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By J. Franchi

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NCEL
Technical Report

FIELD PERFORMANCE OF THREE-PHASE AMORPHOUS METAL CORE DISTRIBUTION TRANSFORMERS AT PEARL HARBOR, HAWAII

ABSTRACT As part of a 3-year project sponsored by the Naval Facilities Engineering Command (NAVFAC) and Office of Naval Research (ONR), eight prototype three-phase amorphous metal core distribution transformers (three 75-kVA and five 150-kVA units) were installed at the Public Works Center (PWC) Pearl Harbor, Hawaii. The program objective was to evaluate the electrical performance and operational reliability of the amorphous metal core transformers compared to conventional silicon-steel transformers, and to determine the stability of the transformer core losses over an extended period of time. Three years of test and evaluation of these amorphous transformers has shown no degradation of the initial low core loss. No failures of any kind occurred. More importantly, test results obtained from these transformers indicate no long-term degradation of the low core loss is expected. No-load losses in the 75-kVA transformers tested were reduced by 62.6 percent and in the 150-kVA units by 70.1 percent. Distribution transformers are an area where more efficient materials, such as amorphous metal, significantly reduce core losses and help to lower the total losses on the distribution system. These eight relatively small three-phase transformers have been in operation at Pearl Harbor for only a few years, but have already produced energy savings of approximately three thousand dollars.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043-5003

METRIC CONVERSION FACTORS

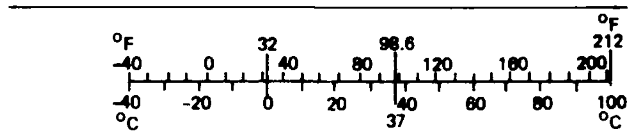
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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As part of a 3-year project sponsored by the Naval Facilities Engineering Command (NAVFAC) and Office of Naval Research (ONR), eight prototype three-phase amorphous metal core distribution transformers (three 75-kVA and five 150-kVA units) were installed at the Public Works Center (PWC) Pearl Harbor, Hawaii. The program objective was to evaluate the electrical performance and operational reliability of the amorphous metal core transformers compared to conventional silicon-steel transformers, and to determine the stability of the transformer core losses over an extended period of time. Three years of test and evaluation of these amorphous transformers has shown no degradation of the initial low core loss. No failures of any kind occurred. More importantly, test results obtained from these transformers indicate no long-term degradation of the low core loss is expected. No-load losses in the 75-kVA transformers tested were reduced by 62.6 percent and in the 150-kVA units by 70.1 percent. Distribution transformers are an area where more efficient materials, such as amorphous metal, significantly reduce core losses and help to lower the total losses on the distribution system. These eight relatively small three-phase transformers have been in operation at Pearl Harbor for only a few years, but have already produced energy savings of approximately three thousand dollars.

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INTRODUCTION

The Naval Civil Engineering Laboratory (NCEL) has recently completed a test and evaluation program for 75-kVA and 150-kVA amorphous core distribution transformers at the Public Works Center (PWC), Pearl Harbor, Hawaii. Results of these tests compare very favorably with industry projections of 60 to 70 percent savings in transformer no-load losses for amorphous core distribution transformers.

Amorphous metal is produced by a process known as rapid solidification. By spraying molten metal in a cold environment, tiny particles are cooled at the rate of one million degrees a second. This process freezes the atoms in place before they can align in a crystalline lattice, as happens with glass. In glassy form, a metal can possess properties of strength, conductivity, and magnetism that are entirely different from its crystalline form. Rapid solidification creates a new state of matter; metals with new structures; and new properties of magnetism, strength, and stiffness.

The technological progress made possible by this advanced material in the amorphous core distribution transformers at Pearl Harbor, Hawaii resulted in reducing no-load losses by 62.6 percent in the 75-kVA transformers and by 70.1 percent in the 150-kVA units.

BACKGROUND

In January 1987, the Public Works Center (PWC), Pearl Harbor, Hawaii initiated a transformer replacement program involving 126 PCB contaminated three-phase pad-mounted indoor and outdoor distribution transformers. The Naval Civil Engineering Laboratory (NCEL), in investigating Navy-wide costs in energy savings, contracted with the General Electric Company to build eight prototype three-phase amorphous core distribution transformers (three 75-kVA and five 150-kVA units) to be included in this transformer replacement program at Pearl Harbor. At the time of installation in 1987, these units were the largest commercial grade amorphous core transformers in the world.

This report chronicles the performance of these transformers over a 2-year period of operation on the utility systems at Ford Island, Barbers Point Naval Air Station, the Naval Shipyard, and the Naval Supply Center at Pearl Harbor, Hawaii.

The main objectives of these field tests were to determine that there is no long-term degradation of the initial low core loss and exciting current due to aging of the amorphous core under normal operating conditions.

INSTALLATION TESTING

NCEL's operating experience with three-phase amorphous core transformers on a distribution system began in October 1987 at the Public Works Center (PWC), Pearl Harbor, Hawaii. The eight amorphous core transformers that were installed at PWC Pearl Harbor were built by the General Electric Company. NCEL monitored the entire manufacturing process of these transformers prior to their shipment to Pearl Harbor, beginning with the design and construction of the amorphous cores at the Hickory, North Carolina facility and culminating with the final assembly of the completed units at the Shreveport, Louisiana plant.

The following commercial tests were conducted by the General Electric Company according to ANSI/IEEE C57.12.90-1980 standards. These tests were conducted in order to determine the transformers electrical performance parameters prior to installation and further field testing at Pearl Harbor, Hawaii. All tests were conducted at the Hickory, North Carolina and Shreveport, Louisiana plants.

Ratio Test

- Objective: The turns ratio of the transformer is the ratio of turns in the high-voltage winding to turns in the low-voltage winding. The objective of the ratio test was to demonstrate that the ratio of turns in the high-voltage and low-voltage windings was correct, so that a given impressed high voltage would produce the expected low voltage, according to the ratio of high-voltage winding turns to low-voltage turns.

Polarity Test

- Objective: The objective of the polarity test was to demonstrate that the leads and polarity marks on the transformer reflected the actual arrangement of the transformer windings. These data are particularly important when two or more transformers are operated in parallel.

No-Load Loss/Exciting Current Test

- Objectives: The objectives of the no-load loss and excitation current tests were to determine: (1) the power loss in the transformer when operating at rated voltage and frequency, but not supplying load; and (2) the excitation current required to maintain the magnetic flux excitation in the transformer core. No-load losses include core loss, dielectric loss, and loss in the windings due to exciting current. Both no-load losses and excitation currents should be determined using sinusoidal sources, or by correcting for the applied source waveforms as described in Section 8 of ANSI/IEEE C57.12.90-1980.

Impedance Voltage/Load Loss Tests

- Objective: The objective of the impedance voltage/load loss tests was to determine the voltage required to circulate the rated current under short-circuit conditions, and the associated watt loss when the source was connected to the rated voltage taps. The impedance voltage consisted of an effective resistance component corresponding to the load losses and a reactive component corresponding to the leakage flux linkages of the windings.

Applied Voltage Tests

- Objective: The objective of the applied voltage tests was to stress the major components of insulation, and the major insulation between the windings and ground. Two types of applied voltage tests were made: high-to-low-to-iron-to-case (HLIC) applied voltage tests, and low-to-high-to-iron-to-case (LHIC) applied voltage tests. In the HLIC tests, the test voltage was applied to the high-voltage transformer bushings (which were tied together), and the low voltage bushings (which were tied together and grounded). In the LHIC tests, all low-voltage bushings were tied together and connected to the source voltage, and the high-voltage bushings were tied together and grounded. The HLIC tests stressed the insulation of the high-voltage windings. The LHIC tests stressed the low-voltage windings.

Induced Potential Test

- Objective: The objective of the induced potential test was to stress interwinding insulation structures, as well as portions of the major insulation. The test applied greater than rated volts per turn to the transformer, so that it was run at higher frequency (400 Hz in this case) to avoid core saturation.

Audible Sound Level Test

- Objective: The objective of the audible sound level test was to determine the audible sound emitted from the transformer when operated at rated voltage and frequency, and no load. Sound level measurements were significant because excessive sounds from transformers can be an annoyance in residential or other populated areas. Also, excessive sound levels may indicate apparent problems in the transformer core, such as loose or fractured core laminations. A sound level meter with an A-weighting frequency network was used for the measurements, since this type of weighting best represents the ability of a remote listener, with normal hearing, to hear the complex sounds generated by the transformer. The tests were conducted in accordance with the procedures in Section 13 of ANSI/IEEE C57.12.90-1980.

Radio Influence Voltage (RIV) Test

- Objective: The objective of the RIV test was to determine the amount of RIV produced by the corona (local overstress) in transformer insulation. RIV, as the name implies, may cause interference to radio communications. Excessive corona may also be an indication of insulation breakdown. The tests were performed with the methods prescribed in NEMA Publication TR 1. Tests were run at 100 percent and 110 percent of rated voltage.

Short-Circuit Test

- Objective: The objective of the short-circuit tests was to demonstrate the ability of the transformer to withstand the stresses resulting from a short circuit applied to the transformer's primary or secondary terminals. The tests were conducted by either closing a breaker at the faulted terminal to apply a short circuit to a previously energized transformer, or by closing a breaker at the source terminal to apply energy to a previously short-circuited transformer.

Temperature Rise Test

- Objective: The objective of the temperature rise test was to determine the maximum temperature rise (above the ambient temperature) of the windings and the insulating fluid in the transformer when the transformer was operated at maximum kVA rating. The temperature rise test was conducted in accordance with the procedures in Section 11 of ANSI/IEEE C57.12.90-1980.

No-Load Loss Corrected to a Sine-Wave Basis

Because no-load loss and current are particularly sensitive to differences in waveshape, no-load loss measurements will vary markedly with the waveshape of the test voltage. The correct no-load loss of a transformer shall be determined from the measured value by means of the following equation:

$$P = \frac{P_m}{P_1 + kP_2}$$

This requires both an average and root mean square (rms) responding voltmeter be used to correct the measured no-load losses to a sine-wave basis.

After receiving the eight amorphous core transformers at the Naval Shipyard at Pearl Harbor and prior to their installation on the distribution system, the following tests were conducted by NCEL personnel in order to insure that the transformers were not damaged in any way during their shipment from the Shreveport, Louisiana plant to Pearl Harbor, Hawaii. No-load loss and exciting current tests showed changes of less than 1 percent from the factory test results, while the ratio and polarity tests were exactly the same.

Figure 1 shows the complete test setup in Building 166 prior to field installation. When no-load loss, excitation current, ratio, and polarity tests were completed, the amorphous core transformers were loaded on flatbed trucks as shown in Figure 2 and permanently installed at various sites throughout the Pearl Harbor complex. Figure 3 shows the final installation of a 150-kVA amorphous core transformer at the Naval Shipyard, Pearl Harbor, Hawaii.

TEST METHODS

Correcting No-Load Loss to Sine-Wave Basis

ANSI Standard C57.12.90 requires that no-load losses be determined based on a sine-wave voltage. Furthermore, it recommends that the average voltmeter method (which requires both an average and rms responding voltmeter) be used to correct the measured no-load losses to a sine-wave basis. Both voltmeters are required because the no-load loss is very sensitive to the waveshape of the test voltage and different waveshapes will result in different losses.

All amorphous transformer testing at Pearl Harbor was accomplished according to ANSI Standard C57.12.90 using a Yokogawa Model 2533 Digital Power Meter, which incorporates both an average and rms responding voltmeter. The correct no-load loss was then determined by means of the following equation:

$$P - \frac{P_m}{P_1 + kP_2}$$

where P = no-load loss (watts) corrected to a sine-wave basis

P_m = no-load loss measured in test

P_1 = per unit hysteresis loss*

P_2 = per unit eddy-current loss*

*If actual percentage values of hysteresis and eddy-current losses are not available, ANSI standard suggests that they be assumed equal, assigning a value of 0.5 per unit:

$$k = \left(\frac{E_r}{E_a} \right)^2$$

where E_r = test voltage measured by rms voltmeter

E_a = test voltage measured by average voltage voltmeter

Figures 4 and 5 show a Yokogawa Model 2533 Digital Power Meter and the different wiring configurations that were used to test the three-phase 3-wire and three-phase 4-wire amorphous core transformers at Pearl Harbor, Hawaii. Figure 6 shows a schematic diagram of the Digital Power Meter connected to a three-phase 4-wire amorphous core transformer under test at Barbers Point Naval Air Station. This testing procedure was strictly adhered to in testing all amorphous core transformers at Pearl Harbor.

It was necessary to use a generator with multiple output load connections to supply rated voltage to the secondaries of the transformers under test. These load-to-generator connections and the generator connection schematic diagram are shown in Figure 7. The required voltages needed to test the eight amorphous core transformers were:

1. Three-phase 4-wire 120/208 WYE.
2. Three-phase 3-wire 240-volt delta.
3. Three-phase 3-wire 230-volt delta.
4. Three-phase 3-wire 480-volt WYE.

These various output voltages are precisely controlled with a potentiometer in the control circuitry of the Onan 7.5-kW generator.

Field Site Testing

Field performance was monitored at 1-year intervals over a 3-year period. The purpose of the field tests was: (1) to evaluate core loss and exciting current stability, and (2) to conduct the most widespread field evaluation of three-phase amorphous core transformer performance to date.

NCEL initiated a test program to evaluate the stability of the amorphous core transformer. The following parameters were recorded over the 3-year period:

1. No-load losses on each phase (watts)
2. Total no-load loss (watts)
3. Corrected no-load loss to a sine-wave basis (watts)
4. Excitation current (amperes)
5. Percent excitation current
6. Root mean square (rms) voltage
7. Average voltage
8. Ambient air temperature

9. Oil temperature inside transformer

10. Maximum oil temperature inside transformer

Following is a list of the stations along with the size and location of each transformer tested on the island of Oahu, Hawaii:

Station	Size	Location
TF-9	75 kVA	Ford Island (B-99)
BP-B169	75 kVA	Barbers Point Naval Air Station (B-169)
TD-10	75 kVA	Ford Island (B-181)
K-28	150 kVA	Naval Supply Center (S-959)
Bldg-166	150 kVA	Naval Shipyard (B-166)
TC-7	150 kVA	Ford Island (S-258)
C-11	150 kVA	Naval Shipyard (B-393)
BP-B91	150 kVA	Barbers Point Naval Air Station (B-91)

These transformers have been in service for over 2 years with little change in no-load loss and excitation current. A summary of the test results of the amorphous core transformers performance on a distribution system measured at intervals over a 3-year period is shown in Tables 1 through 8. Tables 9 and 10 show the results of the same testing procedure used on conventional 150-kVA silicon steel transformers. Table 11 shows the results of a World War II vintage transformer that is still in use today at Pearl Harbor, Hawaii. This transformer had no-load losses of 888 watts compared to 87 watts for a amorphous core transformer of the same size. The amorphous core transformer showed a 90 percent reduction in the energy consumed by losses in the cores of the distribution transformers. This transformer core loss is power which must be supplied every hour of every day. By locating these amorphous core transformers in critical areas throughout the Pearl Harbor complex, PWC Pearl Harbor has taken full advantage of the power saving opportunities these transformers offer.

When testing amorphous core transformers in the field, the power to the transformer had to be shut down, and all primary and secondary leads removed. The secondary leads were removed to completely isolate the transformer from any other electrical circuits. In every case, this resulted in a complete power outage in the test area. Power outages needed to be incorporated into the testing schedule, and time limits observed when testing the equipment. PWC Pearl Harbor scheduled and provided NCEL with a 4-hour power outage for each transformer tested. Frequently, the testing was accomplished in less than half of that time.

NCEL used the following test procedure for each transformer:

1. A high-voltage electrician would shut down the power to the transformer under test.

2. All primary and secondary leads were removed from the transformer under test.

3. NCEL personnel then tested the transformer.

4. All primary and secondary leads to the transformer were then reconnected.

5. The high-voltage electrician then switched the high voltage back on the primary of the transformer.

In addition to showing no indications of degradation in performance of magnetic properties, none of these eight amorphous core transformers have required any maintenance or repair. Although the periodic testing of these transformers has been discontinued, they are still in operation today and are expected to continue providing reliable service for the next 20 to 30 years.

Equipment Used

The core loss and exciting current performance of the amorphous core transformers required test equipment of known accuracy. This test equipment, as pictured in Figure 8, was periodically calibrated and the calibration results are traceable to the National Bureau of Standards in accordance with MIL-STD-45662.

Because of the very nature of the tests, the transformers being installed at eight different locations around the island of Oahu, required that all the test equipment be portable. This equipment was purposely designed and selected by NCEL for transport by pickup truck since three of the test sites were located on Ford Island and accessible solely by ferryboat.

Two portable generators were used to conduct all installation and later field site testing of the amorphous core transformers. The main power source used throughout the test program was an Onan 7.5-kW 4-cycle-2-cylinder vertical in-line, gasoline-driven, air-cooled, alternating current generator (see Figure 9). This generator was selected because it could provide nine different three-phase output voltages, which vary from 120/208 to 277/480 volts in both WYE and DELTA configurations. The main purpose of this generator was to supply rated voltage to the secondary of the transformer under test. Its starting source is a 12-volt battery. Figure 10 shows the cover removed from the throat of an amorphous core transformer exposing the secondary tabs where rated voltage is applied during testing. The frequency of the generator was continually monitored and, when required, adjusted to exactly 60.0 Hz for all the different output voltages needed to conduct the tests. A Simpson Model 2726 electronic counter was used to monitor the output frequency of the 7.5-kW Onan generator while it was providing rated voltage to the secondary of the transformer under test. This piece of equipment is a very accurate solid state device with a six-digit numerical display, which has a frequency range from 5 Hz to 32 MHz with an accuracy of ±0.001 percent ±digit.

The second generator, a Honda Model EG650-550 watt, four-stroke, one cylinder air-cooled, gasoline-driven generator, was used to provide power for the two test instruments. These instruments include the Simpson Model 2726 electronic counter and the very heart of the testing program, the YOKOGAWA Model 2533 Digital Power Meter (see Figure 11).

This power measuring instrument primarily measures voltage, current, and power in single- and three-phase circuits with an accuracy of ±0.1 percent of reading +0.1 percent of range within 44 to 66 Hz, over a frequency range of 10 Hz to 20 KHz. Three values among measured or computed values are simultaneously displayed; voltage, current, and power of single-phase to three-phase 3-wire or three-phase 4-wire circuits.

When testing the three-phase amorphous core transformers using this instrument, it was possible to obtain voltage, current, and power on each phase of the transformer along with the total current and power of the transformer under test. This was especially important since a determination could be made concerning the distribution of the core loss in each phase of the transformer.

A Model HT14K Digital Thermometer was used to monitor the ambient air temperature. It has a range of -50 °F to 140 °F with an accuracy of ±0.75 percent to 1 °F.

A complete block diagram of the test program is shown in Figure 12.

CONCLUSIONS

The results of testing the three-phase amorphous core distribution transformers at Pearl Harbor, Hawaii confirm the reliability and dependability of these transformers. The 75-kVA three-phase amorphous transformers showed a 62.6 percent reduction in core loss as compared to silicon iron transformers, while the 150-kVA units showed a 70.1 percent reduction (see Table 12).

Some of the new 150-kVA silicon-steel transformers that were installed at Pearl Harbor as part of the transformer replacement program had no-load losses that were 78 percent higher than comparable amorphous core units (Tables 9 and 10). Reductions in core losses as high as 90 percent were observed when comparing the new ultra efficient amorphous core distribution transformers with similar older transformers that are still in operation today at Pearl Harbor Hawaii (see Table 11).

Amorphous metal core distribution transformers are a reliable means of reducing day-to-day operating costs. Although silicon-steel distribution transformers are relatively efficient devices, the total annual energy lost in their use is significant. This core loss is power that must be supplied every hour of every day to these transformers.

Amorphous metals represent a major advance in transformer core technology and the Navy has taken full advantage of this quantum step in efficiency improvement with its test program at Pearl Harbor, Hawaii.

For further information on transformers, a list of related NCEL technical documents is included as an appendix to this report.

FUTURE WORK

The main objective of the amorphous core transformer field tests was to determine if there would be any change in no-load losses and exciting current due to the aging of the amorphous core under normal operating conditions over extended periods of time. Although the periodic testing of these transformers has been discontinued, they are still in service today, and based on the limited data base that has been acquired, are expected to continue performing for the normal expected transformer life of 20 to 30 years.

Three-phase amorphous core transformers have only recently become commercially available and the results of the field tests at Pearl Harbor, Hawaii are the only field performance data that has been acquired by the Navy thus far.

In order to obtain a larger data base from which to better evaluate the performance of these transformers, NCEL would need to extend this program to at least 5 years. This would require further testing in 1990 and 1991 on an annual basis.

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Table 1. 75-kVA Amorphous Transformer Performance on the Distribution System at Ford Island (B-99)

Serial No. P180311TVB; Transformer No. LN 3519

a. Specifications

Station......TF-9	Impedence........4.59% @ 85 °C
Type.........Three-Phase	BIL-HV Winding...95 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........1,950 lb
HV...........12,000	Liquid...........90 Gallons, Mineral Oil
LV...........230	
Temp. Rise...65 °C	Installed........10-21-87

b. Test Results

Parameters Tested	Test Date		
	10-20-87	5-16-88	6-13-89
RMS, Volts	230.43	230.60	230.40
AVG, Volts	230.32	230.40	230.30
No-Load Loss (W)	47.50	46.80	47.30
Corrected No-Load Loss to Sine-Wave Basis (W)	47.48	46.76	47.28
Exciting Current (A)	0.2744	0.2577	0.2536
Exciting Current (%)	0.09	0.07	0.07
Ambient Air Temp.	85 °F	82 °F	82 °F
Oil Temp. Inside Transformer	30 °C	28 °C	26 °C
Oil Temp. Inside Transformer (Max)	30 °C	28 °C	29 °C

Table 2. 75-kVA Amorphous Transformer Performance on the Distribution System at Barbers Point Naval Air Station (B-169)

Serial No. P180312TVB; Transformer No. LN 4307

a. Specifications

Station......BP-B169	Impedence........4.46% @ 85 °C
Type.........Three-Phase	BIL-HV Winding...60 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........1,950 lb
HV...........4,160	Liquid...........89 Gallons, Silicone Oil
LV...........480	
Temp. Rise...65 °C	Installed........10-20-87

b. Test Results

Parameters Tested	Test Date		
	10-20-87	5-19-88	6-15-89
RMS, Volts	480.03	480.03	480.10
AVG, Volts	478.82	479.00	478.40
No-Load Loss (W)	48.37	48.00	48.20
Corrected No-Load Loss to Sine-Wave Basis (W)	48.27	47.87	48.03
Exciting Current (A)	0.1927	0.1830	0.1881
Exciting Current (%)	0.12	0.12	0.12
Ambient Air Temp.	85 °F	83 °F	85 °F
Oil Temp. Inside Transformer	28 °C	30 °C	30 °C
Oil Temp. Inside Transformer (Max)	28 °C	30 °C	40 °C

Table 3. 75-kVA Amorphous Transformer Performance on the Distribution System at Ford Island (B-181)

Serial No. P180313TVB; Transformer No. LN 3571

a. Specifications

Station......TD-10	Impedence........4.60% @ 85 °C
Type.........Three-Phase	BIL-HV Winding...95 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........1,950 lb
HV...........12,000	Liquid...........90 Gallons, Mineral Oil
LV...........230	
Temp. Rise...65 °C	Installed........10-23-87

b. Test Results

Parameters Tested	Test Date		
	10-22-87	5-17-88	6-13-89
RMS, Volts	230.20	230.20	230.60
AVG, Volts	230.00	230.00	230.30
No-Load Loss (W)	51.20	49.90	50.30
Corrected No-Load Loss to Sine-Wave Basis (W)	51.16	49.82	50.23
Exciting Current (A)	0.2668	0.2611	0.2569
Exciting Current (%)	0.08	0.08	0.08
Ambient Air Temp.	84 °F	81 °F	85 °F
Oil Temp. Inside Transformer	27 °C	28 °C	28 °C
Oil Temp. Inside Transformer (Max)	27 °C	32 °C	32 °C

Table 4. 150-kVA Amorphous Core Transformer Performance on the Distribution System at the Naval Supply Center (S-959)

Serial No. P180323TVB; Transformer No. LN 2040

a. Specifications

Station......K-28	Impedence........4.42% @ 85 °C
Type.........Three-Phase	BIL-HV Winding...95 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........2,700 lb
HV...........12,000	Liquid...........120 Gallons, Mineral Oil
LV...........208Y/120	
Temp. Rise...65 °C	Installed........10-19-87

b. Test Results

Parameters Tested	Test Date		
	10-16-87	5-15-88	6-12-89
RMS, Volts	120.39	120.21	120.37
AVG, Volts	120.39	120.28	120.15
No-Load Loss (W)	86.68	86.50	88.50
Corrected No-Load Loss to Sine-Wave Basis (W)	86.68	86.55	88.34
Exciting Current (A)	0.6185	0.5926	0.6997
Exciting Current (%)	0.09	0.08	0.09
Ambient Air Temp.	86 °F	87 °F	84 °F
Oil Temp. Inside Transformer	28 °C	32 °C	30 °C
Oil Temp. Inside Transformer (Max)	28 °C	32 °C	32 °C

Table 5. 150-kVA Amorphous Core Transformer Performance on the Distribution System at the Naval Shipyard (Bldg-166)

Serial No. P180324TVB; Transformer No. LN 4433

a. Specifications

Station......Bldg 166	Impedence........4.45% @ 85 °C
Type.........Three-Phase	BIL-HV Winding...95 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........2,800 lb
HV...........12,000	Liquid...........120 Gallons, Silicone Oil
LV...........208Y/120	
Temp. Rise...65 °C	Installed........10-25-87

b. Test Results

Parameters Tested	Test Date		
	10-26-87	5-11-88	6-8-89
RMS, Volts	120.12	120.17	120.60
AVG, Volts	120.19	120.31	120.70
No-Load Loss (W)	86.36	85.74	86.80
Corrected No-Load Loss to Sine-Wave Basis (W)	86.41	85.80	86.88
Exciting Current (A)	0.6046	0.5859	0.5986
Exciting Current (%)	0.08	0.08	0.08
Ambient Air Temp.	87 °F	81 °F	85 °F
Oil Temp. Inside Transformer	27 °C	26 °C	25 °C
Oil Temp. Inside Transformer (Max)	27 °C	28 °C	25 °C

Table 6. 150-kVA Amorphous Core Transformer Performance on the Distribution System at Ford Island (S-258)

Serial No. P180325TVB; Transformer No. LN 3533

a. Specifications

Station......TC-7	Impedence........4.54% @ 85 °C
Type.........Three-Phase	BIL-HV Winding...95 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........2,700 lb
HV...........12,000	Liquid...........120 Gallons, Mineral Oil
LV...........208Y/120	
Temp. Rise...65 °C	Installed........10-18-87

b. Test Results

Parameters Tested	Test Date		
	10-17-87	5-12-88	6-16-89
RMS, Volts	120.39	120.07	120.00
AVG, Volts	120.33	119.94	119.80
No-Load Loss (W)	91.62	90.30	89.53
Corrected No-Load Loss to Sine-Wave Basis (W)	91.58	90.31	89.36
Exciting Current (A)	0.6634	0.6200	0.6262
Exciting Current (%)	0.09	0.09	0.09
Ambient Air Temp.	87 °F	81 °F	84 °F
Oil Temp. Inside Transformer	30 °C	32 °C	32 °C
Oil Temp. Inside Transformer (Max)	30 °C	34 °C	33 °C

Table 7. 150-kVA Amorphous Core Transformer Performance on the Distributiion System at the Naval Shipyard (B-393)

Serial No. P180326TVB; Transformer No. LN 2016

a. Specifications

Station......C-11	Impedence........4.50% @ 85 °C
Type.........Three-Phase	BIL-HV Winding...95 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........2,700 lb
HV...........12,000	Liquid...........120 Gallons, Mineral Oil
LV...........208Y/120	
Temp. Rise...65 °C	Installed........10-19-87

b. Test Results

Parameters Tested	Test Date		
	10-17-87	5-14-88	6-10-89
RMS, Volts	120.41	120.28	120.51
AVG, Volts	120.41	120.32	120.38
No-Load Loss (W)	85.64	85.21	84.00
Corrected No-Load Loss to Sine-Wave Basis (W)	85.63	85.23	83.92
Exciting Current (A)	0.6253	0.6306	0.5852
Exciting Current (%)	0.09	0.09	0.08
Ambient Air Temp.	86 °F	81 °F	84 °F
Oil Temp. Inside Transformer	26 °C	28 °C	27 °C
Oil Temp. Inside Transformer (Max)	26 °C	28 °C	28 °C

Table 8. 150-kVA Amorphous Core Transformer Performance on the Distribution System at Barbers Point Naval Air Station (B-91)

Serial No. P180327TVB; Transformer No. LN 4125

a. Specifications

Station......BP-B91	Impedence........4.47% @ 85 °C
Type.........Three-Phase	BIL-HV Winding...60 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........2,550 lb
HV...........4,160	Liquid...........120 Gallons, Mineral Oil
LV...........480	
Temp. Rise...65 °C	Installed........10-20-87

b. Test Results

Parameters Tested	Test Date		
	10-19-87	5-18-88	6-17-89
RMS, Volts	480.20	480.70	480.83
AVG, Volts	480.25	478.83	479.05
No-Load Loss (W)	87.18	88.64	88.43
Corrected No-Load Loss to Sine-Wave Basis (W)	87.21	88.33	88.07
Exciting Current (A)	0.3409	0.3427	0.3465
Exciting Current (%)	0.11	0.11	0.11
Ambient Air Temp.	90 °F	85 °F	86 °F
Oil Temp. Inside Transformer	30 °C	32 °C	32 °C
Oil Temp. Inside Transformer (Max)	30 °C	33 °C	33 °C

Table 9. Conventional 150-kVA Silicone Steel Transformer Spare Unit in Bldg. 166 (Manufactured in 1987)

Serial No. 87-51079-B; Transformer No. Spare

a. Specifications

Station......Bldg. 166	Impedence........4.15%
Type.........Three-Phase	BIL-HV Winding...95 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........2,575 lb
HV...........2,400	Liquid...........100 Gallons, Silicone Oil
LV...........208Y/120	
Temp. Rise...65 °C	Installed........5-19-88

b. Test Results

Parameters Tested	Test Date, 5-19-88
RMS, Volts	120.5
AVG, Volts	120.1
No-Load Loss (W)	405.00
Corrected No-Load Loss to Sine-Wave Basis (W)	404.35
Exciting Current (A)	2.909
Exciting Current (%)	0.23
Ambient Air Temp.	84 °F
Oil Temp. Inside Transformer	28 °C
Oil Temp. Inside Transformer (Max)	28 °C

Table 10. Coventional 150-kVA Silicone Steel Transformer Spare Unit in Bldg. 166 (Manufactured in 1987)

Serial No. 87-51079-E; Transformer No. Spare

a. Specifications

Station......Bldg. 166	Impedence........4.38%
Type.........Three-Phase	BIL-HV Winding...95 kV
Frequency....60 Hertz	BIL-LV Winding...30 kV
Class........OA	Weight...........2,400 lb
HV...........12,000	Liquid...........97 Gallons, Silicone Oil
LV...........208Y/120	
Temp. Rise...65 °C	Installed........5-19-88

b. Test Results

Parameters Tested	Test Date, 5-19-88
RMS, Volts	120.1
AVG, Volts	120.0
No-Load Loss (W)	402.00
Corrected No-Load Loss to Sine-Wave Basis (W)	401.68
Exciting Current (A)	1.956
Exciting Current (%)	0.16
Ambient Air Temp.	84 °F
Oil Temp. Inside Transformer	30 °C
Oil Temp. Inside Transformer (Max)	30 °C

Table 11. Conventional 150-kVA Silicone Steel Transformer on the Distribution System at the Naval Shipyard (World War II Vintage)

Serial No. 65543; Transformer No. LN 3563-E-09436

a. Specifications

Station......E-9	Impedence.........3.5%
Type.........C	Weight............4,770 lb
Frequency....60 Hertz	Liquid............158 Gallons
HV...........12,000	Core & Coil.......2,450 lb
LV...........208Y/120	Tank & Fittings...1,150 lb
Temp. Rise...55 °C	

b. Test Results

Parameters Tested	Test Date, 9-17-88
RMS, Volts	120.45
AVG, Volts	120.01
No-Load Loss (W)	888.00
Corrected No-Load Loss to Sine-Wave Basis (W)	886.40
Exciting Current (A)	7.974
Exciting Current (%)	0.64
Ambient Air Temp.	87 °F
Oil Temp. Inside Transformer	43 °C
Oil Temp. Inside Transformer (Max)	45 °C

Table 12. Three-Year Amorphous Transformer Performance Summary at Pearl Harbor, Hawaii

Transformer Number	Location	Rating (kVA)	1987 Core Loss (watts)	1988 Core Loss (watts)	1989 Core Loss (watts)	Change from Initial Installation (%)
K-28	NSC S-959	150	86.6	86.5	88.5	+2.1
C-11	S/Y B-393	150	85.6	85.2	84.0	-1.8
TC-7	Ford Is. S-258	150	91.6	90.3	89.5	-2.2
BP-B91	BARPT B-91	150	87.2	88.6	88.4	+1.3
TF-9	Ford Is. B-99	75	47.5	46.8	47.3	-0.4
BP-B169	BARBPT B-169	75	48.3	48.0	48.2	-0.2
TD-10	Ford Is. B-181	75	51.2	49.9	50.3	-1.7
I-3	Bldg #166	150	86.4	85.7	86.8	+0.4

75-kVA Three-Phase Amorphous Transformer
versus
Silicone Iron Transformer

	Amorphous	Silicon Iron	Change in Core Loss
Core Loss (watts)	49	131	62.6%

150-kVA Three-Phase Amorphous Transformer
versus
Silicon Iron Transformer

	Amorphous	Silicon Iron	Change in Core Loss
Core Loss (watts)	87	291	70.1%

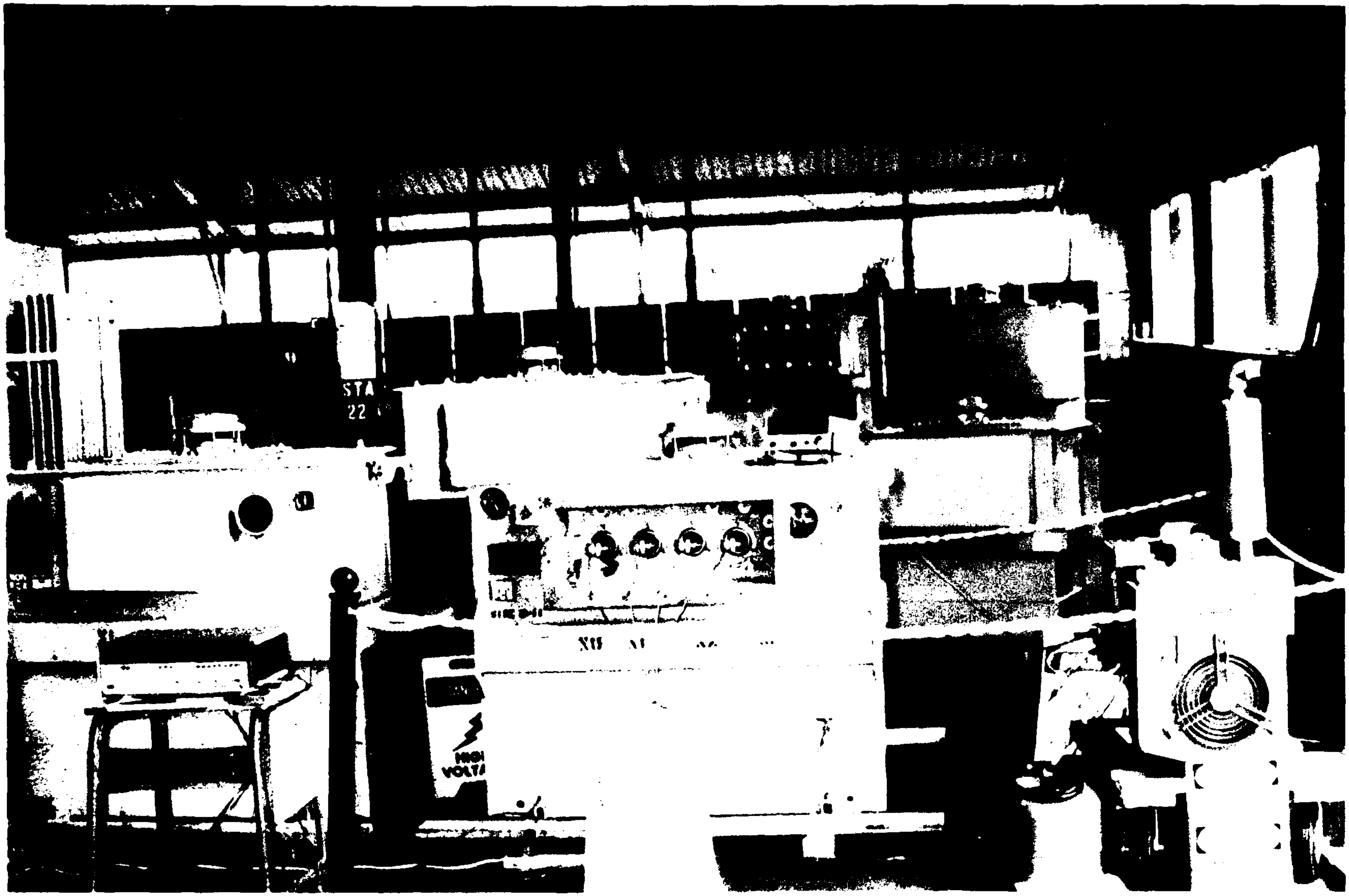


Figure 1. Complete test setup in Building 166 prior to field installation.

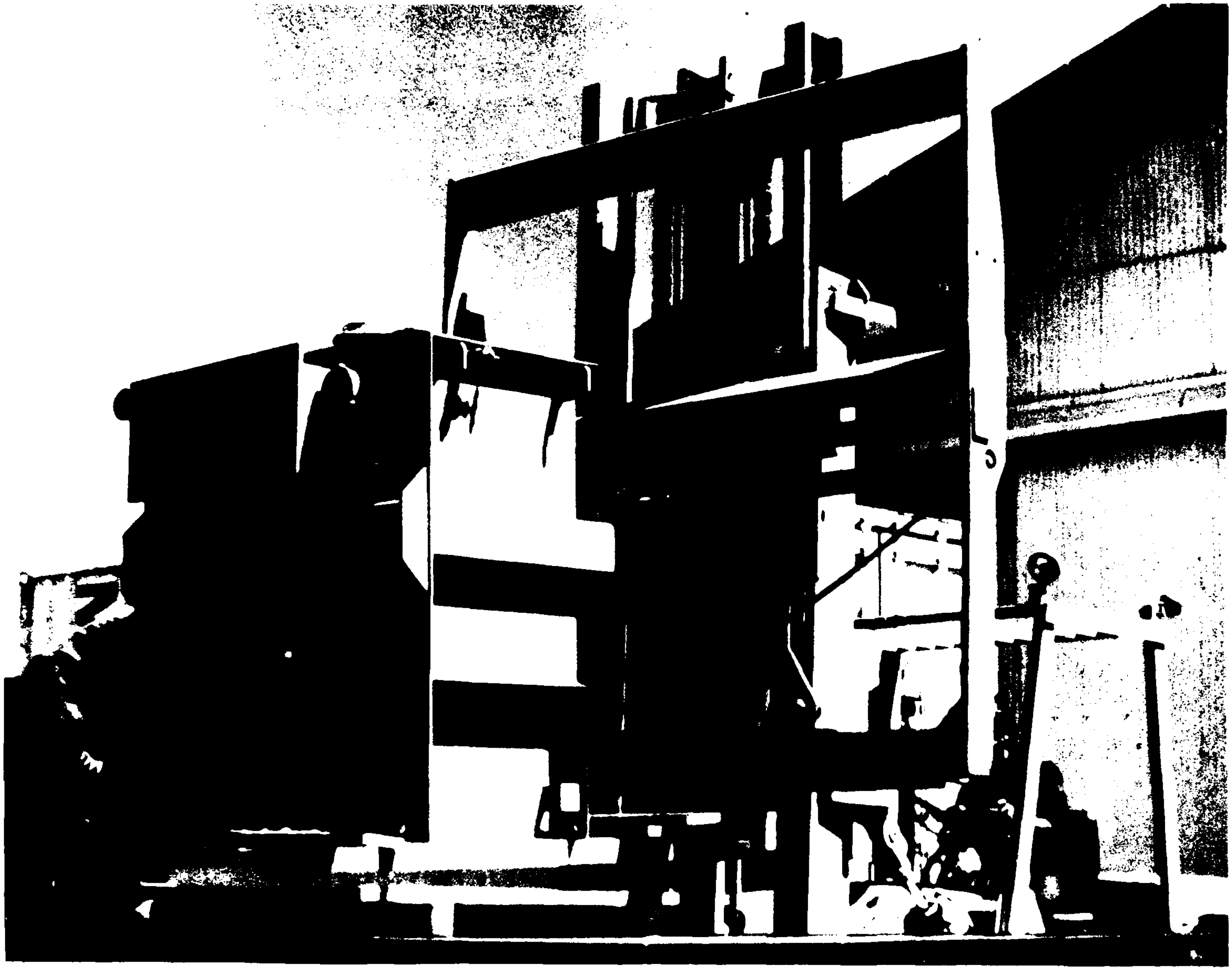


Figure 2. Loading of an amorphous core transformer on a flatbed truck.

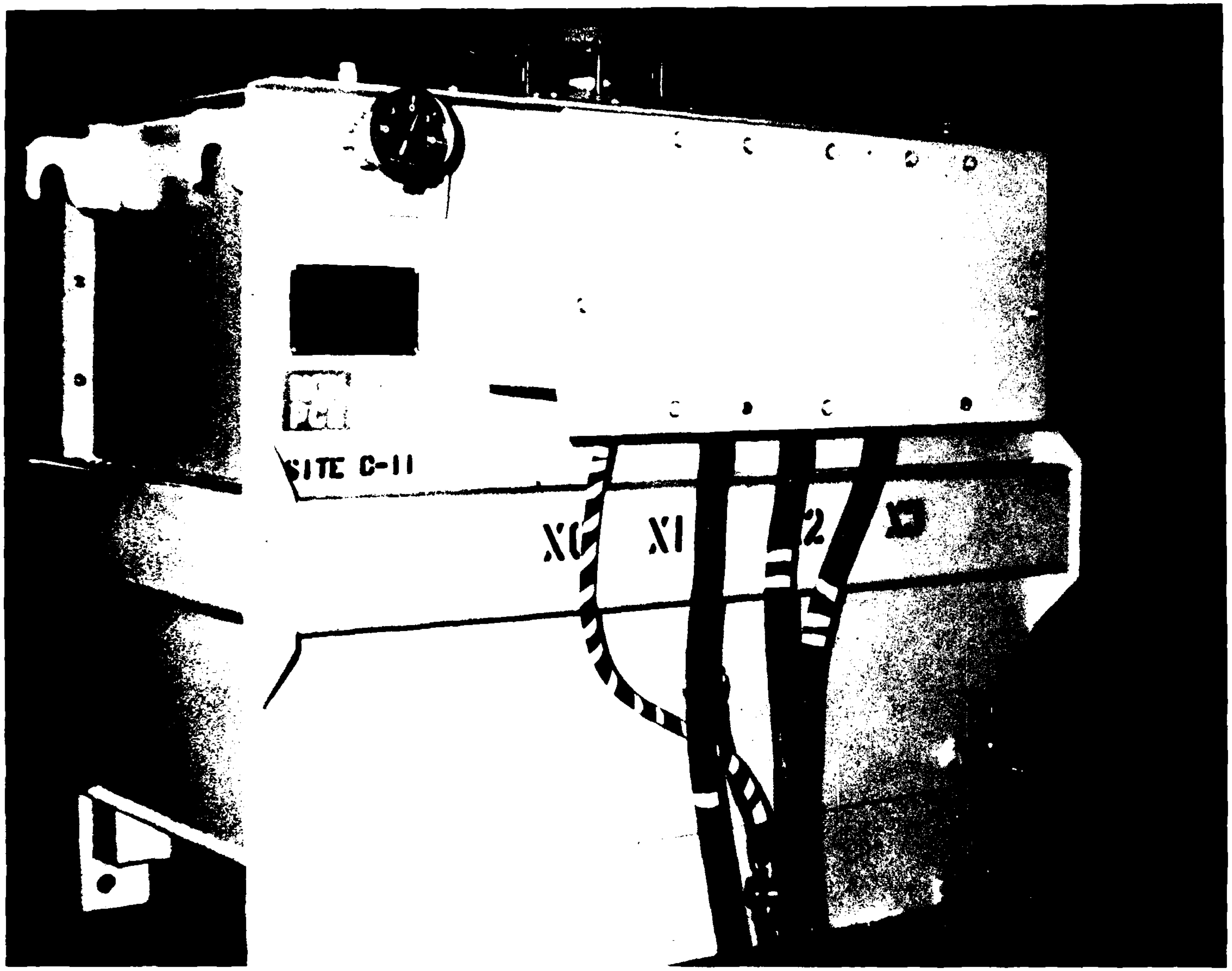
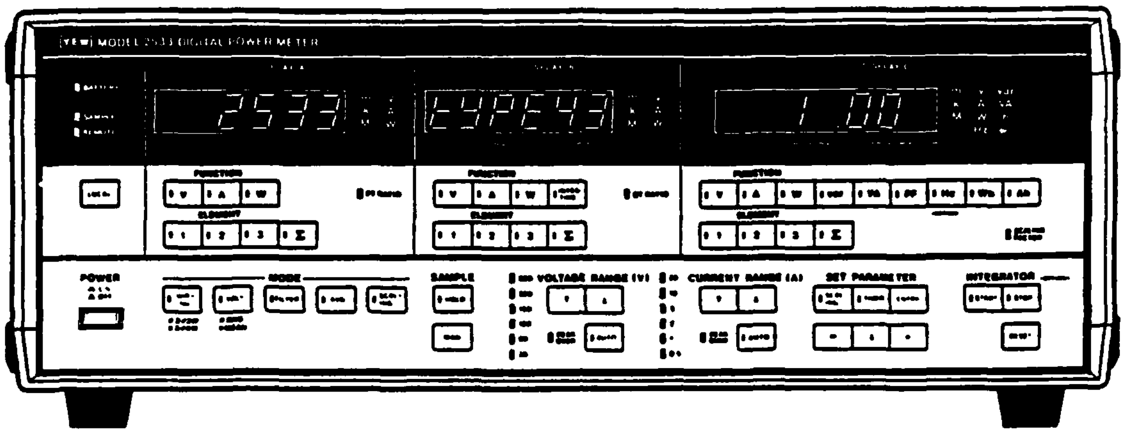
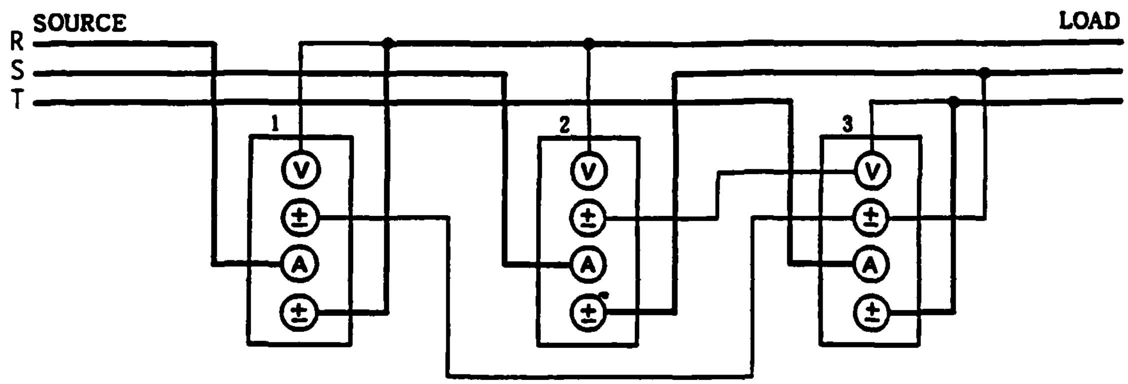


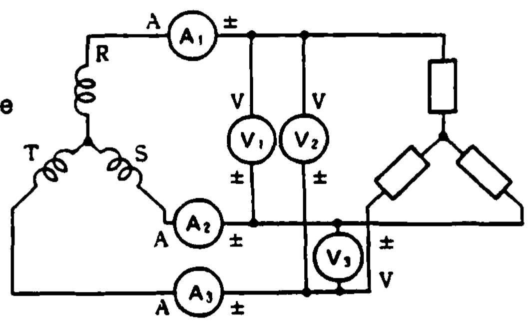
Figure 3. Amorphous core transformer (C-11) after its installation at the Naval Shipyard (B-393) Pearl Harbor, Hawaii.

Model 2533



Wiring configuration when measuring voltage, current, and power



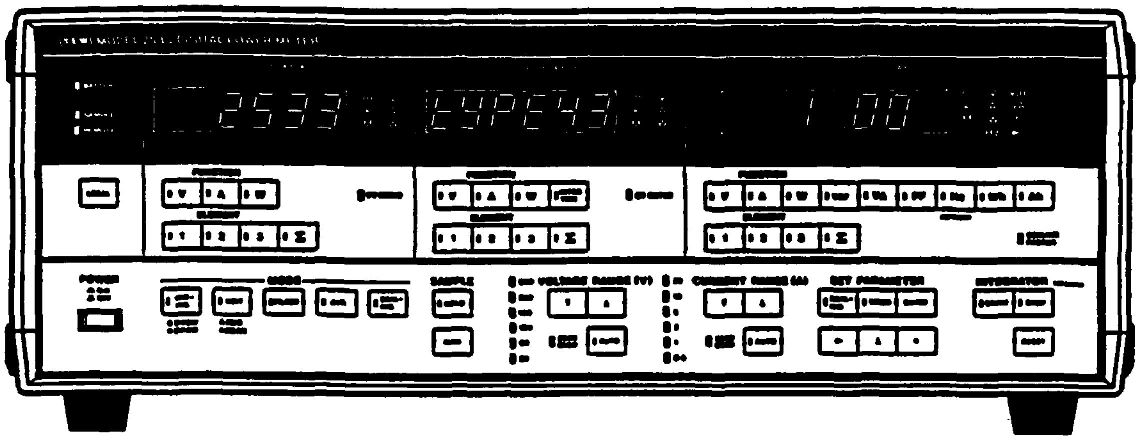


This wiring configuration was used to test the three-phase 3-wire amorphous core transformers at the following locations throughout the island of Oahu.

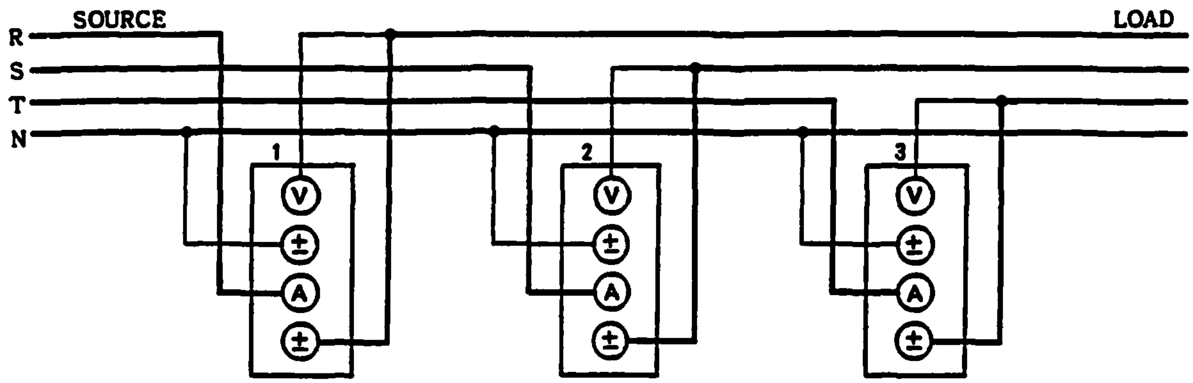
Station	Size	Location
BP-B91	150 kVA	Barbers Point Naval Air Station
BP-B169	75 kVA	Barbers Point Naval Air Station
TF-9	75 kVA	Ford Island
TD-10	75 kVA	Ford Island

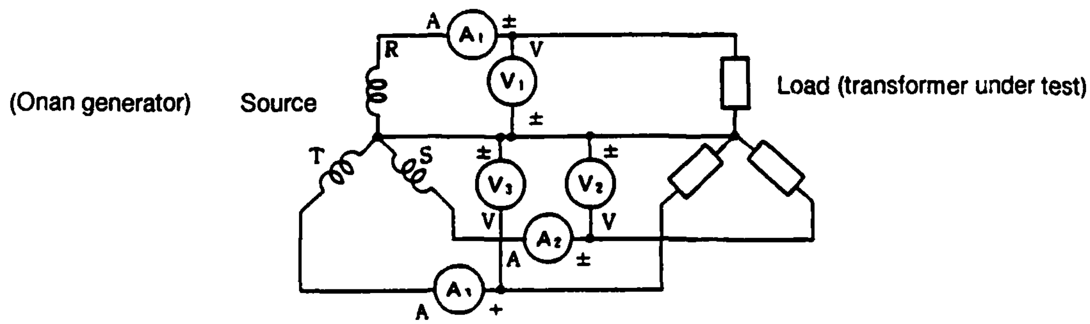
Figure 4. Power measurement of three-phase 3-wire system.

Model 2533



Wiring configuration when measuring voltage, current, and power

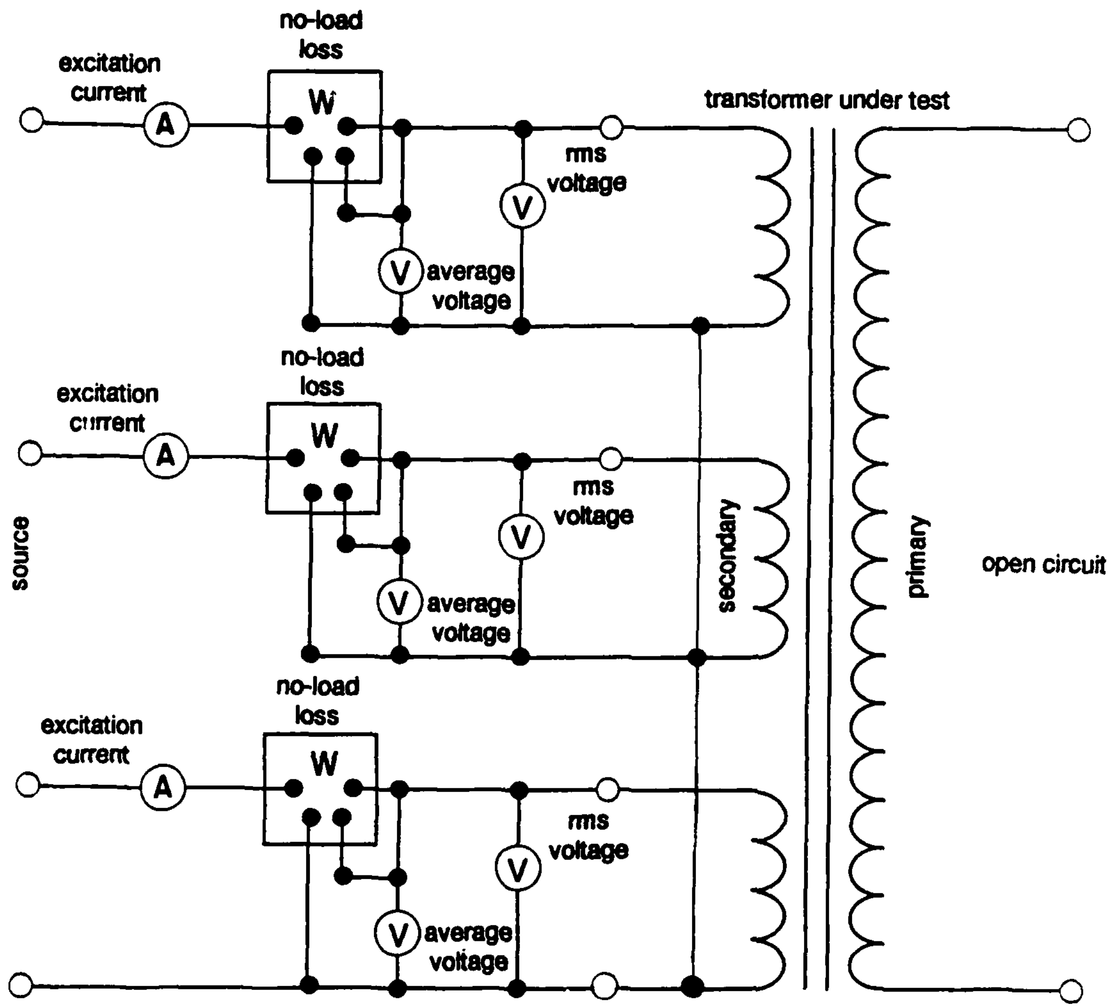




This wiring configuration was used to test the three-phase 4-wire amorphous core transformers at the following locations throughout the island of Oahu.

Station	Size	Location
K-28	150 kVA	Naval Supply Center
C-11	150 kVA	Naval Ship Yard
TC-7	150 kVA	Ford Island
Bldg 166	150kVA	Naval Ship Yard

Figure 5. Power measurement of three-phase 4-wire system.



1. Connect test equipment to secondary of transformer to be tested.
2. Guard high-voltage terminals of transformer. They will be energized.
3. Apply rated secondary voltage to transformer.
4. Record voltage indicated by rms responding voltmeter.
5. Record voltage indicated by average responding voltmeter.
6. Record losses indicated by wattmeter.
7. Correct losses to a sine wave basis.

Figure 6. Measuring the no-load loss of a typical three-phase 4-wire amorphous core transformer at Barbers Point Naval Air Station, Pearl Harbor, Hawaii.

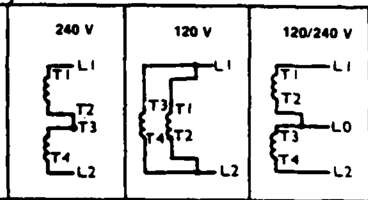
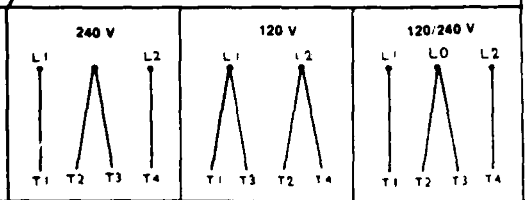
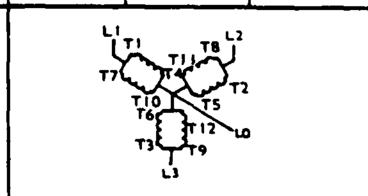
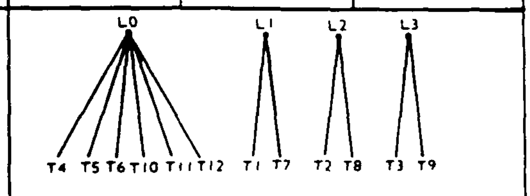
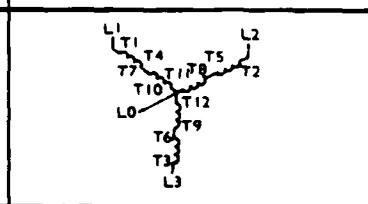
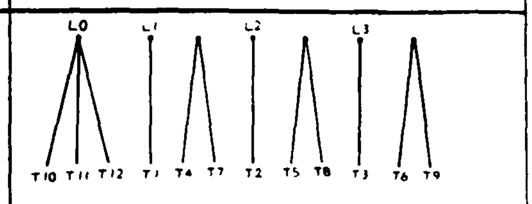
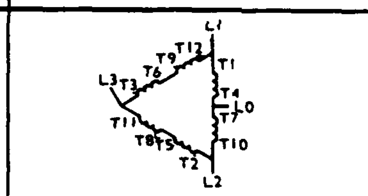
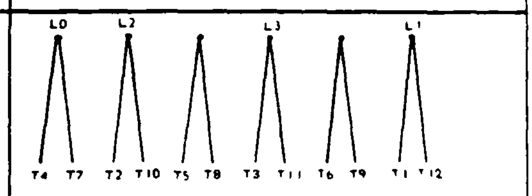
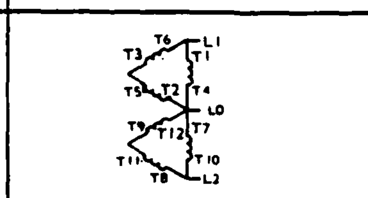
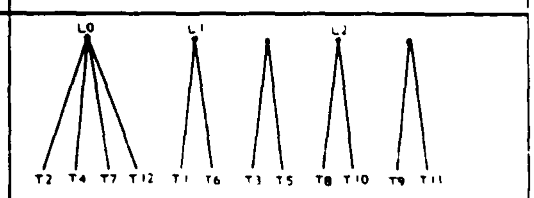
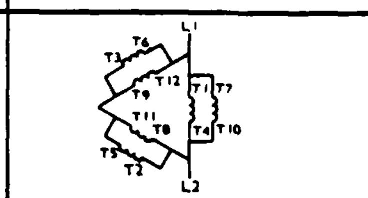
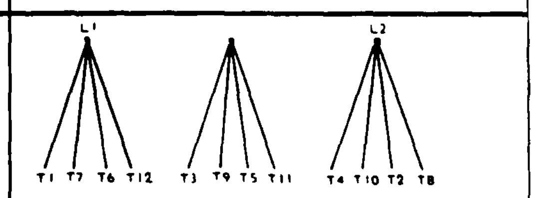
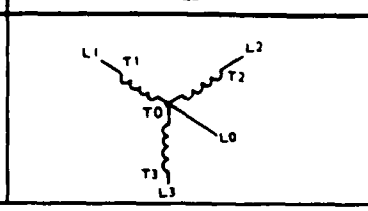
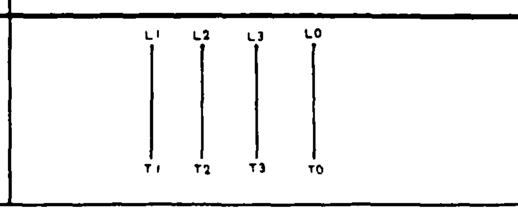
NAMEPLATE VOLTAGE CODE	VOLTAGE	PHASE	FREQUENCY	CONNECT W10 JUMPER WIRE FROM V4 TO	GENERATOR CONNECTION	GENERATOR CONNECTION SCHEMATIC DIAGRAM	LOAD-TO-GENERATOR CONNECTIONS (CONNECT X1 TO TERMINAL 5 OF PRINTED CIRCUIT BOARD FOR 50 Hz. TO TERMINAL 6 FOR 60 Hz.)
3C	120/240	1	60	V1		240 V, 120 V, 120/240 V 	240 V, 120 V, 120/240 V 
53C	120/240	1	50	V3			
	115/230	1	50	V2			
	110/220	1	50	V1			
18	120/208	3	60	V1	PARALLEL WYE		
	127/220	3	60	V2			
	139/240	3	60	V4			
518	110/190	3	50	V1			
	115/200	3	50	V2			
	120/208	3	50	V3			
	127/220	3	50	V4			
18	240/416	3	60	V1	SERIES WYE		
	254/440	3	60	V2			
	277/480	3	60	V4			
518	220/380	3	50	V1			
	230/400	3	50	V2			
	240/416	3	50	V3			
	254/440	3	50	V4			
18	120/240	3	60	V1	SERIES DELTA		
518	110/220	3	50	V1			
	115/230	3	50	V2			
	120/240	3	50	V3			
18	120/240	1	60	V1	DOUBLE DELTA		
518	110/220	1	50	V1			
	115/230	1	50	V2			
	120/240	1	50	V3			
18	120	1	60	V1	PARALLEL DELTA		
518	110	1	50	V1			
	115	1	50	V2			
	120	1	50	V3			
9X	347/600	3	60	V4	WYE		

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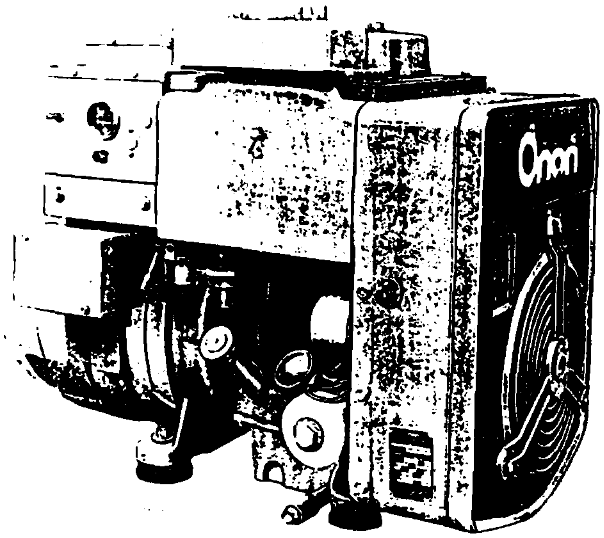
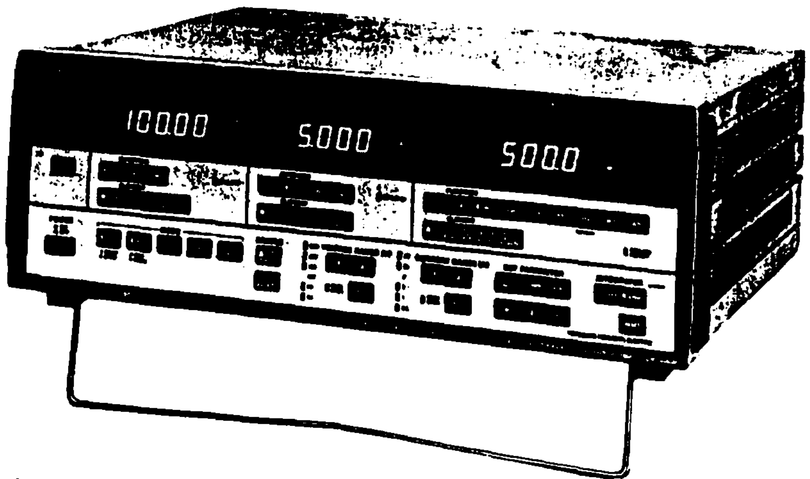
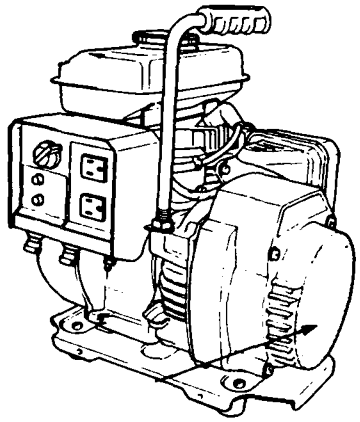
Figure 7. Generator wiring and connection diagrams.



ONAN 7.5 JB-18R Generator

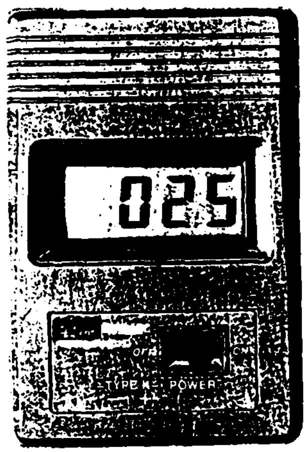


Yokogawa Model 2533 Digital Power Meter



Honda EG650 Generator

Simpson Model 2726 Electronic Counter



Model HT14K
Digital Thermometer

Figure 8. Test equipment used to measure the core loss and exciting current of amorphous core transformers.

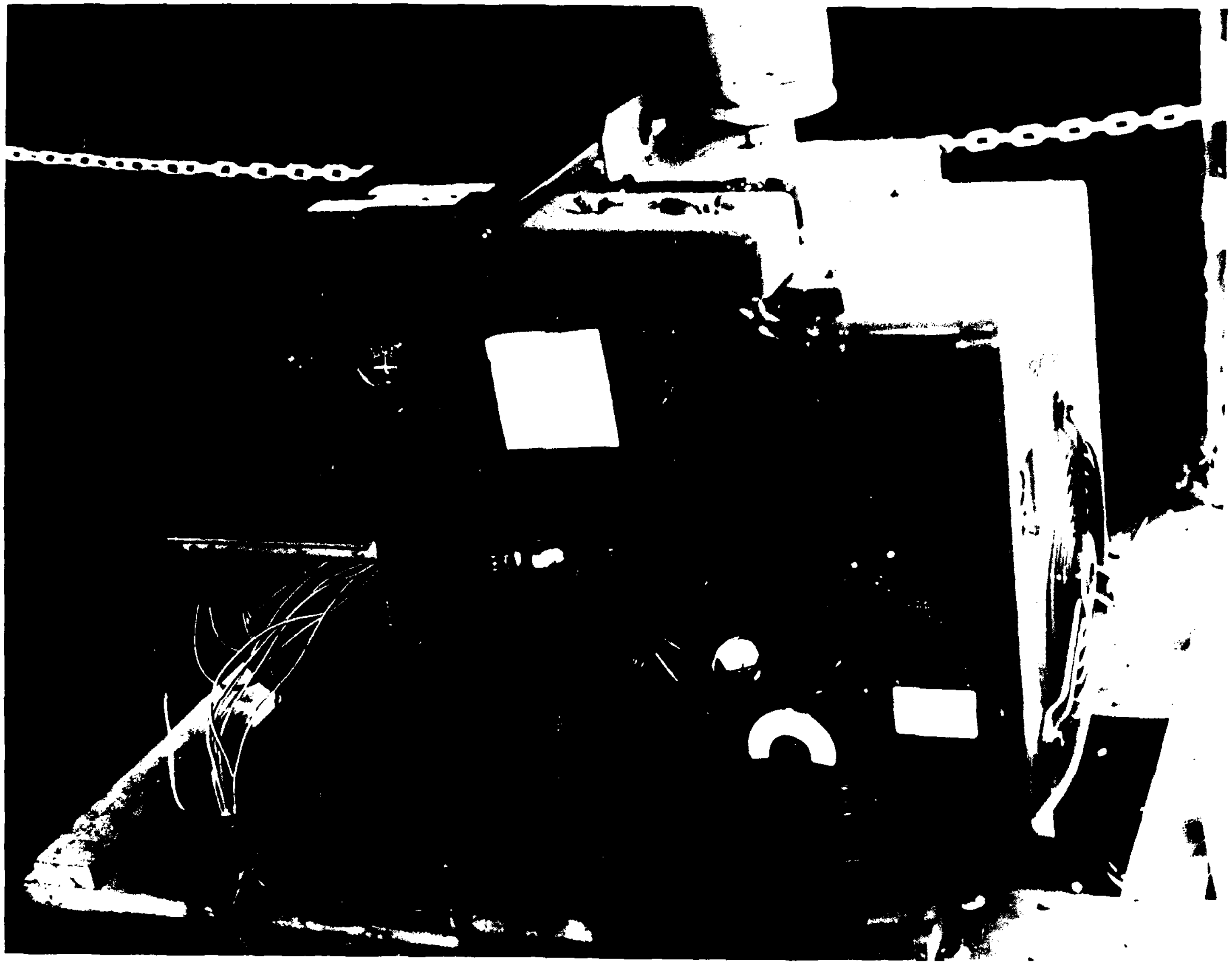


Figure 9. Onan 7.5 JB-18R generator.

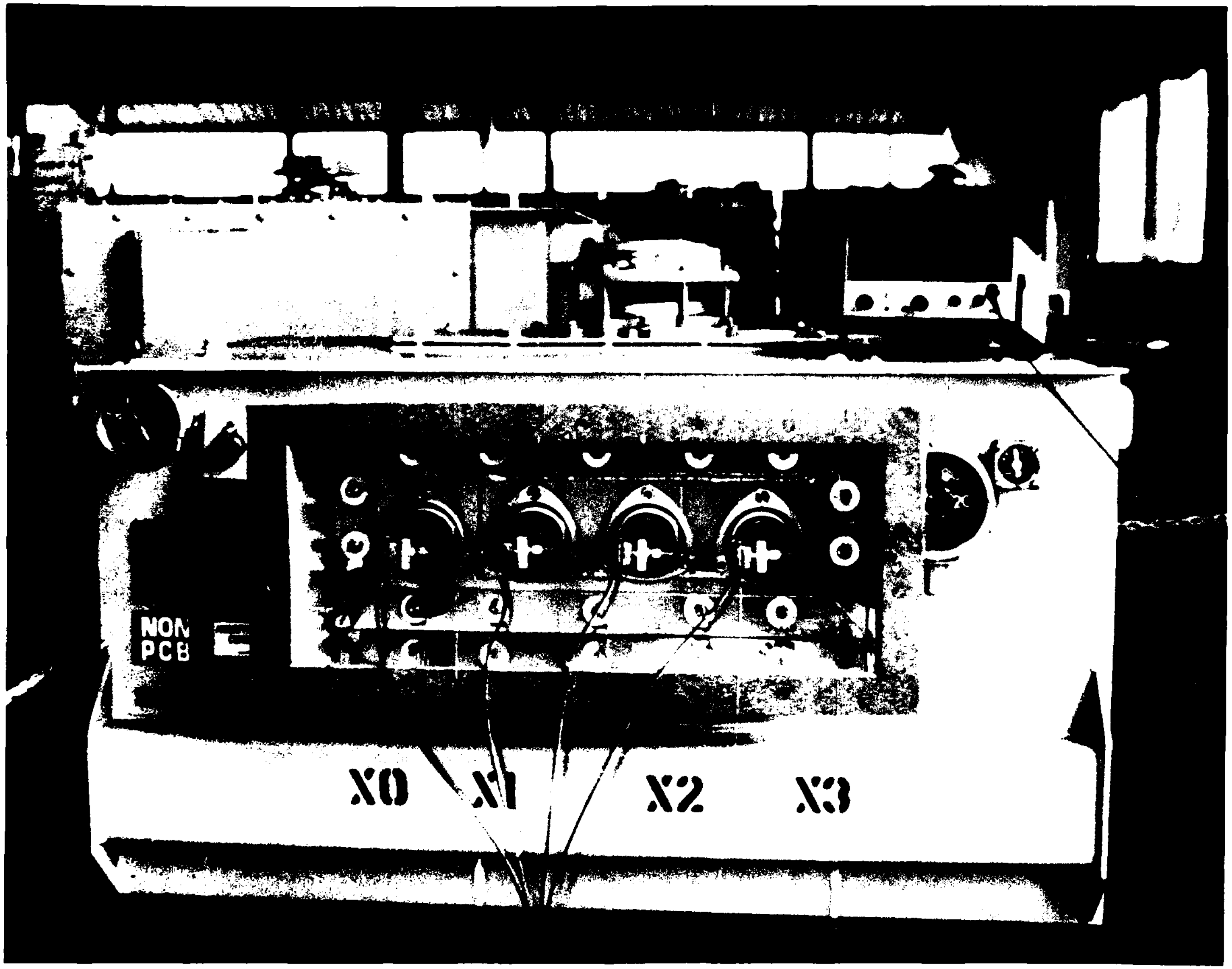


Figure 10. Secondary of amorphous core transformer under test.

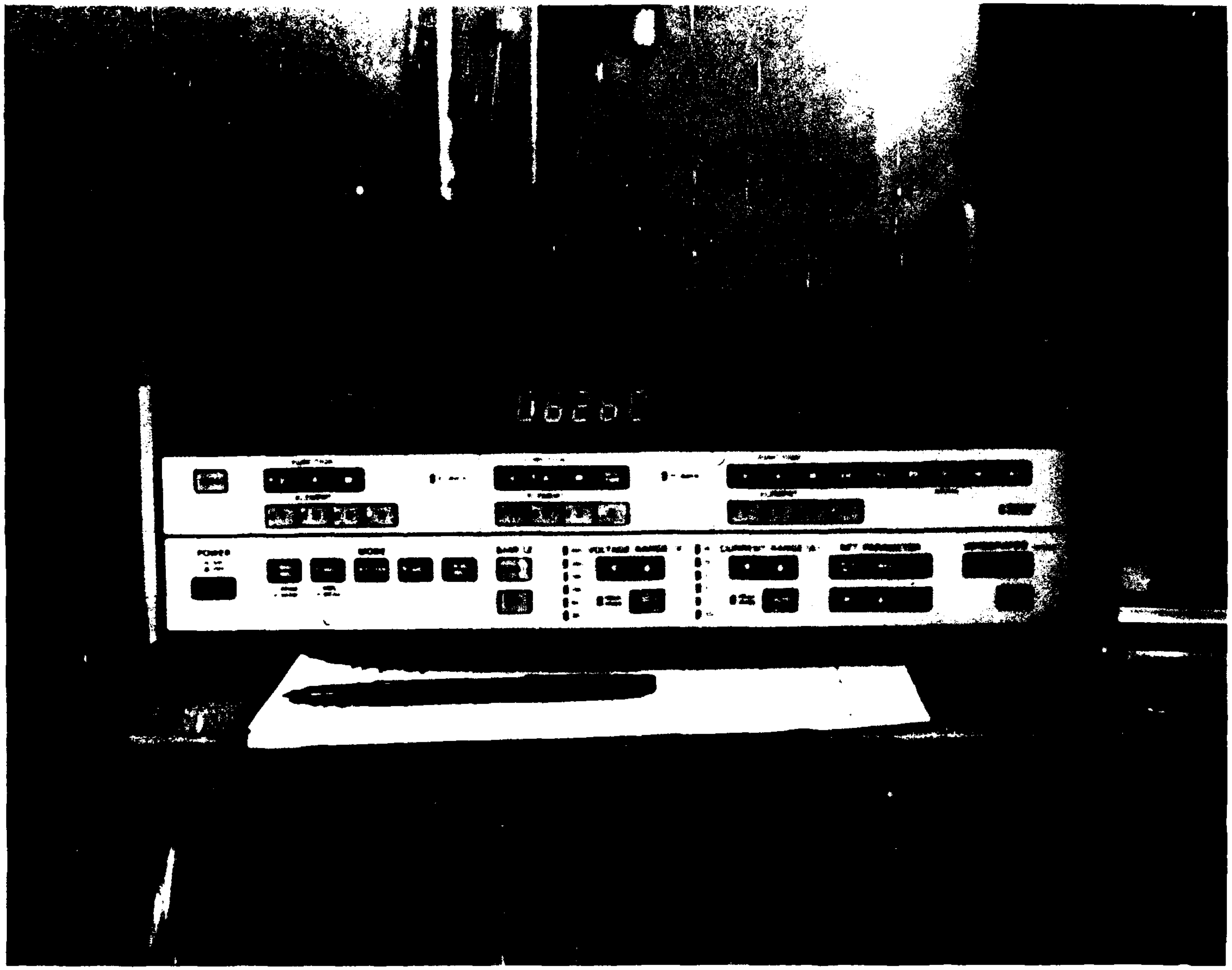


Figure 11. Yokogawa Model 2533 Digital Power Meter.

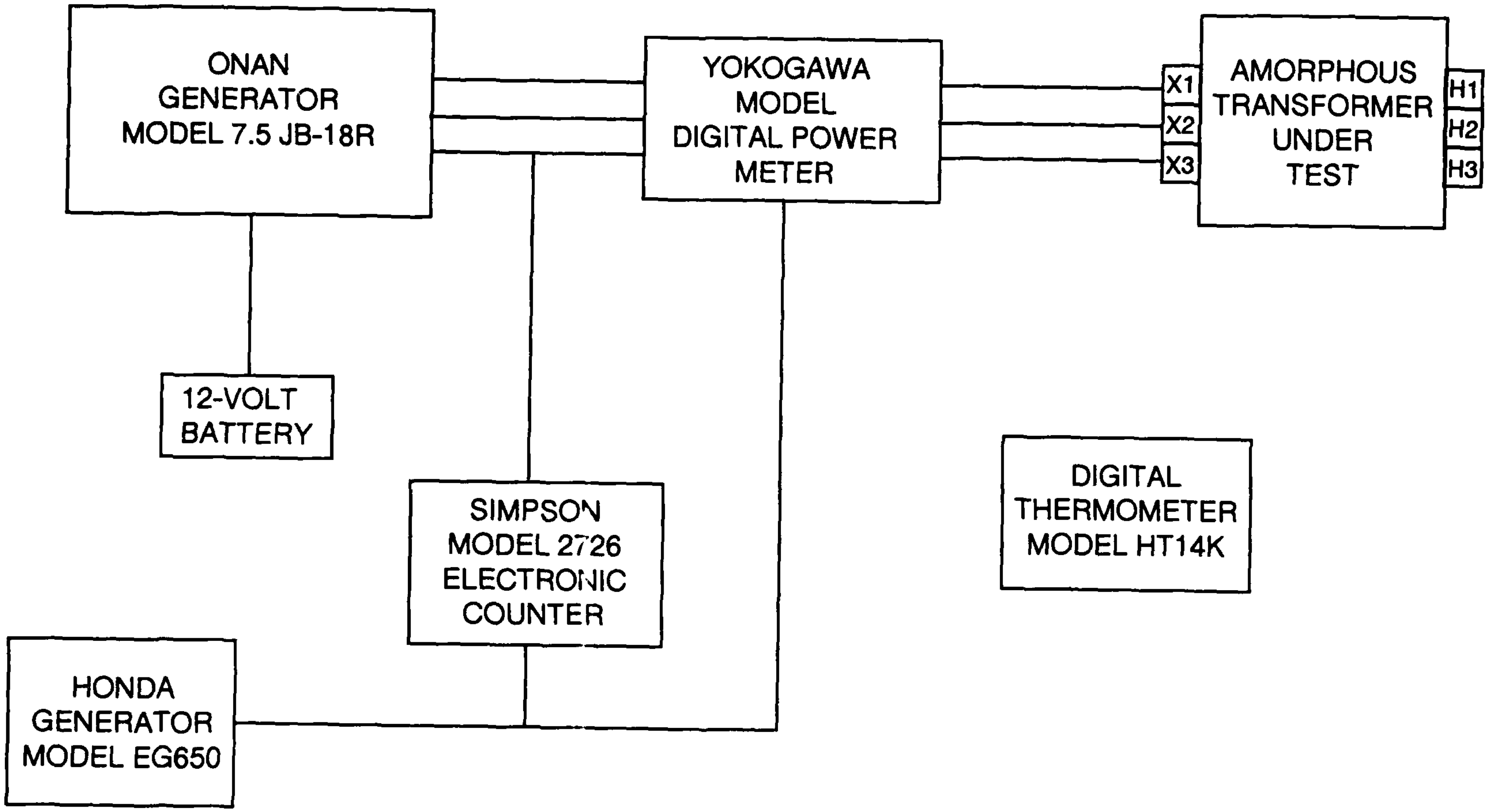


Figure 12. Block diagram of amorphous transformer test configuration.

Appendix

RELATED NCEL TECHNICAL DOCUMENTS ON TRANSFORMERS

NCEL Technical Note N-1801.........25-kVA Amorphous Metal-Core Transformer Developmental Test Report

NCEL Techdata Sheet 90-01..........Save Money By Procuring Energy-Efficient Transformer

NCEL Contract Report CR 90.004.....Life Cycle Costs of Non-PCB Distribution Transformer Alternatives

NCEL Contract Report CR 90.010.....Evaluation of a 300-kVA Amorphous Core Transformer

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