Microprocessor-Based Automatic Instrument Transformer Comparator

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Abstract—**A new self-balancing comparator for instrument transformers was developed. The instrument is capable of determining the errors of voltage or current transformers with the aid of a calibrated reference standard transformer. A microprocessor is used to enhance the performance of the instrument by controlling the balancing, automatic zero, and calibration routines.**

INTRODUCTION

ONE OF THE more convenient methods of calibrating an instrument current or voltage transformer is to compare it to a reference standard transformer of nominally the same ratio and known errors. The comparison is typically carried out with the aid of an ac potentiometer which is capable of separating the difference (current or voltage) between the transformers into in-phase and quadrature components. If powered with a signal from the reference transformer, the ac potentiometer circuit provides a readout directly in percent-ratio error or ratio-correction factor for the in-phase component, and in minutes or centiradians for the quadrature component. Automatic, or self-balancing circuits have been also designed and described in the literature. Zinn [1] described an analog self-balancing circuit, while Braun [2] described an instrument using sample-and-hold techniques. Both of these instruments display the measured errors in digital form.

The instrument to be described here is basically an automatic ac potentiometer operating under the control of a microprocessor. When operating together with the proper input circuitry, the instrument measures and displays the ratio and phase-angle errors of instrument current or voltage transformers.

THE DEVELOPED INSTRUMENT

The aim of the development was to produce an automatic comparator suitable for testing both current and voltage transformers.

Other requirements included:

50- and 60-Hz operation
automatic zero correction
automatic calibration
automatic phase-angle correction for ratio errors
digital display of test results.

The circuitry of the comparator can be divided into the following portions:

input circuitry
analog computing circuitry
digital circuitry
display and keyboard circuitry.

Each of these portions will be discussed in turn.

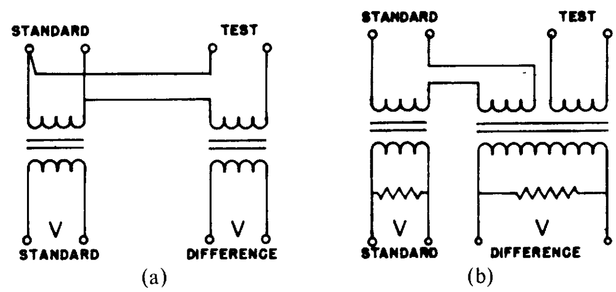

Fig. 1. Generation of signals for comparator. (a) PT testing. (b) CT testing.

Input Circuitry

The input circuitry is shown in Fig. 1. It consists of suitable isolating transformers that provide an output proportional to the reference current or voltage, as well as an output proportional to the difference between two currents, or two voltages. The output of this input network is applied to the analog computing circuitry for processing.

It should be pointed out that the primary windings of the CT configuration can be multiple-wound, allowing CT's of different ratios to be tested. This allows for the testing of 1-A CT's with a 5-A standard, or vice-versa.

Analog Computing

The analog computing circuitry performs all manipulations that are necessary to perform a measurement. The circuitry is shown in block form in Fig. 2. It can be divided into two major circuits; namely, the parallel summing circuit and the null detector circuit.

In the parallel summing circuit, the following are added together so that their sum is equal to zero:

difference signal, scaled according to range (A);
portion of reference signal as determined by P;
portion of 90°-shifted reference signal as determined by Q.

The parallel summing circuit is equivalent to the summing

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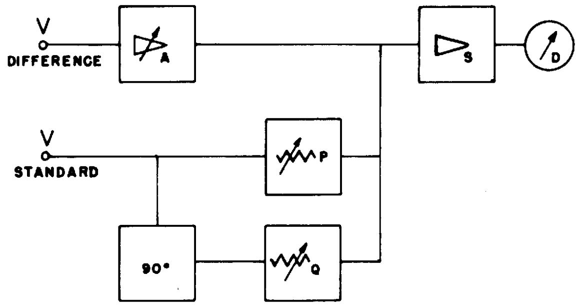

Fig. 2. Analog computing circuit; simplified block diagram.

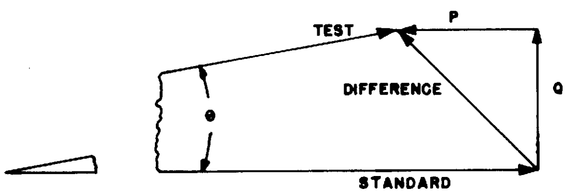

Fig. 3. Vector diagram for comparator.

circuit used by Zinn [1], and all his explanations of the measuring circuit apply.

Shown in Fig. 3 is the vector diagram showing the relationship between the difference, and the P and Q signals. It can be shown that the ratio error is equal to P divided by standard and the phase error is proportional to Q divided by standard.

A more complete block diagram of the analog computing circuitry is shown in Fig. 4. In that figure, P and Q are digitally controlled attenuators and their value is determined by the microprocessor during the balancing procedure. The zero, or balance condition, is determined by means of synchronous and phase-sensitive null detectors. Two four-quadrant multipliers (X_1 and X_2) are used to provide the detector with two simultaneous signals, one proportional to the in-phase component, and the other proportional to the quadrature component. As an aid in balancing, the value of the reference is maintained at a set level, and the gain of the null detector is maintained such that it has the same sensitivity regardless of the magnitude of the reference signal. This condition is accomplished by means of two digitally controlled attenuators (R_1 and R_2), which are also controlled by the microprocessor.

At balance, the outputs of the two null detectors are zero and the measured ratio and phase errors are proportional to the setting of the P and Q attenuators.

Digital Circuitry

The digital circuitry controls the operation of the instrument. It consists of a microprocessor, required memory, decoding and driving circuitry, an analog-to-digital converter, and a scanner. The microprocessor carries out the following routines:

1) zero correction
2) calibration
3) measurement
4) correction and display of measured values.

Display and Keyboard

For communicating with the operator, the instrument has two $3\frac{1}{2}$-digit displays, as well as an 8-digit display, a 25-key keyboard, and a printer. The 8-digit display is used during manual entries of date, serial number, burden, and dead band. It is also used for informing the operator of certain out-of-limits conditions, such as a reference signal being outside acceptable levels, and for displaying the measured value. The measured value can be displayed in amperes, volts, or in percent or rated value.

The two $3\frac{1}{2}$-digit displays are used for displaying the ratio and phase-angle errors. The ratio error is limited to ± 19.99 percent and the phase-angle error to ± 19.99 crad. The limit in phase-angle error is 687 min if displayed in minutes rather than centiradians. The keyboard, in addition to a 12-key numeric pad has 13 special function keys.

CORRECTIONS

The reason for making the instrument controlled by a microprocessor is not only to make it automatic, but also have it apply all the necessary corrections. These are discussed in the following paragraphs.

Zero Correction

The zero of the in-phase and quadrature null detectors may drift with temperature or the amplitude of the reference signal input. To correct for such drifts, the output of the two null detectors is read at prescribed intervals with the error signal disconnected. This "zero" reading is applied during the calibration and balancing routines.

Calibration

Following a zero test, the instrument performs an automatic calibration check. This is accomplished by injecting a portion of the reference signal (both in phase and shifted by 90°) into the measuring circuit. This calibration technique checks the operation of the instrument except for the input circuit and the ranging amplifier. The calibration connection is shown in Fig. 5.

Frequency Correction

The phase shifter used in the instrument is basically an integrator, and its output amplitude is, therefore, frequency sensitive. By measuring the reference signal and the output of the phase shifter, the microprocessor can compute the operating frequency and apply corrections to the phase-angle measurement as required.

Phase-Angle Correction

Referring to Fig. 3, the angle θ can be computed from the tangent, where $\tan\theta = Q/S - P$. The instrument measures tan

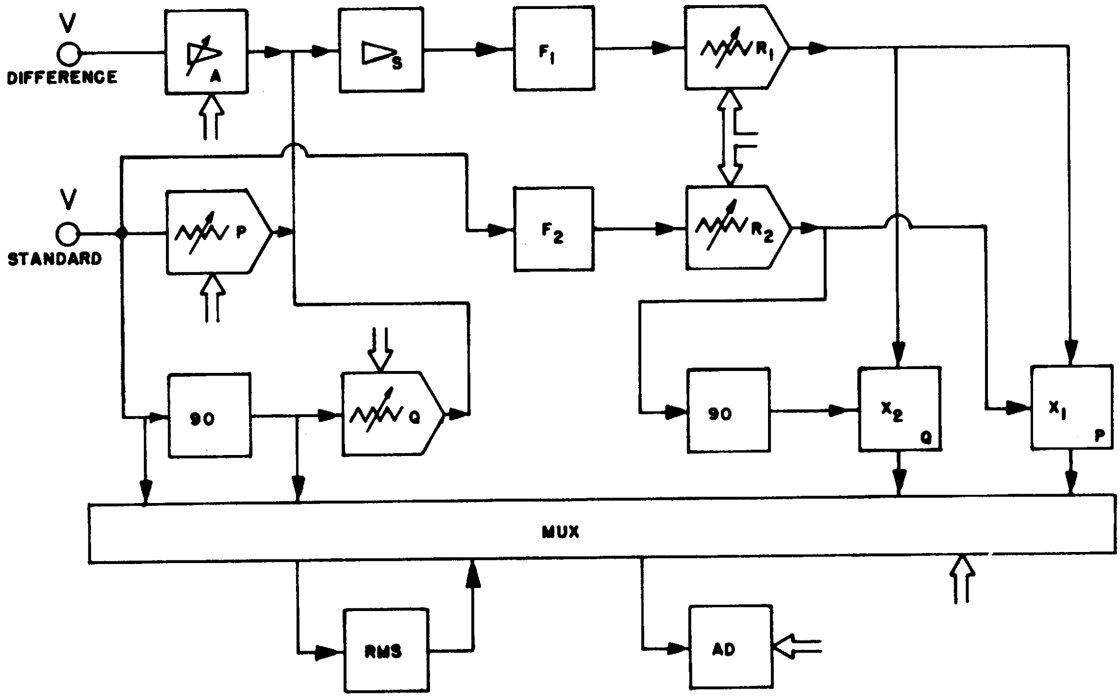

Fig. 4. Block diagram of computing circuitry.

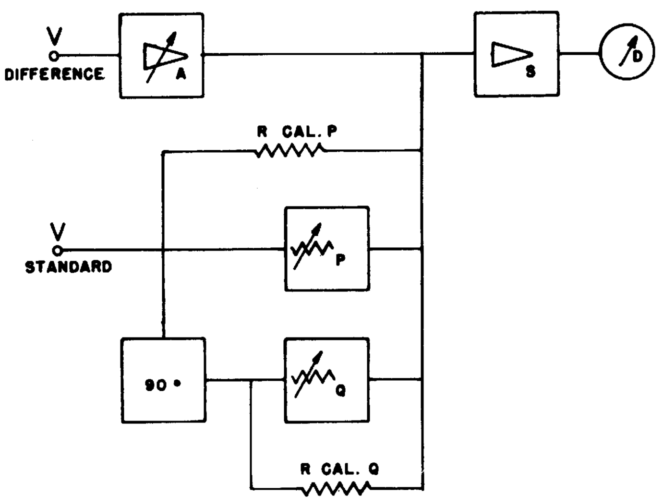

Fig. 5. Comparator calibration connection.

$\theta = Q/S$. This discrepancy is corrected by the microprocessor.

Ratio Correction

Referring again to Fig. 3, the ratio is in error if the phase angle θ becomes larger. The ratio error is therefore corrected by the cosine of θ before being displayed.

Accuracy Considerations

The accuracy and stability of the instrument depends largely on the characteristics of a small number of components. These include

linearity of attenuators P and Q (± 0.05 percent);
ratio stability of ranging resistors (± 0.2 percent);
stability of calibrating resistors (± 0.1 percent);
stability of phase shifter components (± 0.2 percent).

Without resorting to precision components, selected commercial components can furnish the precision indicated above. Based on these values, an initial accuracy of ± 0.5 percent, and a long-term accuracy of ± 1 percent is expected in both the ratio and phase measurements.

Programming

Balancing Routine

The balancing routine was especially challenging because the instrument was to operate on three error ranges, and over a 200 to 1 range in signal level (1 to 200 percent of nominal input). It was found necessary to generate and apply damping factors related to error range, signal level, and degree of unbalance. These factors were selected so that the instrument balances in the fastest possible time, under all operating conditions.

Accuracy Class

The instrument calculates and displays the ANSI accuracy class of the test transformer. Both the CT and PT parallelograms are stored in memory for this application.

Error Messages

The instrument communicates with the operator by means of lights and displays. Some of the error messages include the following:

HELP 1—input below minimum level (1 percent);
HELP 2—input above maximum level (200 percent);
HELP 3—measurement unstable.

Performance

A number of automatic instrument transformer comparators, of the type described, have been produced and tested. All of the instruments perform well within the accuracy tolerances given in the Appendix. Of special interest are the balancing times of the bridge. Shown in Table I are the times to balance under various operating conditions. It should be pointed out that the times shown include zero check, calibration check, and measurement. The first value listed in Table I is for a reading near zero error, while the second number listed is for a reading well upscale on the range.

As can be seen from Table I, the measurement time increases with reading as well as with the input level, especially on the most sensitive range. This is expected since the signal-to-noise ratio is the lowest on this range; and the instrument must take time and due care to make a measurement.

TABLE I

Time to Balance (seconds)

Input Level	Range 20%	2%	0.2%
100%	4 - 9	4 - 9	7 - 16
50%	4 - 9	4 - 9	8 - 16
20%	4 - 9	4 - 9	11 - 16
10%	4 - 9	5 - 10	12 - 18
5%	4 - 9	5 - 10	14 - 22
2%	4 - 10	6 - 11	27 - 30
1%	4 - 11	8 - 12	35 - 40

Conclusion

This paper has described the development of an automatic comparator for instrument current and voltage transformers. The development culminated in a microprocessor-based instrument which operates over a 1- to 200-percent range of input current or voltage, and three error-measuring ranges.

Appendix

Specification for Instrument Transformer Comparator

1) Inputs:

Voltage: 120 V, nominal

Current: 5 A, nominal
1 A, nominal.

2) Operating Range:

1 ··· 200 percent of nominal.

3) Error Measuring Ranges:

Ratio:	±19.99 percent	±1.999 percent	±1999 ppm
Phase:	±19.99 crad	±1.999 crad	±1999 μrad
	±680 min	±68.0 min	±6.80 min.

4) Burden:

Voltage: 0.1 V · A at 120 V
Current: 0.5 V · A at 5 A.

5) Accuracy:

Range (percent)	at 100-percent Input	at 10-percent Input
20	±1 percent R ±0.2 percent FS	±1 percent R ±0.5 percent FS
2	±1 percent R ±0.2 percent FS	±1 percent R ±0.5 percent FS
0.2	±1 percent R ±0.5 percent FS	±1 percent R ±1 percent FS

6) Controls—25-key keyboard consisting of:

12-key numeric pad	voltage input
20-percent range	centiradian/minutes
2-percent range	date
0.2-percent range	serial number
auto ranging	burden
5-A input	dead band
1-A input	print

7) Displays:

$3\frac{1}{2}$ digits for ratio error
$3\frac{1}{2}$ digits for phase-angle error
8 digits for measured value
indicator lights for
balance condition
out-of-range condition.
(Measured value can be displayed in volts, amperes, or percent of rated value. The percent of rated value is keyboard entered.)

8) Measuring Time:

4 ··· 20 s (depending on input signal level and error range).

9) Printer:

20 column thermal printer
Printing: date

serial number
burden (V · A)
test condition
ratio error
phase error

Print time: 10 s.

References

[1] E. Zinn, "An electronic self-balancing instrument transformer testing device," *IEEE Trans. Instrum. Meas.*, vol. IM-21, no. 4, pp. 291–296, Dec. 1971.

[2] A. Braun and H. J. Koehler, "Meseinrichtung für die automatische Fehlerbestimmung an Strom und Spannungswandlern," *ETZ-A*, vol. 99, no. 2, 1978.