THE HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
RESEARCH DIVISION REPORT

To Mr. H.C. Ross
Director of Research

AN INSULATION POWER FACTOR TEST SET

A design has been developed for an insulation power factor test set operating on the principle of the current comparator. The test set exhibits several advantages over existing conventional equipment.

The power factor test set is an instrument by means of which the capacitance and the power factor of electrical insulation can be determined. The test set functions similarly to a high-voltage capacitance bridge, but has important advantages over the bridge. Two of these advantages are that the test set is not affected by stray capacitance and that the suppression of interference can be much more easily accomplished. This report gives the design specifications for the power factor test set and outlines its principle of operation, construction and usage. Recommendations are drawn concerning the building of a prototype for evaluation purposes.

Specifications

The power factor test set to be described can be considered as a modified and simplified version of the high-voltage capacitance bridge described by N.L. Kusters and O. Petersons in IEEE Paper 63-168. A schematic diagram of the test set appears in Figure 2 and the specifications for it are listed below.

Capacitance Range: 1.333 microfarads to 1333 picofarads, top of range, in 10 ranges.

Capacitance Balance: 3 digits and a vernier.

Dissipation Factor Range: zero to 23 per cent.

Dissipation Factor Balance: 2 digits and a vernier.

Operating Voltage: up to 10 kv with a grounded or ungrounded specimen.

Sensitivity: 0.02 per cent of capacitance or dissipation factor per mm deflection at 10 kv.

JOB	FILE	DATE	REPORT No.
740606-13-4007	815.6	February 9, 1966	66-53-K

Accuracy*: 0.1 per cent of capacitance range and 0.001 in dissipation factor.

Repeatability*: 0.02 per cent of capacitance range and 0.0002 in dissipation factor.

Other Features:
(a) Built-in interference suppressor for synchronous interference.
(b) Provision for injecting a signal from an external interference suppressor.
(c) Can be operated with an external detector, such as General Radio type 1232-A, to obtain improved accuracy and repeatability at low voltage.

Principle of Operation

The power factor test set establishes the ratio between the currents through a known and an unknown impedance, when the same voltage is applied to both impedances. Referring to Figure 1, and assuming an ideal transformer, the balance equations for the bridge are:

$$N_s \frac{E}{Z_s} = N_x \frac{E}{Z_x} \qquad (1)$$

$$D = \frac{R_s}{X_s} = \frac{R_x}{X_x} \qquad (2)$$

Where,

D = dissipation factor

N_s, N_x = number of turns on the ratio windings

$Z_s = R_s + jX_s$

$Z_x = R_x + jX_x$

$X_s = \frac{1}{2\pi f C_s}$

$X_x = \frac{1}{2\pi f C_x}$

E = applied voltage.

If we adjust the number of turns on the ratio windings and the magnitude of R_s to obtain a balance of the bridge, then the magnitude of the unknown capacitor will be proportional to the ratio of the turns on the ratio windings and its dissipation factor will be proportional to R_s.

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* Expected values.

Because the ratio transformer we use is not an ideal one, that is, it has ratio errors and its windings have impedance, the bridge balance equations (1) and (2) will have errors. Ratio transformers, however, can be easily built to have ratio errors small enough, and winding impedances low enough that the errors they contribute are smaller than the desired accuracy and can be therefore neglected.

The Test Set

The schematic diagram of the power factor test set appears in Figure 2. The heart of the device consists of a high permeability core with winding W_1 through W_9 wound on it. W_1 to W_4 make up N_s which turns can be adjusted by S_1, S_2, S_3 and R_4 in steps of 100, 10, 1 and fractional turns. W_7 makes up N_x and can be selected to have 1, 2, 5, 10, 20, 50, 100, 200, 500 or 1000 turns. With this selection of turns ratio between N_s and N_x, and a 1000-picofarad standard for C_s, capacitors of 1.333 microfarads or less can be measured.

To make the test set compact, the standard capacitor may have to be of the solid dielectric type. Windings W_5 and W_6 with conductance G_s are designed to cancel out the dissipation factor of the standard. To balance the dissipation factor of the unknown, R_x, the dissipation factor of the standard capacitor is adjusted by means of R_1 to R_3 and R_5. This adjustment provides a range of zero to 23.5 per cent for the dissipation factor.

The balance of the bridge is detected by means of a phase sensitive microammeter M, which measures the voltage induced in the detection winding, W_8. Transformers T_1, T_2 and T_3, capacitor C, and resistors R_6 through R_{13} form networks which make M sensitive either to the capacitor or to the dissipation factor adjustments as selected by S_4. Diodes D_3 and D_4 make the indication of the detector logarithmic, thereby eliminating the necessity for a sensitivity switch. The detector zero is controlled by resistors R_6 and R_7. These same adjustments can be utilized to suppress any synchronous interference that may be present. Winding W_9 is provided for the suppression of non-synchronous interference. The interference suppressor connected to W_9 must have a high impedance output.

Using the Test Set

The test set can be used to measure the capacitance and dissipation factor of both grounded and ungrounded specimens. Figure 3 illustrates the use of the test set. The only limitation on the size of the stray capacitor, C_2, is that the supply E must have sufficient capacity to energize it as well as the test specimen. Stray capacitor, C_1, is shunting one of the windings, and theoretically causes an error. In practice, the resistance and reactance of the winding is very small so that the error due to shunting is negligible for our purpose. The same capacitor, C_1, is reflected across the detector winding and tends to reduce the sensitivity of the detector.

The test set is particularly well-suited to the measurement of an ungrounded specimen associated with stray capacitance and interference. A bushing with a capacitor tap may be a good example. In this case, the capacitance, C_1, between the tap and ground, shunts the detector, and any interference on the high-voltage conductor, A, appears across the supply E which causes no errors in the test set. On the other hand, when measuring the same specimen with conventional equipment, the specimen must be measured grounded in which case the interference on the high-voltage conductor A appears across one arm of the bridge, or an auxiliary isolating current transformer must be used which has to be bulky and expensive if it is to provide suitable accuracy.

Conclusions and Recommendations

The construction details and special features of a power factor test set, operating on the current comparator principle, have been outlined. It is felt that the advantages of this test set over conventional equipment warrants the construction of a sample which could then be properly assessed by all concerned. The cost of building such a sample has been estimated to be between two and four thousand dollars.

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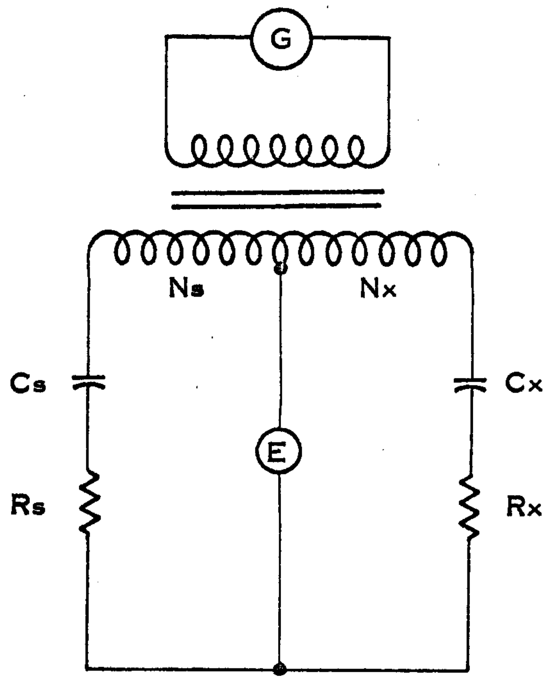


FIGURE I
POWER FACTOR TEST SET

116078—RD

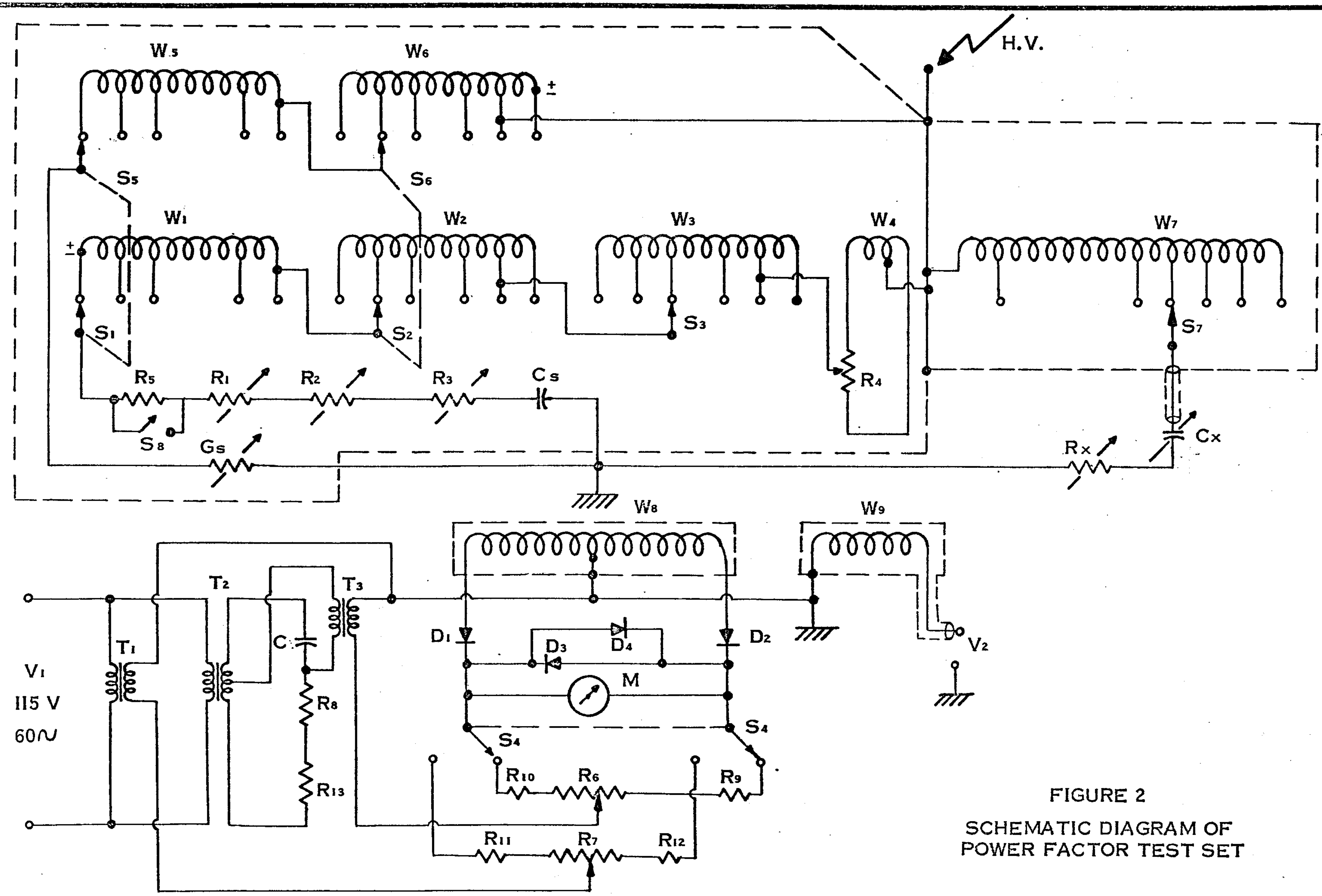
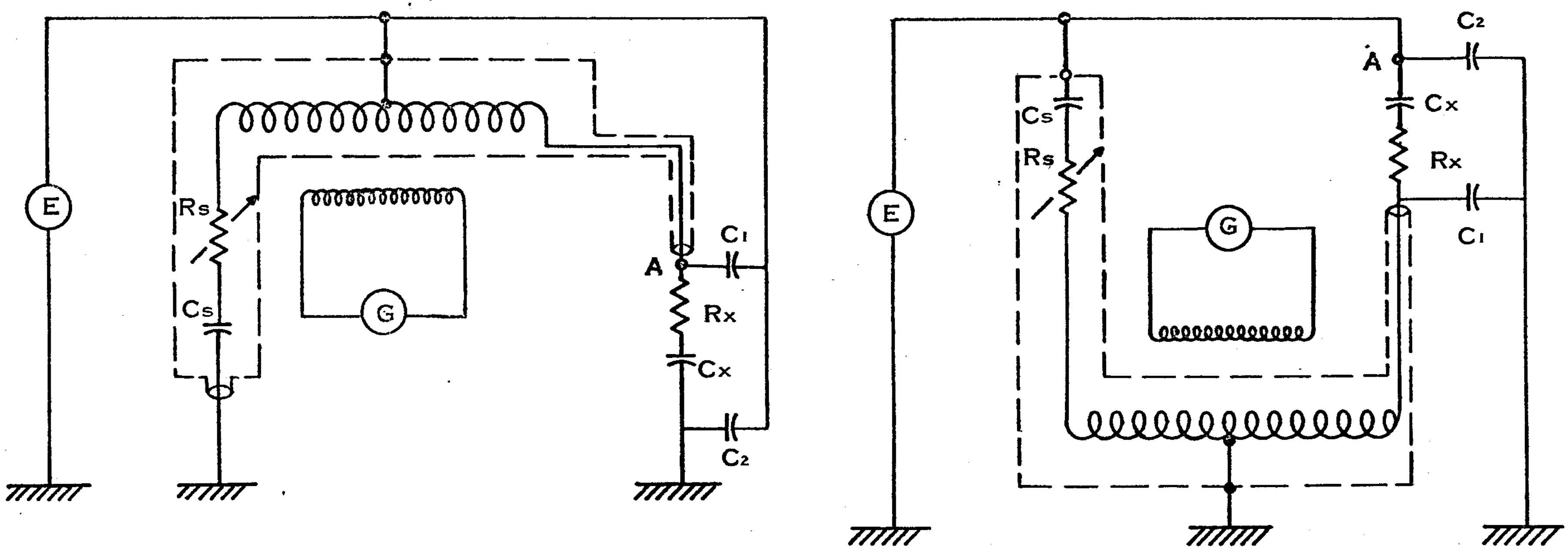


FIGURE 2

SCHEMATIC DIAGRAM OF POWER FACTOR TEST SET

116079 —RD



A. SPECIMEN GROUNDED

B. SPECIMEN UNGROUNDED

FIGURE 3

SIMPLIFIED DIAGRAMS OF TEST SET USAGE

116084—RD

LIST OF COMPONENTS

C	- 2-microfarad paper 100 volts
C_s	- 1000-picofarad standard capacitor (10 kv; mica)
C_x	- unknown capacitor
D_1 to D_4	- germanium diodes
R_x	- equivalent series resistance of C_s
G_s	- compensation for the dissipation factor of standard capacitor (265 megohms for 0.1%; 26.5 megohms for 1%)
S_1; S_5 S_2; S_6	- 12-position, 2-circuit, shorting switches
S_3	- 12-position, shorting switch
S_4	- DPDT switch
S_7	- 10-position shorting switch
S_8	- SPST switch
R_1	- 12 steps of 26.5 kilo-ohms each, 1 watt (non-inductive)
R_2	- 12 steps of 2.65 kilo-ohms each (non-inductive)
R_3	- 5-kilo-ohm wire wound potentiometer
R_4	- 10-ohm wire wound potentiometer
R_5	- 265 kilo-ohms, 10 watts (non-inductive)
R_6; R_7	- 1000-ohm potentiometer
R_8 to R_{12}	- 1000 ohms, 1 watt
R_{13}	- 500-ohm potentiometer
T_1	- 120-to-12-volt transformer ... Hammond 167K
T_2; T_3	- 120-to-50-volt transformer ... Hammond 167W
W_1 to W_9	- windings wound with enameled wire on a mumetal core - 4 inches ID, 6 inches OD and 1 inch high
W_1	- 12 sections, 100 turns each, #26
W_2; W_5	- 12 sections, 10 turns each, #26
W_3; W_6	- 12 sections, 1 turn each (3 windings in parallel and evenly distributed around the core), #26

W_4 - 3 turns, #26 (3 windings in parallel and evenly distributed around the core)

W_7 - 1000 turns, #26, tapped at 500, 200 and 100 turns;
50 turns, #22, tapped at 20 and 10 turns;
5 turns, #18;
2 turns, #18 (2 windings in parallel and distributed);
1 turn, #18 (3 windings in parallel and distributed)

W_8 - 500 turns (approximately) #32 bifilar (one layer on core)

W_9 - 10 turns, #26

M - 10-0-10 microamperes, 1500 ohms