OPERATING AND SERVICE MANUAL FOR PRIMARY AC CURRENT SHUNT SET MODEL HCS-1 AF

CLAIM FOR DAMAGE IN SHIPMENT

The instrument should be tested as soon as it is received. If it fails to operate properly, or it is damaged in any way, a claim should be filed with the carrier. Also, notify Holt Instrument Laboratories or the local representative immediately. A full report of the damage should be obtained by the claim agent and this report should be forwarded to us. We will advise you of the disposition to be made of the equipment and arrange for repair or replacement. Include model number and serial number when referring to this instrument for any reason.

WARRANTY

Holt Instrument Laboratories Division of C.P. D. Engineering, Inc. warrants each instrument manufactured by them to be free from defects in material and workmanship. Our liability under this warranty is limited to servicing or adjusting any instrument returned to the factory for that purpose and to replace any defective parts thereof. This warranty is effective for one year after delivery to the original purchaser when the instrument is returned, transportation charges prepaid, and when upon our examination it is to our satisfaction defective. If the fault has been caused by misuse or abnormal conditions of operation, repairs will be billed at cost. In this case, an estimate will be submitted before the work is started.

If any fault develops the following steps should be taken:

1. Notify either the factory or the area Holt representative, giving full details of the difficulty, and include the model and serial numbers. Upon receipt of this information we will give you service data or shipping instructions.

2. On receipt of shipping instructions, forward the instrument prepaid to the factory or the authorized repair station indicated in the instructions. If requested, an estimate of the charges will be made before the work begins is such work is not covered by warranty. All shipments of Holt Instrument Laboratories' equipment should be packed in a strong exterior container surrounded by two or three inches of shock absorbing material.

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INTRODUCTION

1.0 General Description

1.1 The Holt Primary AC Current Shunt Set- Model HCS-1 AF consists of a group of shunts, a storage case and the connecting cables. It is designed for the accurate measurement of alternating currents. The Model HCS-1AF is designed to be used in conjunction with the Holt Thermal Transfer Voltmeter Model 6B, or the Fluke Model 540B. The primary function of the Model HCS-1AF is to permit accurate comparison of unknown values of AC currents with a corresponding value of DC current whose magnitude is known or can be accurately determined.

1.2 The Model HCS-1AF consists of six shunt modules which connect to the shunt input connector of the thermal transfer voltmeter via the output cable. The input cable provided connects the shunt modules to a shunt AC to DC transfer switch or an AC/DC Transconductance amplifier. The shunt module set and cables are supplied with a walnut finished carrying case.

1.3 The Model HCS-1AF has been designed for use over a frequency range of DC to 100 kHz at currents from 10 milli-amps to 200 milli-amps and D.C. to 20 kHz at currents from 250 milli-amps to 20 amperes.

0.02 AMP SHUNT
P/N 81688-11

0.2 AMP SHUNT
P/N 81688-12

0.5 AMP SHUNT
P/N 81688-13

INPUT CABLE
P/N86987

OUTPUT CABLE
P/N 86988

2 AMP SHUNT
P/N 81688-14

5 AMP SHUNT
P/N81688-15

20 AMP SHUNT
P/N81688-16

SECTION 2
TECHNICAL SPECIFICATIONS

2.0 SCOPE: The Holt Model HCS-1AF current shunt standards are used for the calibration of high accuracy AC current source. A secondary use for the shunts is to develop voltage from a current source for the measurement of power factors.

2.1 COMPATIBILITY: The shunts are compatible, both electrically and mechanically, with Fluke Model 540B and the Holt Model 6B Thermal Transfer Voltmeters to the accuracies shown below.

2.2 OUTPUT VOLTAGE: Output voltage from the shunts over the useful operating range is 0.25 volts minimum When used with a voltmeter of appropriate range these shunts may be operated at output voltages up to 1 volt for all modules up thru the 5 amp module and the 20 amp module may be used at currents up to 25 amperes, output voltages up to 0.625 volts

2.3 PERFORMANCE SPECIFICATIONS: The Shunts meet accuracy specification for AC/DC differences as specified in the table below. AC/DC difference is defined as the difference between AC current and the average of 2 polarities of Direct Current required to produce the same voltage at the output terminals of the shunt output cable.

TABLE 2-1
PERFORMANCE

NOMINAL SHUNT RATING (Amps)	USEFUL RANGE (Amps)	MAXIMUM AC/DC DIFFERENCE (Percent)	FREQUENCY RANGE
20	10-20	0.03	5Hz- 20kHz
5	2.5-5	0.02	5Hz- 20kHz
2	1-2.0	0.02	5Hz - 20kHz
0.5	0.25-0.5	0.02	5Hz - 20kHz
0.2	0.1-0.2	0.05	5Hz - 100kHz
0.02	0.01-0.02	0.05	5Hz - 100kHz

2.4 CALIBRATION: These shunts are calibrated for AC/DC difference at points specified in the Table below. They are provided with a calibration certificate, showing the AC/DC correction factors for each shunt module.

TABLE 2-2

CALIBRATION UNCERTAINTIES

NOMINAL SHUNT RATING (Amps)	NOMINAL TEST CURRENT (Amps)	TEST FREQUENCY (kHz)	MAXIMUM CALIBRATION UNCERTAINTY (Percent)
20	20	1, 10, 20	0.015
5.0	5.0	1, 10, 20	0.010
2.0	2.0	1, 10, 20	0.010
0.5	0.5	1, 10, 20	0.010
0.2	0.2	1, 10, 100	0.015

2.5 TRACEABILITY TO NBS: Documentation of traceability to the National Bureau of Standards is provided for the standards used in the calibration above.

2.6 ACCESSORIES: Cables are provided for input current to the shunts, and output connections to the 540B. Each set is provided with a permanent case for transporting and storage.

CAUTION!
THE OUTSIDE SHELL OF THE SHUNT IS CONNECTED
TO THE CIRCUIT UNDER TEST!
DO NOT OPERATE IT AT DANGEROUS VOLTAGES ABOVE GROUND!

SECTION 3
OPERATING INSTRUCTIONS

3.1 Preparation for Use: The Primary AC Current Shunt Set, Model HCS-1AF is supplied factory tested and calibrated. No power connections other than the circuits under test are required. The Model HCS-1AF should require no preliminary service by the customer.

3.2 Controls and Connections

The terminals on the Model HCS-1AF are described below. There are no internal adjustments or controls in the shunt set.

3.2.1 Connections: Each shunt module has a UHF receptacle for coaxial connection to the shunt transfer switch or a transconductance amplifier alternating and direct current source . At the opposite end of the module is a UHF plug for connection to the Transfer Voltmeter.

3.3 Applications:

3.31 CALIBRATION OF TRANSCONDUCTANCE AMPLIFIERS: The Model HCS-1AF Shunts may be used for the calibration of current regulated electronic supplies such as transconductance amplifiers (ammeter calibrators) In this application the unknown current is applied to the shunt, Thermal transfer voltmeter combination and the null controls of the TVM are adjusted to a null thereby “remembering” the temperature of the thermoelement heater. The transfer switch is then used to apply a direct current to the shunt and TVM. The DC is adjusted to produce a null on the TVM, the same temperature of the thermoelement heater. that existed with the alternating current. The magnitude of the DC is then read using conventional direct current measurement technique. The magnitude of the unknown AC is equal to the magnitude of the DC which produced the equivalent heating effect.

3.32 CALIBRATION OF AMMETERS: AC ammeters are calibrated by a technique similar to the one described above. In this case the AC is adjusted to bring the ammeter to the desired scale deflection and the TVM is adjusted for null. Then DC is applied to the shunt, adjusted for a null on the TVM and read with the DC instruments.

3.3.3 DETERMINATION OF POWER FACTOR: The power factor of a particular AC circuit may be determined by connecting an appropriate current range shunt module in series with the circuit to develop a voltage which is a function of the current in the circuit under test both in magnitude and in phase. The output voltage of the shunt may then be connected to the “unknown” input terminals of a phase meter or the vertical input of a scope. The voltage across the device under test (DUT) is connected to the Reference input of the phase meter or the horizontal input to the scope. Using conventional phase measurement technique the phase angle between the voltage and current may be determined. Knowing the magnitude of the voltage and the current and this angle the power factor may be computed. The HCS-1AF is particularly suited to this application because of its extremely low reactance at frequencies from DC to 50 Khz. In Figure 3-3 is the deflection I_1 is set to equal to E_m

$$\text{Sine of the Phase Angle} = \frac{I_2}{I_1}$$

3.3.4 Other Uses: These shunts may also be used to extend the range of AC Digital Multimeters. For instance, if the 5 amp (0.1 ohm) shunt is connected across the AC voltage input of an AC DMM the resulting combination is a direct reading AC digital ammeter for currents up to 10 Amps at frequencies up to 50 kHz. The uncorrected accuracy will be better than 1% plus the DMM accuracy and with correction factors for the absolute resistance of the shunt and DMM accuracies of 0.1% can be realized.

3.4 Auxiliary Equipment

3.4.1 Transfer Voltmeter: These shunts are designed to produce a voltage which is proportional in magnitude and phase to the current passing thru them. This output voltage may then be measured with a voltage measuring instrument of appropriate accuracy. At the highest levels of accuracy a Thermal Voltage Converter such as the Holt Model 84506 is used for this purpose. If Primary levels of accuracy are not required Thermal Transfer Voltmeters such as the Holt Model 6B or the Fluke Model 540 B may be used. If a measurement of nominal accuracy is desired (0.1%) a high quality digital voltmeter may be used as a fast convenient instrument which is far easier to operate and less subject to damage by overload.

Some Thermal transfer devices such as TVC modules and the Fluke 540B are subject to thermoelement burn out at input voltages as low as 200% of full scale. Other instruments such as the Holt Model 6B incorporate protective circuitry which will prevent TE burn out under most overload conditions.

3.4.2 DC Supply: A stable current regulated DC supply with variable output voltage and sufficient current capacity is required. If a current regulated supply is not available, a voltage regulated supply may be used with protective series resistor to limit current flow.

3.4.3 DC Measuring Equipment: The accuracy with which the DC current can be measure is a determining factor in the accuracy of the system. A precision shunt, standard cell voltbox and potentiometer or a precision digital DC Ammmeter system is recommended. The recommended precision shunts are listed in the table below.

TABLE 3-1
RECOMMENDED PRECISION SHUNTS

RESISTANCE	CURRENT	P/N	MANUFACTURER
0.01 Ohm	30 amp	3200	Tettex
0.1	10	3200	Tettex
1.0	3.3	3200	Tettex
10	1.0	3200	Tettex
100	0.03	4030B	Leeds & Northrup
1000	0.01	4035B	Leeds & Nortrup

3.4.4 AC Supply: A stable current regulated supply such as the Holt Model 250 is required if calibration and frequency response measurements of an AC Ammeter are to be conducted.

3.5 OPERATING TECHNIQUE

3.5.1 General: When using the HCS-1AF for Alternating current measurement the proper shunt module is connected to the Shunt Input Terminals of the Thermal Transfer Voltmeter. Consult the TVM manual before using this instrument. Set up the proper test configuration as shown in Fig. 3-1, 3-2, or 3-3. The fundamental procedure for transfer measurements is as described in paragraph 3.3 above. A high degree of accuracy may be achieved by following the procedures outlined below.

3.5.2 Detailed Operating Technique:

3.5.2.1 Timing: The transfer measurement is based on establishment of equal temperature in the thermoelement heter when heated by AC and DC. The heater temperature varies with time during the procedure. It starts cold, warms on AC to the temperature at which the first null adjustment is made, cools off during the transfer to DC warms again to the temperature at which the DC is set for measurement. It is important that these temperature transients be understood and the proper timing be used to reduce the transient effect. Start the test sequence by adjusting the AC to the desired setting to be calibrated, (i.e. the AC calibrator setting or AC ammeter indication desired). The Thermoelement (TE) and the shunt should be allowed to reach equilibrium, before the first null is made. Usually about 2 minutes after application of the AC for low current increasing to 15 minutes for the 20 amp range where shunt power dissipation is appreciable. The proper warm up should result in an observed null indicator drift of less than twice the desired measurement. Set an approximate null on the TVM and switch to the DC Supply. Adjust the DC supply to produce on approximate null on the TVM and switch back to the AC supply. Wait time “T” about 30 seconds. Carefully null the TVM as the time “T” approaches and, at time “T”, switch to DC as rapidly as possible (less than 30 milliseconds) to avoid excessive cooling of the TE. Then wait time “T”.
About 20 seconds after the switch to DC start adjusting the DC to produce a null so that when the 30 seconds is reached the TVM will be at null and the DC reading can be taken at time “T”. If this procedure is followed carefully the temperarature of the heater in the TE will be at the same point along the switching transient curve for both the AC and DC readings.

3.5.2.2 DC Reversal: Most TVM instruments have small and controlled DC Reversal errors but for the most accurate results measurements should be made with both positive and negative DC and the results averaged to calculate the equivalent magnitude of the unknown AC.

3.5.2.3 Drift: Drift using a measurement is largely due to one of two effects. Self heating in the shunt resistor and drift in the TVM balance circuit. Some older TVM’s used internal batteries as references. These batteries often drift badly. Other newer instruments such as the Holt Mod. 6 B and Model 68 have precision zener references and exhibit drift of less than 1 ppm/minute. If drift is a problem it can usually be localized by applying a stable direct current to the shunt TVM combination and observing the voltage at the shunt input terminals of the TVM with a precision digital volt meter. If the shunt warm up time is a problem, preheating the shunts on a separate 0.5 volt supply will reduce the overall test time.

3.5.2.4 Resolution: Readings may be taken several different ways, if the null detector is provided with an indicator having sufficient resolution and well defined scale markings as in the Holt Model 6 B the null detector scale itself may be calibrated in percent and used as the readout device. If this is not satisfactory, the controls of the AC and DC supplies may be calibrated in percent or auxiliary DMM readouts of AC, DC, or Null may be used to determine the AC/DC Difference.

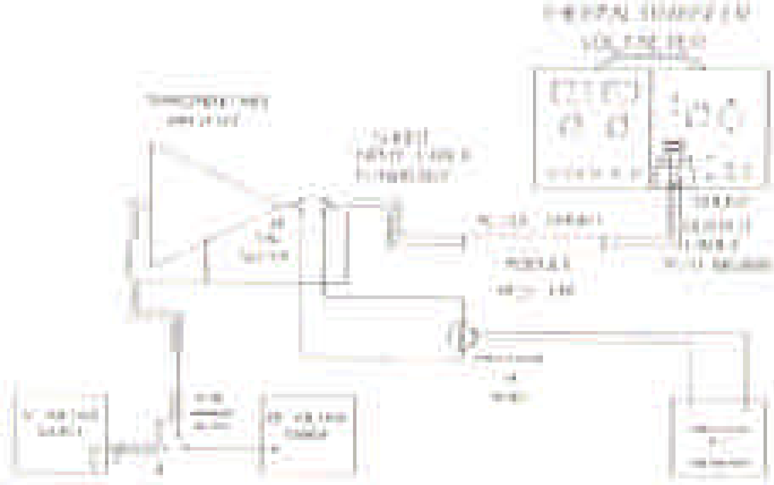

Fig. 3 - 1
Transconductance Amplifier Calibration

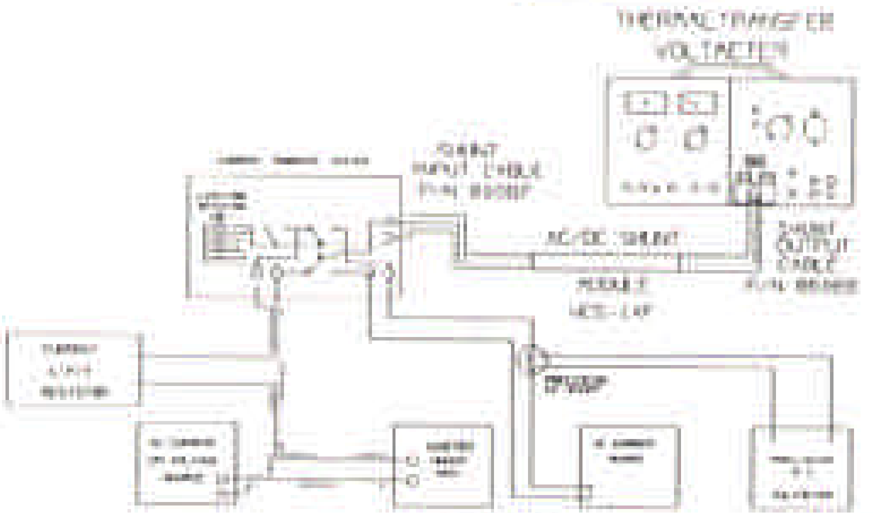

Fig. 3 - 2
Ammeter Calibration

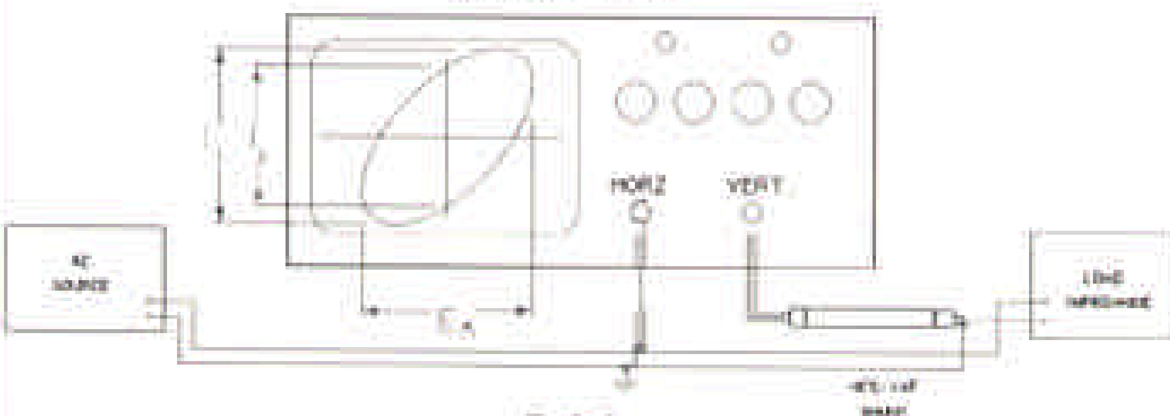

Fig. 3 - 3
Power Factor, Phase Angle Measurement

3.5.2.5 Summary - The following procedure assumes that the AC and DC sources have direct reading controls calibrated in percent offset or the main controls can be adjusted and read with resolution finer than the accuracy required of the measurement.

STEP ACTION

1. Connect the test set up and set TVM controls
2. Apply AC current and adjust approximate null using the TVM balance controls.
3. Switch to DC and adjust DC source for approximate null.
4. Switch to AC and wait for warm up. Record setting of AC (AC1).
5. Adjust TVM to exact null and switch to + DC.
6. Wait 20 seconds and start tracking null with controls of the DC source.
7. At 30 seconds and null, read the magnitude of the + DC. Record this magnitude as DC1 and immediately switch to AC
8. Wait 20 seconds and start tracking null with controls of the AC Source
9. At 30 seconds and null, read the magnitude of the AC. Record this value as AC 2 and immediately switch to - DC.
10. Wait 20 seconds and start tracking null with controls of the DC Source
11. At 30 seconds and null, read the magnitude of the - DC. Record this magnitude as DC2 and immediately switch to AC
12. Wait 20 seconds and start tracking null with controls of the AC source.
13. At 30 seconds and null, read the magnitude of the AC. Record this value as AC 3
14. Calculate as follows:

Direct Reading AC Source Correction Factor in PPM

$$\text{Correction Factor} = \left[\frac{3\,(DC_1 + DC_2)}{2\,(AC1 + AC2 + AC3)} - 1 \right] \times 10^6$$

A positive correction factor means that the absolute magnitude of the AC current is greater than the AC source dials indicate

3.5.2.6 It is further recommended that any transfer be repeated a number of times to insure precision of the reading. Average these results for the most accurate value. This is especially important when the desired accuracy approaches the resolution of the Null Detector of the drift between AC and DC measurements.

3.5.3 Additional Precautions:

3.5.3.1 Protection of Voltage Sources: The Model HCS-1 AF is designed for use with current regulated sources or high impedance voltage regulated sources. When using voltage regulated sources, some general precautions must be followed when connecting the unit to an AC or a DC source. When using a voltage regulated source, a series resistor must be connected between the source and the meter under test. A decade power resistor is recommended for this purpose. Using such a decade resistor, the total resistance in the circuit may be adjusted so that the current bears a simple relationship to the supply voltage. If the limiting resistor (RL) is properly chosen with respect to the resistance of the shunt (RS) and the meter under test (RX), the calibrated output dial or the output voltmeter of the source will read directly in amperes or milliamperes with a reasonable degree of accuracy. Choose the value (RL) as follows:

Full scale Current of meter	Limiting Resistor (R_L) Ohms
3 Amps	1 - (RS + RX)
1 Amps	10 - (RS + RX)
100 ma	100 - (RS + RX)
10 ma	1000 - (RS + RX)
1 ma	10K - (RS + RX)

3.5.3.2 Current Measurements (10 kHz to 50 kHz). The Model HCS- 1 AF is capable of measurements to 50 kHz. Procedure is the same as in paragraph 3.5.3. Above 10 Khz certain external effects occur which should be considered. Losses due to wiring inductance between the sources and the shunt become large enough to be a factor. The AC sources must be capable of supplying these added volt-ampere requirements.

Parallel Capacitance Leakage: At higher frequencies the current passing thru the shunt and the DUT may not be equal if there are capacitive paths by which the current can bypass one device or the other. These capacitive currents are particulary important on the lowest current ranges. Keep cables short. The possible effect may be calculated as follows using the diagram in Fig. 3-4

$$I = \sqrt{(I_{shunt})^2 + (I_{capacitance})^2}$$

The operator should be careful to route any non coaxial current carrying conductors away from the Thermal Transfer Voltmeter to avoid inductive coupling to the voltage measuring circuits

3.5.3.3 When using the Fluke Model 540B be extra careful to avoid applying voltage above 0.5 volts to this unit as it is not protected from overload on the shunt input circuit.

3.5.3.4 Ground connections and Common Mode Voltages: As current measurements must always be made with devices connected in series, the operator must always arrange the test circuit and its connection to ground in such a way that the current flowing thru the DUT. At low frequencies this is relatively simple, at 20 Khz it is almost impossible
Some suggestions follow:

1. If the device under test has a line operated power supply and a "green wire" chassis ground it will probably be best to ground the chassis of that device and let the HCS-1AF float above ground. In this case be careful to avoid placing the HCS-1AF at a potential of more than 10 volts RMS above ground. Voltages in excess of this may rupture the bead in the thermoelement.

2. If the DUT is a passive device or a small battery operated device ground the HCS-1AF and float the DUT.

3. If neither of these conditions is possible a low capacitance triple shielded isolation transformer may be used between the AC source and the test circuit, thereby allowing both the DUT and the HCS-1AF to be grounded. If this is done the burdens produced by the DUT and the HCS-1AF should be padded with small series resistors to present a balanced load to the source transformer and the test should be repeated after interchanging the HCS-1AF and the DUT to determine the magnitude of unbalance in the source transformer.

4. Leads should be kept as short as possible and circuit stray capacitance should be minimized.

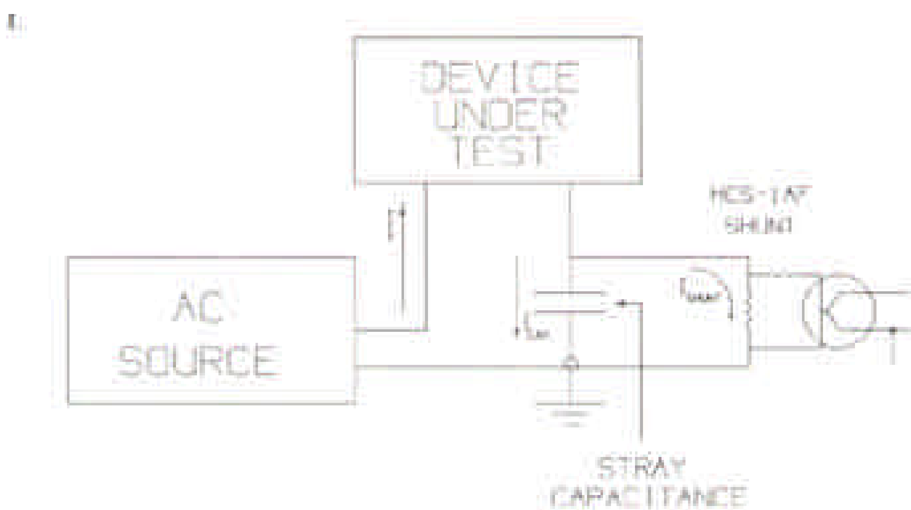

Fig. 3 - 4
Effect of Stray Capacitive Current

SECTION 4
DESIGN FUNDAMENTALS

The design of the Holt Model HCS-1 Shunt resistors is based on work done by Dr. John Park at the National Bureau of Standards as reported in reference 1. Dr. Park was interested in measuring high energy pulses of current of the type occurring in laboratory simulation of lightning discharge. However Holt engineers found that the concept of coaxially constructed shunt resistors similar to Dr. Parks design could be adapted for high accuracy measurements of lower currents. Due to their inherent low inductance and the fact that no mechanical adjustment was needed for mutual magnetic coupling of the current and potential leads these shunts could be reproduced and would have AC/DC differences which would repeat within 50 ppm at 50,000 hz with no trimming or modification of the individual finished units. The general principle of construction is shown in Fig. 4.1 The shunt consists of a central conductor surrounded by a concentric resistance element of a low thermal emf low temperature coefficient material. This element is in turn surrounded by a concentric outer conductor. The current is introduced at the female connector and flows down the inner rod to the junction with the resistor, it then flows on down the resistor and to the outer tube at the output end to the shell where is folds back flowing down the outer tube to the module of the female connector. The potential is sampled at the male connector the center of which is connected to the central rod and the shell of which is connected to the common end of the resistor. Due to this use of concentric triaxial conductors the potential lead is coupled to the resistor in a path which is essentially free of the magnetic field of the current flowing in the resistor. The space between the resistor element and the outer conductor is kept extremely small to reduce the inductance. The space in between the resistor element and the outer shell is filled with a thermal transfer compound and the outer shell is constructed with an integral heat sink to assist in the control of self heating effects.

As an example of the effectiveness of the HCS-1 design, the shunt constructed for use in the electronic power measurement system designed by Mr. S.P. Mehta of RTE-ASEA is one of this family of shunts. This particular unit is a two ohm shunt adjusted to a tolerance of less than 0.1% over a current range of 0 to 2 amperes. The frequency response was measured using Thermal Transfer techniques traceable to the National Bureau of Standards at frequencies from 50 Hz to 10 MHz. Calculation of the reactance of the shunt from the data indicated that the phase shift of the output voltage vs the input current at 60 Hz should be less than 10 micro - radians. System tests at NBS later confirmed that these goals were met. (Ref. 2)

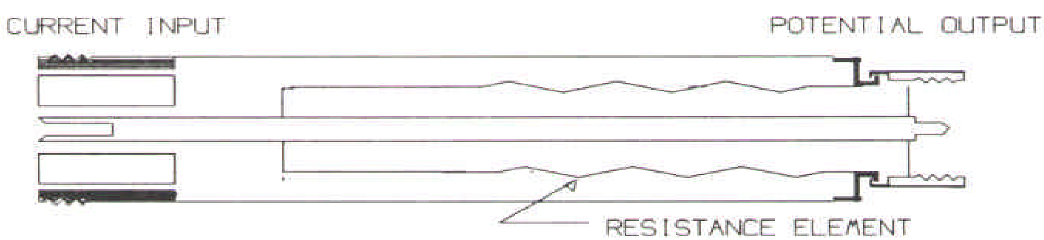

FIG. 4.1 SHUNT MODULE CONSTRUCTION

Ref. 1 "Shunts and Inductors for Surge- current Measurements,"
John H. Park
RP 1823 Volume 39, Sept. 1947 U.S. National Bureau of Standards

Ref. 2:
"Calibration of Test Systems for Measuring Power Losses of Transformers,"
O. Petersons & S. Mehta
Tech Note 1204 N.B.S. Aug. 1985

SECTION 5
RECALIBRATION AND SERVICING

5.1 Recalibration: There are no calibration adjustments to be made on any of the shunts. All components are fixed, passive types, factory selected for proper performance. Under normal conditions there is no deterioration of performance with age when proper handling precautions are observed and the shunts are operated within specified current limits. The shunts are usually checked for AC-DC difference by comparison with a set of shunts which have been submitted to NBS for testing. These tests can only be conducted in a properly equipped standards laboratory that has the test fixtures and special test equipment to perform the tests. It is recommended that AC-DC difference tests be made by NBS or Holt Instrument Laboratories. Both are properly instrumented to make these tests.

5.2 Service: Service is restricted to keeping the connectors clean and the cables in good condition. Periodically the four terminal resistance of the shunt modules should be measured. This is a good check to detect damage to a module due to current overload. Refer to the Table 5.1 below. Check D.C. resistance of the modules as listed in the table.

There are no replaceable parts inside the shunt modules. Service or repair of any of the shunts may result in performance being out of specification limits. Internal components and wiring are factory selected and adjusted to meet specified performance. Units should be returned to Holt Instrument Laboratories for service if it is required.

SHUNT RANGE	P/N	NOMINAL	RESISTANCE MAXIMUM	MINIMUM
20A	81688-16	0.025	0.026	0.024
5A	81688-15	0.100	0.102	0.098
2A	81688-14	0.251	0.256	0.246
0.5A	81688-13	1.010	1.030	0.990
0.2A	81688-12	2.564	2.615	2.531
0.02A	81688-11	33.33	34.00	32.