voltage drop in the error winding. The suggested technique of using light magnetic shielding over the error winding should effectively reduce the problem in mode A. However, in mode B where close coupling already exists, an additional voltage would be induced in the ratio windings because of an unbalance in their ampere-turns. Consequently, the burdens on the test and standard transformers would be increased. This additional burden could become significant if the error of a transformer approaches 0.1 percent.

Since this comparator was constructed, it has become apparent that the same shielding ratio could have been achieved with less magnetic material by employing a more efficient arrangement of the shields. With less material required for adequate shielding, the resulting shield magnetizing impedance and, accordingly, the induced voltage, will be reduced as stated.

A second question concerns the method by which direct currents arising in the amplifier are prevented from magnetizing the test and/or standard transformers, thereby causing drifts in their respective errors. While both capacitor and transformer coupling are possible solutions, increased stability problems made these techniques less desirable than an attenuated dc coupling. In this method, the amplifier gain as determined by a local feedback loop, is reduced to unity as the frequency approaches zero. Under these conditions, the dc offset voltage appearing at the amplifier output is equal to the input offset voltage, which can readily be held below a few hundred microvolts. One hundred ohms coupling the amplifier output to the remaining circuit then reduces the direct current component to a few microamperes. Current of this magnitude has been found to have no significant effect on the various transformers tested.

The author is aware of the work described in the paper by Miljanic *et al.* [9] and regrets the oversight in excluding it from his bibliography. The intent in making the statement as quoted was to point out that extension of the compensated current comparator, per se, to higher ratios was commercially unpractical. In Miljanic's system it was recognized that the cascade was found to be more practical when the primary unit was operated as a two-stage transformer, rather than a compensated current comparator. It should be pointed out that the system, as described in the paper under discussion, also uses in effect a transformer cascading technique for extension to higher ratios. Admittedly, a two-stage transformer cascade is capable of higher accuracy; however, such a transformer will in general be larger and more complex than single-stage transformers. Furthermore, single-stage transformers are already standard equipment for most power companies. Where additional accuracy may be required, the basic comparator design does not necessarily preclude cascading with a two-stage transformer.

Finally, in response to the question posed by Mr. Barnwell, it is assumed that the feature referred to is similar to that termed "secondary feed" described in previously published papers by Kusters *et al.* In the present system, it is not possible to use secondary feed in mode B, for this would impose a very large, negative burden on the standard transformer whose errors must be accurately known. In mode A, secondary feed is possible if the auxiliary transformer has a volt-ampere rating sufficiently high to guarantee at least 1 percent accuracy under secondary feed conditions. In general, precision transformers are unable to support the large burdens encountered under secondary feed at the higher ratios. For these cases, separate loading transformers would be required.

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