U. S. ARMY TEST AND EVALUATION COMMAND
COMMODITY ENGINEERING TEST PROCEDURE

FANS, ELECTRIC

1. OBJECTIVE

This document provides test methods and techniques necessary to determine the technical performance and safety characteristics of fans and their associated tools and equipment, as described in Qualitative Materiel Requirements (QMR's), Small Development Requirements (SDR's), Military and/or Technical Characteristics (MC's or TC's), and to determine the item's suitability for service tests.

2. BACKGROUND

A requirement exists for a device which can provide for the forced motion of air or similar gases for such purposes as cooling or transporting required volumes of a gas from one place to another in a physical system. This motion of gases occurs naturally whenever a difference in pressure exists between two points in a system. Fans can however, provide for the same type of motion by artificially creating a pressure differential when they are inserted at the proper position in the system. The term "fans" implies a general device class in which there are two subclasses defined as exhauster and blower. (Appendix A contains a summary of fan types and their descriptions.) These two subclasses refer to the position of the fan in the duct system rather than to the type of fan. A blower is a fan which is used to force a gas under pressure into a space whereas an exhauster is a fan which is used to withdraw a gas from a space under suction. Fan performance is a measure of many different properties. However, the one which is considered most indicative of the fan's usefulness is the volume of air per unit of time which the fan can move against a stated pressure or resistance. This measures the work which the fan is doing and when this is compared with the input power to the fan whether it be electrical or mechanical energy, there exists a measure of the fan's efficiency.

3. REQUIRED EQUIPMENT

a. Ohmmeter
b. Dielectric Strength Tester (0-2000 VRMS, 25-60 Hz)
c. Megohmmeter or Megohm-bridge (500 V dc)
d. Voltmeters - Alternating current and direct current
e. Ammeters - Alternating current and direct current
f. Wattmeters - Direct current, single and three-phase alternating current
g. Dynamometer
h. Tachometer Generator
i. Electronic Counter with time base
j. Millivolt Potentiometer or Calibrated Temperature Bridge with thermocouple
k. Sound Level Meter per USAS S1.4 - 1961
l. Field Intensity Meter with rod, dipole and discone antennas
m. Drop Test Stand, quick release hook and miscellaneous blocks
n. Octave Band Analyzer USAS Z24.10 - 1953 or USAS S1.6 - 1960

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o. Pitot Tube, Flow Straightener, and Duct Traverse Plan (AMCA Standard).
p. Manometer, liquid in glass inclined.
q. Miscellaneous air ducting.
r. Shock Test Stand.
s. Vibration Test Stand.
t. Vibration Amplitude Indicator.
u. Wet and Dry Bulb Thermometers F scale and C scale.

4. REFERENCES

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R. MIL-STD-810B, Method 516, Shock Tests, 15 June 1967.
S. MIL-F-16081E, Fan Ventilating, Propeller.
T. MIL-F-16082C, Fan, Ventilating Propeller, Electric Spray Booth Exhaust.
U. MIL-F-16716B, Fan Centrifugal, Industrial.
V. MIL-F-18953, Fan Vaneaxial and Tubeaxial Fixed and Portable Ventilation, Naval Shipboard.
W. MIL-F-26051A, Fan Vaneaxial, Ventilation Garment Airborne Type MD-1.
X. MIL-F-43200, Fan Centrifugal, For Tent, Double Wall, Air Supported, Assembly Area, Nike Hercules.
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AA. MIL-STD-130C, Identification Marking of U. S. Military Property.
BB. MIL-M-13786 (SIG C) Motors, Fractional Horsepower, Direct Current and Universal.
CC. PTC.10 - 1965, Compressors and Exhausters - Power Test Codes, The American Society of Mechanical Engineers.
DD. HEL Standard S-1-63B, Maximum Noise Level for Army Materiel Command Equipment June 1965.
EE. USATECOM Regulation 385-6, Safety Release.
FF. USATECOM Regulation 700-1, Value Engineering.
GG. USATECOM Regulation 705-4, Equipment Performance Report.
HH. MTP 10-2-500, Physical Characteristics.
II. MTP 10-2-501, Operator Training and Familiarization.
JJ. MTP 10-2-503, Transportability.
KK. MTP 10-2-505, Human Factors.
LL. MTP 10-2-507, Maintenance Evaluation.

5. SCOPE

5.1 SUMMARY

This procedure describes the preparation for and methods of evaluating the technical characteristics of fans and their suitability for service testing. The contents of this MTP is composed of tests designed to measure all performance parameters of the fan, to determine the motor-fan set efficiency and to verify the fans selection for a particular application as being optimum.

a. Preparation for Test - An evaluation to determine the condition of the test item upon arrival, its physical characteristics, its suitability for subjection to further tests and operator training and familiarization procedures.

b. Preliminary Electrical Tests - An evaluation to determine the test item's motor-winding resistance, dielectric strength and insulation resistance prior to the application of normal operating power.

c. Performance - An evaluation to determine the following characteristics of the fan: pressure and air flow, horsepower, efficiencies and other variables which must be known to determine the above quantities.

d. Electromagnetic Interference - An evaluation to determine the degree to which the test item produces radiated or line-conducted interference.

e. Balance Test - An evaluation to determine effective weight distribution in the test item so that forces introduced by rotating components are counter-balanced.

f. Durability - An evaluation of the test item's ability to retain original performance characteristics after extended operation.

g. Transportability - An evaluation to determine the ability of the test item to withstand the forces which it will experience during normal handling and transporting.

h. Environmental Tests - An evaluation to determine the ability of the test item to resist physical damage and to function properly during or after exposure to the extremes of environment.

i. Maintainability and Reliability Evaluation - That portion of the test which is concerned with the following: verification and appraisal of failures; determination and appraisal of maintenance characteristics and requirements; appraisal of design-for maintainability; appraisal of the maintenence test package; and, calculation of indicators which express the effects of the preceding aspects.

j. Safety - An evaluation to determine the safety characteristics and hazards of the test item.

k. Human Factors - An evaluation of the man-item relationship during operation and maintenance of the test item including the noise level generated and design deficiencies which affect operability.

l. Value Analysis - An evaluation to determine whether or not the test item has any unnecessary features which can be eliminated without affecting the technical performance or safety of the test item.

5.2 LIMITATIONS

The tests described in this materiel test procedure are directly applicable to the evaluation of any air moving device regardless of whether the device is classified as a fan, blower, exhauster or booster. Not all tests, however, are necessary on a particular unit and it should be determined prior to the start of testing which procedures are applicable. To provide consistency throughout this MTP, the test item will be referred to as "fan".

6. PROCEDURES

6.1 PREPARATION FOR TEST

6.1.1 Initial Inspection

The test item shall be subject to the following upon its arrival at the test site:

6.1.1.1 Packaging Inspection

Visually inspect the test item container (s) and record the following:

a. Evidence of packing damage or deterioration
b. Identification markings including:

1) Name of contractor
2) Number and date of contract
3) Date of manufacture
4) All other pertinent markings

c. For each package record the following:

1) Weight.
2) Length, width, and height.
3) Cubage.
4) Package contents, including mechanical and electrical drawings

and manual containing operating, installation and maintenance data.

6.1.1.2 Test Item Inspection

Remove the test item from its package(s), visually inspect it and record the following when applicable:

a. Evidence of defects in:

1) Manufacturing
2) Material
3) Workmanship

b. Evidence of damage.
c. Evidence of wear.
d. The presence of an identification tag with the motor electrical requirements.
e. Correlation of accompanying printed material with the test item's markings.

6.1.2 Physical Characteristics

Determine the physical characteristics of the test item as described in the applicable sections of MTP 10-2-500 and record pertinent data.

6.1.3 Operator Training and Familiarization

a. Ensure the availability of test personnel who have been, or are being trained using the criteria of MTP 10-2-501 and are familiar with the following:

1) Test objectives
2) Test item operation
3) Test item maintenance
4) Safety precautions

b. Record the adequacy of the draft technical manuals for training purposes.
c. Record any unusual difficulties in training personnel.
d. Record test personnel data as described in MTP 10-2-501.

6.2 TEST CONDUCT

NOTE: Prepare an Equipment Performance Report (EPR) for all equipment failures.

6.2.1 Preliminary Electrical Tests

a. Using an ohmmeter, check for and record the continuity of each motor winding and the presence of appropriate ground connections.

NOTE: Where a separate input exists to carry building or earth ground this input shall be tested for continuity from the line cord or terminal block to the test item housing.

b. Using a Wheatstone bridge, measure and record the direct current resistance of each motor winding.

c. Using a megohmmeter, measure and record the insulation resistance between each winding; and between each winding and the test item housing.

d. Using the dielectric strength tester, measure and record the dielectric strength between each winding and all of the other windings and the housing tied together. (The procedure and test values will depend on the type and size of the motor. See Appendix B for the applicable requirements.)

6.2.2 Performance Test

6.2.2.1 Preparation for Test

The fan shall be prepared for test as directed in the appropriate AMCA Bulletin, (see reference 4Q), or as follows:

a. Mount the fan firmly in place and attach the ducting as directed in the operator's manual.

b. Connect the power lines to the motor through the metering as shown in Figure 1.

c. Attach a thermocouple to the motor housing specifically in a location which appears as one where overheating may occur.

NOTE: If a Seely motor tester, or equivalent is available, a more precise method of determining overheating by measuring the electrical resistance of a-c energized windings, can be used. See Appendix C.

d. Connect a pitot tube manometer configuration at the middle of the duct (use an inclined manometer for pressures below 2 inches water gauge).

e. Insert a dry bulb thermometer into the duct.

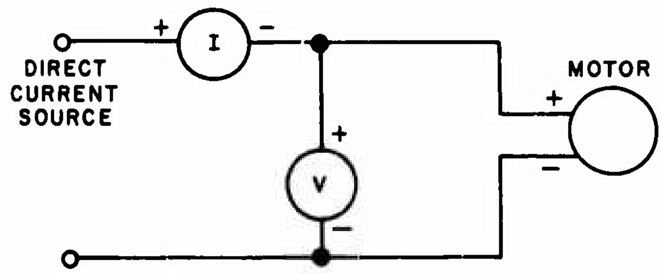
6.2.2.2 Test Conduct

a. Apply power to the fan and run until the temperature stabilizes. Record the temperature.

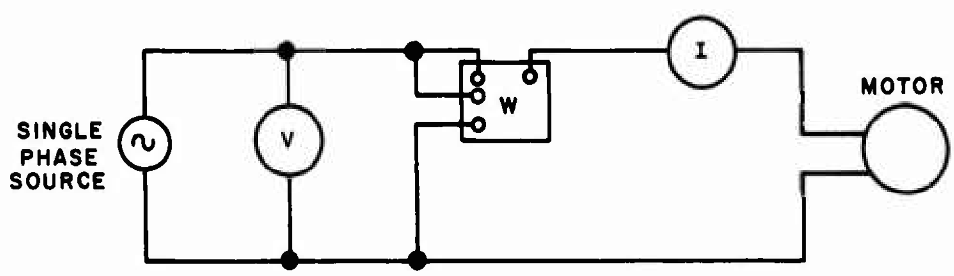
b. Adjust the throttling so that a static pressure reading is obtained which is equal to the static pressure at the point where the system resistance curve intersects the fan characteristics curve (see Figure 2).

NOTE: If the system resistance is unknown, use approximately ½ the maximum value which the pressure reaches on the characteristics curve or the tables supplied by the manufacturer.

1. DIRECT CURRENT MOTOR

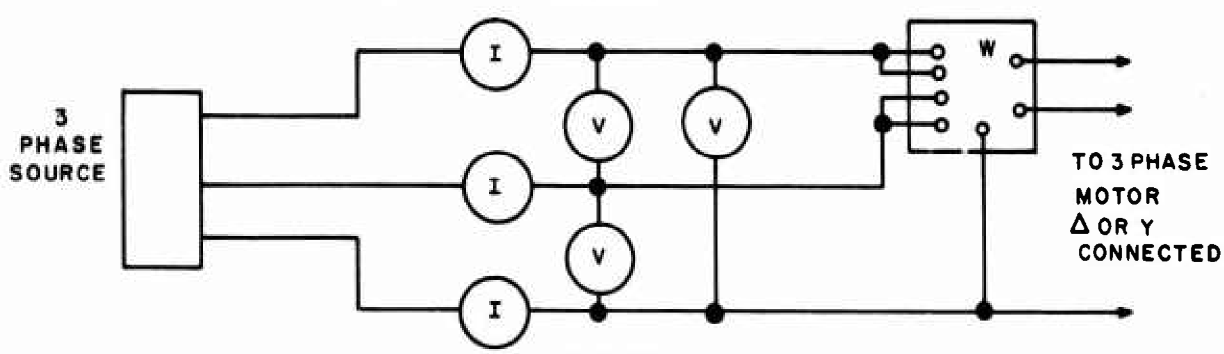


2. SINGLE PHASE ALTERNATING CURRENT



3. THREE PHASE ALTERNATING CURRENT

NOTE: The 2½- or 3- element voltmeter should be used to measure a 3-phase -4 wire circuit.



LEGEND
I = AMMETER
V = VOLTMMETER
W = WATTMETER

Figure 1 - Meter Power Measurement

c. Measure and record the following for the motor:

1) Power input
2) Voltage
3) Current
4) Number of phases motor has
5) Motor operating temperature

d. Measure and record the dry bulb temperature at the measuring plane.

e. Measure and record the following ambient meteorological data:

1) Barometric pressure
2) Ambient dry bulb temperature
3) Ambient wet bulb temperature

f. Measure and record the static pressure and velocity pressure at each duct location along the two orthogonal traverses shown in Figure 3.

g. Repeat step d and e with the static pressure set for approximately plus and minus 50% of that pressure used in step b.

h. Remove power to the fan.

i. Disconnect the fan from the duct and take the rotating element from the motor shaft (do not disconnect the motor power leads).

j. Attach a dynamometer and tachometer to the motor shaft.

k. Reapply motor power and adjust the dynamometer until the power is the same as the power reading of step c.

l. Measure and record the dynometer force and the motor speed.

m. Measure and record the radius of the duct at:

1) The fan outlet
2) The measuring plane

6.2.3 Electromagnetic Interference (See Glossary for definition of terms)

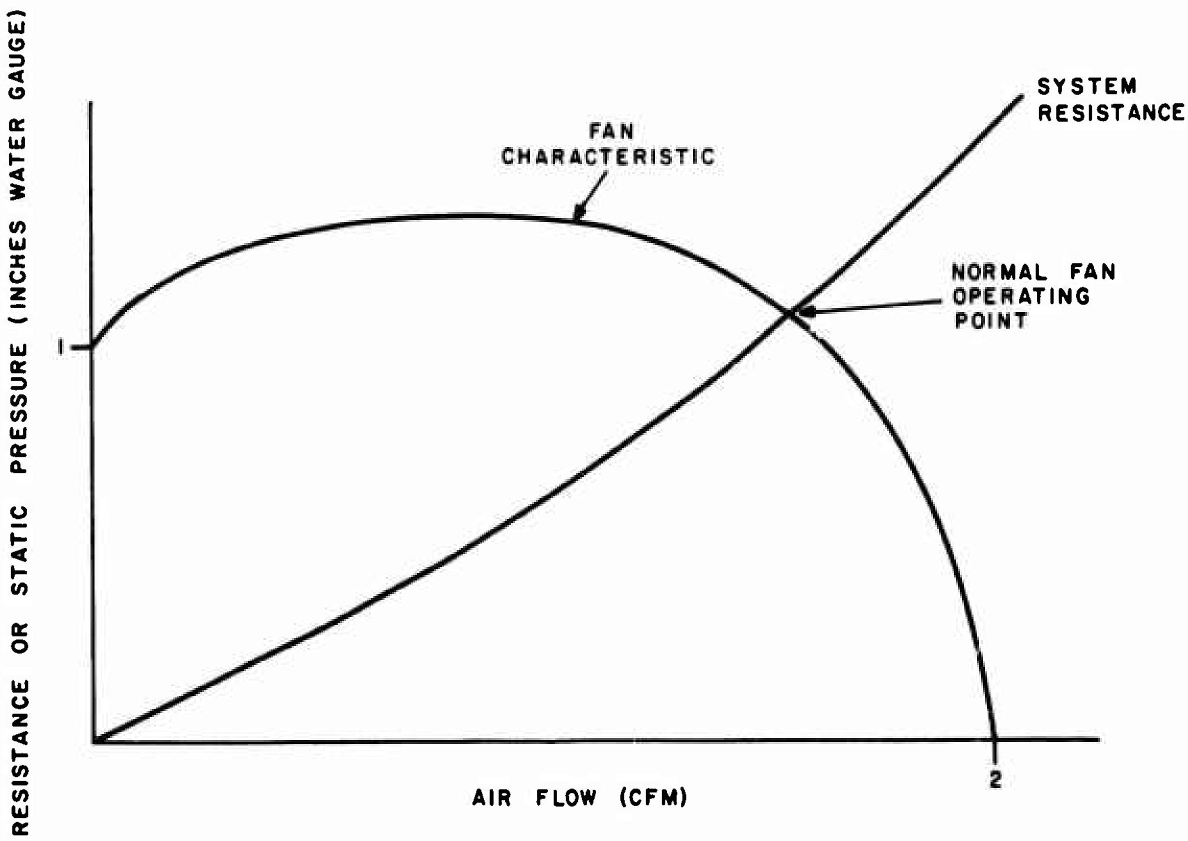
6.2.3.1 Preparation for Test

a. Set up the test equipment in an open area such that the following conditions shall be met:

1) The measuring antenna and the test item shall be positioned a minimum of 1000 yards from any large reflecting metallic objects.
2) The angular positions of the antenna and the test item with respect to any flat reflecting surfaces shall be chosen to minimize direct reflections.

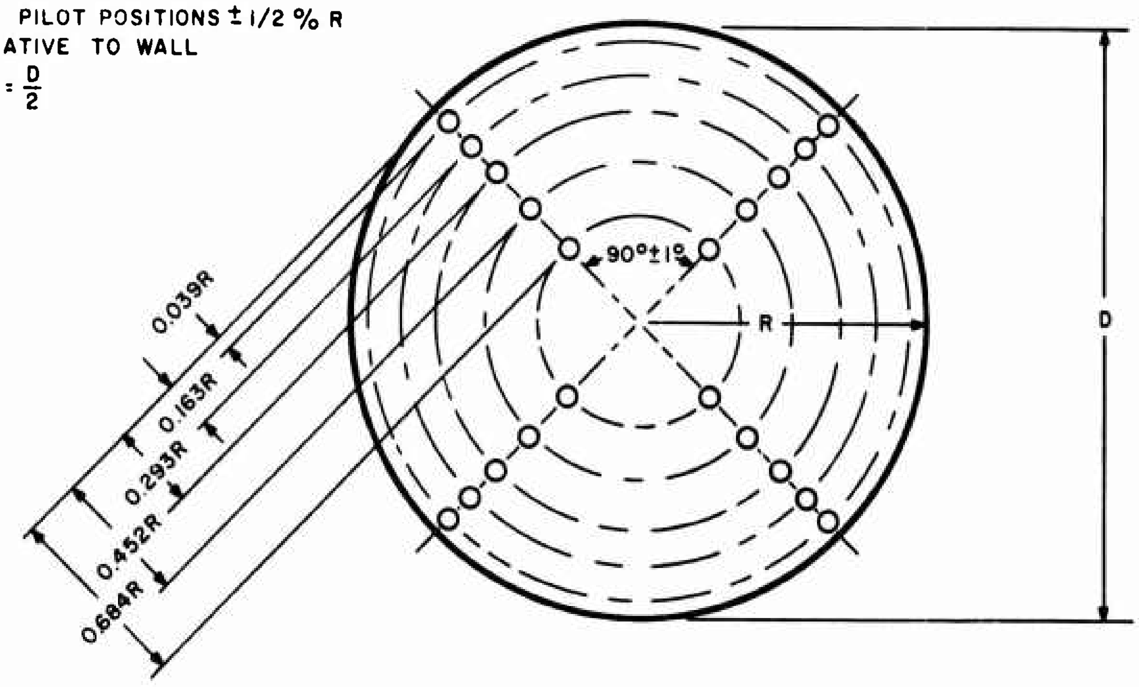
NOTE: The test can also be run in an electromagnetic anechoic chamber which has less than 25% power reflection from ceilings and walls and which is also large enough to house the test set up.

b. Mount the test item using one of the following methods and the



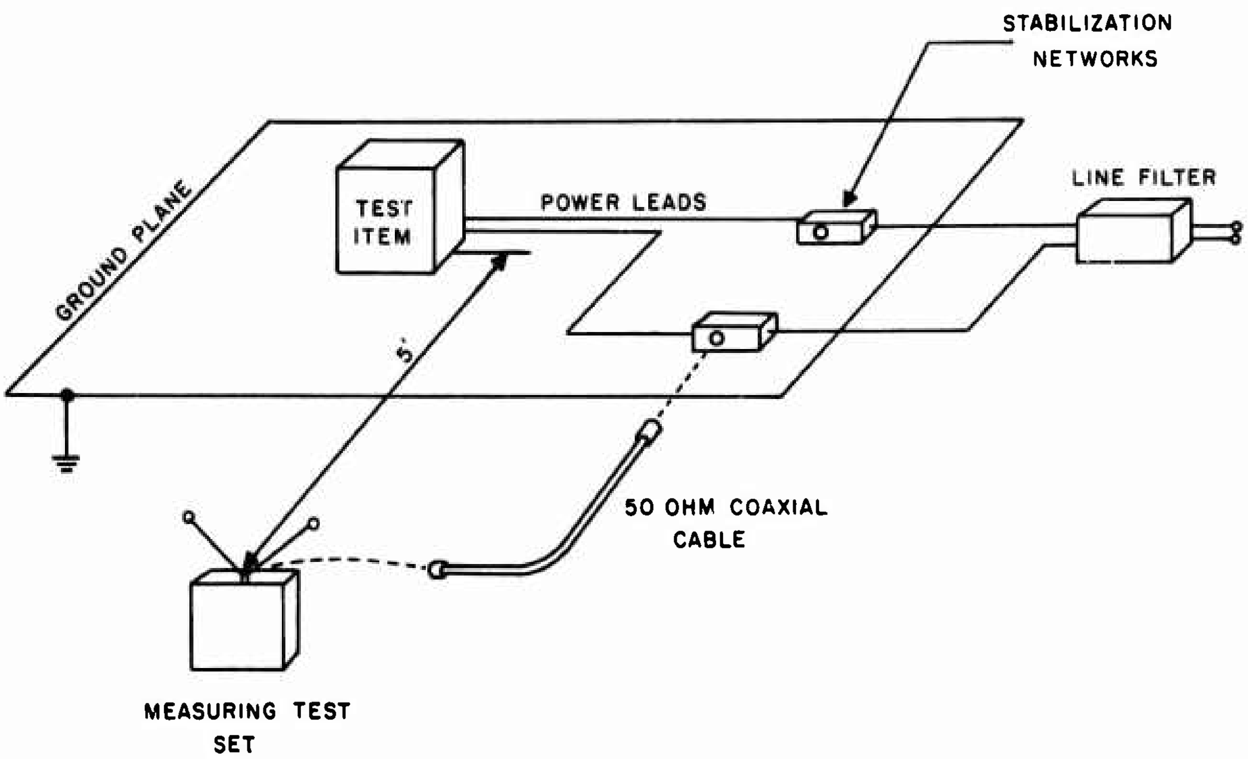
NOTES: AT 1 THE FAN OUTLET IS CLOSED, AIR FLOW GOES TO 0 AND THE PRESSURE DEVELOPED IS AT ITS MAXIMUM, THIS PRESSURE IS CALLED THE STATIC NO DELIVERY PRESSURE (SND) AT 2 THE PRESSURE approaches 0, there is no RESISTANCE AND THE FAN IS OPERATING AT FREE DELIVERY OR WIDE OPEN

Figure 2 -Fan Characteristic Curve



D IS THE AVERAGE OF FOUR MEASUREMENTS AT TRAVERSE PLANE AT 45° ANGLES MEASURED TO ACCURACY OF 0.2 % D. TRAVERSE DUCT SHALL BE ROUND WITHIN ± 1/2 % D AT TRAVERSE PLANE AND FOR A DISTANCE OF 1/2 D ON EITHER SIDE OF TRAVERSE PLANE.

Figure 3 - Traverse Points in Duct



NOTES: 1 THE NUMBER OF STABILIZATION NETWORKS USED WILL BE EQUAL TO THE NUMBER OF POWER LEADS

2 DURING THE RADIATION TESTS THE 50 OHM COAX OUTLETS ON THE NETWORKS WILL BE TERMINATED IN CLOSED 50 OHM CAPS

3 DURING THE CONDUCTED INTERFERENCE TESTS THE ANTENNA IS REPLACED BY A 50 OHM COAX CABLE WHICH IS CONNECTED IN TURN TO EACH OF THE NETWORKS. ALL NETWORKS WILL BE TERMINATED EXCEPT THAT ONE ON WHICH MEASUREMENTS ARE BEING TAKEN

Figure 4 - Electromagnetic Test Setup

conditions indicated in Figure 4:

1) For test item which is normally grounded to other metallic equipment such as a vehicle - the test item shall be mounted in its normal operating position on a ground plane which meets the following requirements:

   a) Ground plane shall be made of copper, brass or aluminum.
   b) The plane shall be a minimum of 12 square feet in area.
   c) The plane shall be a minimum of 12 inches above the earth unless it is in a screen room.
   d) The plane shall be grounded as follows:

      (1) Planes in a screen room - bond the plane to the wall at intervals not exceeding 12 inches.
      (2) Planes in open area - ground the plane to an earth ground consisting of a grounding stake extending a minimum of 30 inches below the earth's surface.

2) A test item which is equipped with a power cable having a ground conductor but otherwise is ungrounded shall be grounded as follows:

   a) Mount the test item on an insulating stand of suitable size.
   b) Position test item, mounted on the insulating stand, centrally on the ground plane described in step b.1) and approximately 3 feet above it.
   c) Attach the ground conductor to the ground plane near where the power cord joins the line impedance stabilization networks (See Figure 5).

3) A test item which is grounded in mounting in addition to having a ground conductor in its power cable shall be grounded as follows:

   a) Mount the test item as directed in step b.1).
   b) Attach the ground conductor to the ground plane near where the power cord joins the line impedance stabilization network.

4) Test items which are normally ungrounded shall be mounted as follows:

   a) Mount the test item on an insulating stand of suitable size.
   b) Position the test item, mounted on the insulating stand, centrally on the ground plane described in step b.1) and approximately 3 feet above it.

c. Attach cables between the test item and the impedance stabilization networks, which are or simulate the type of cable normally used.

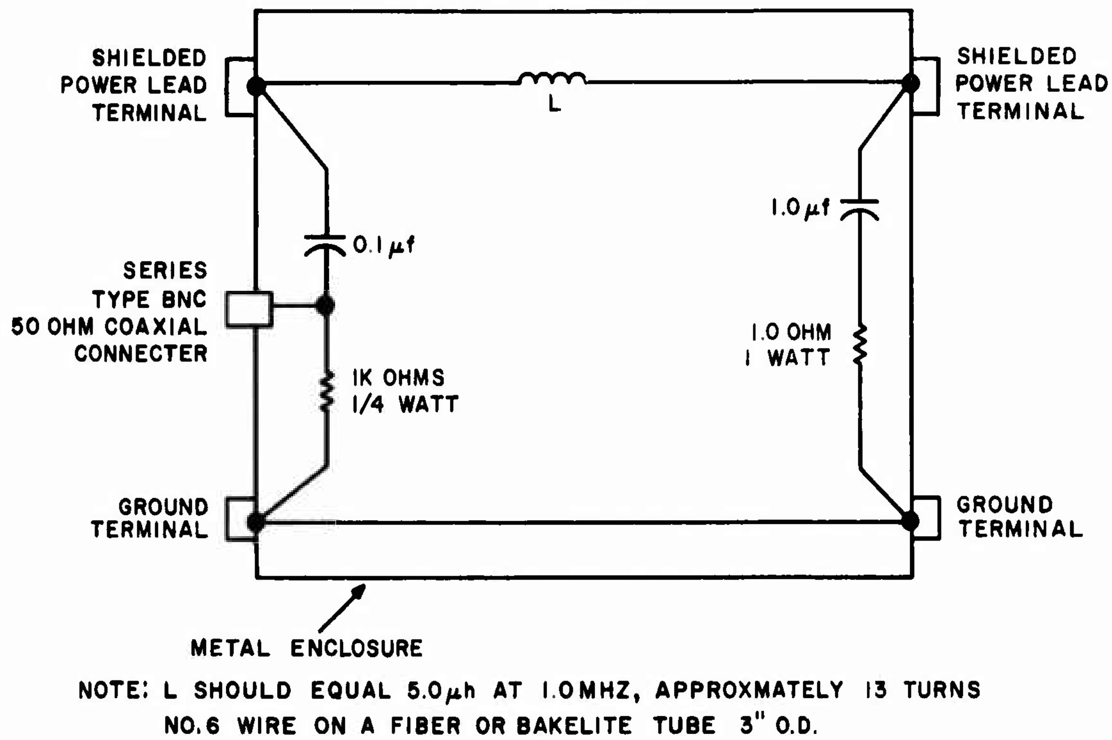


Figure 5 - Line Impedance Stabilization Network

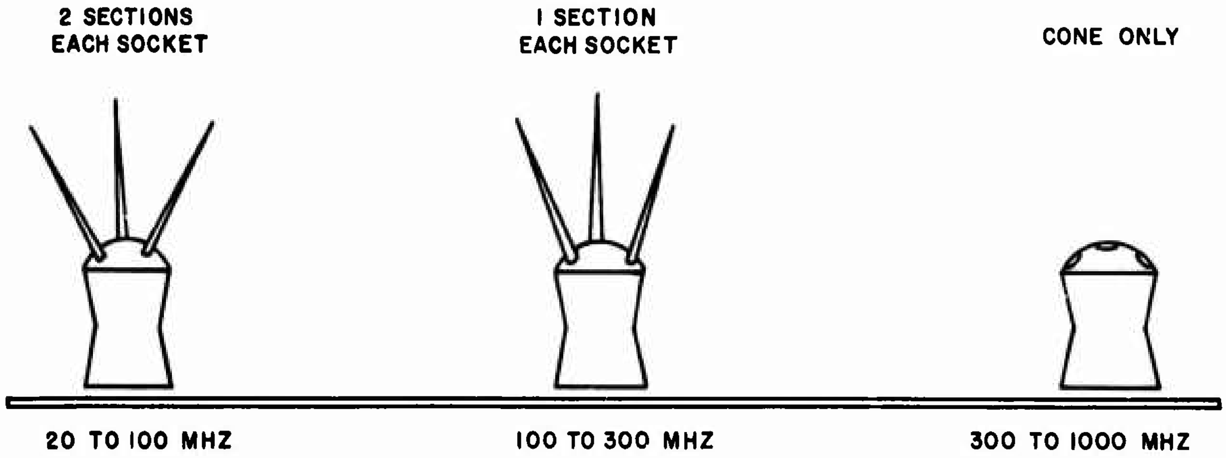


Figure 6 - Discone Antenna Frequency Configurations

NOTE: Shielded cables shall be used only if they are also used with the test item in normal use.

d. Place impedance stabilization networks (see Figure 5) on each power or load line of the test item and ground them to the ground plane or to each other and earth ground if no ground plane is used.

NOTE: All 50 ohm cable connectors on the network will be terminated in 50 ohms when conducting radiation tests.

e. Prepare a field intensity meter or its equivalent, having either an internal or external method of calibration, for operation. The meter shall be equipped with the following:

1) A range of frequencies from 0.014MHz to 1000 MHz
2) An external or internal method for calibration
3) Appropriate connections for the following antennas:

   a) 0.014 to 20 MHz whip antenna
   b) 20.0 to 1000 MHz discone antenna

6.2.3.2 Test Conduct

NOTE: The level of ambient interference at any frequency at which measurements will be taken shall be at least 6 db below the interference limits specified in the test plan except when sum of the ambient interference and that emitted by the test item does not exceed the specification limit.

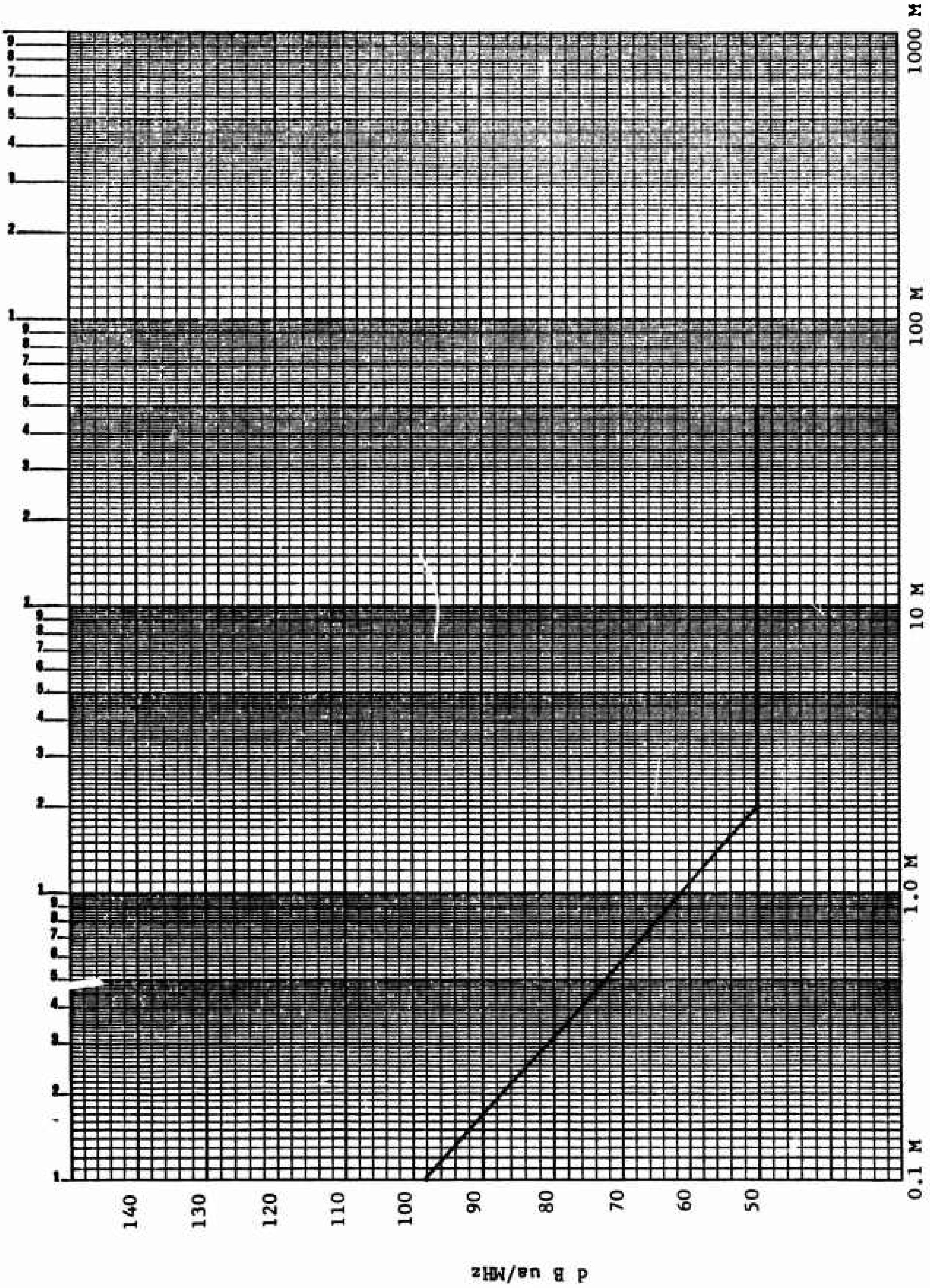
6.2.3.2.1 Radiation Measurements - Place the test item in the normal operating mode and perform the following:

a. At a distance of five feet from the test item, scan the electromagnetic interference spectrum from 0.15 to 1000 MHz with the applicable antenna positioned as follows:

NOTE: 1. The reference point for measuring the test item-measuring antenna distance will be as follows:

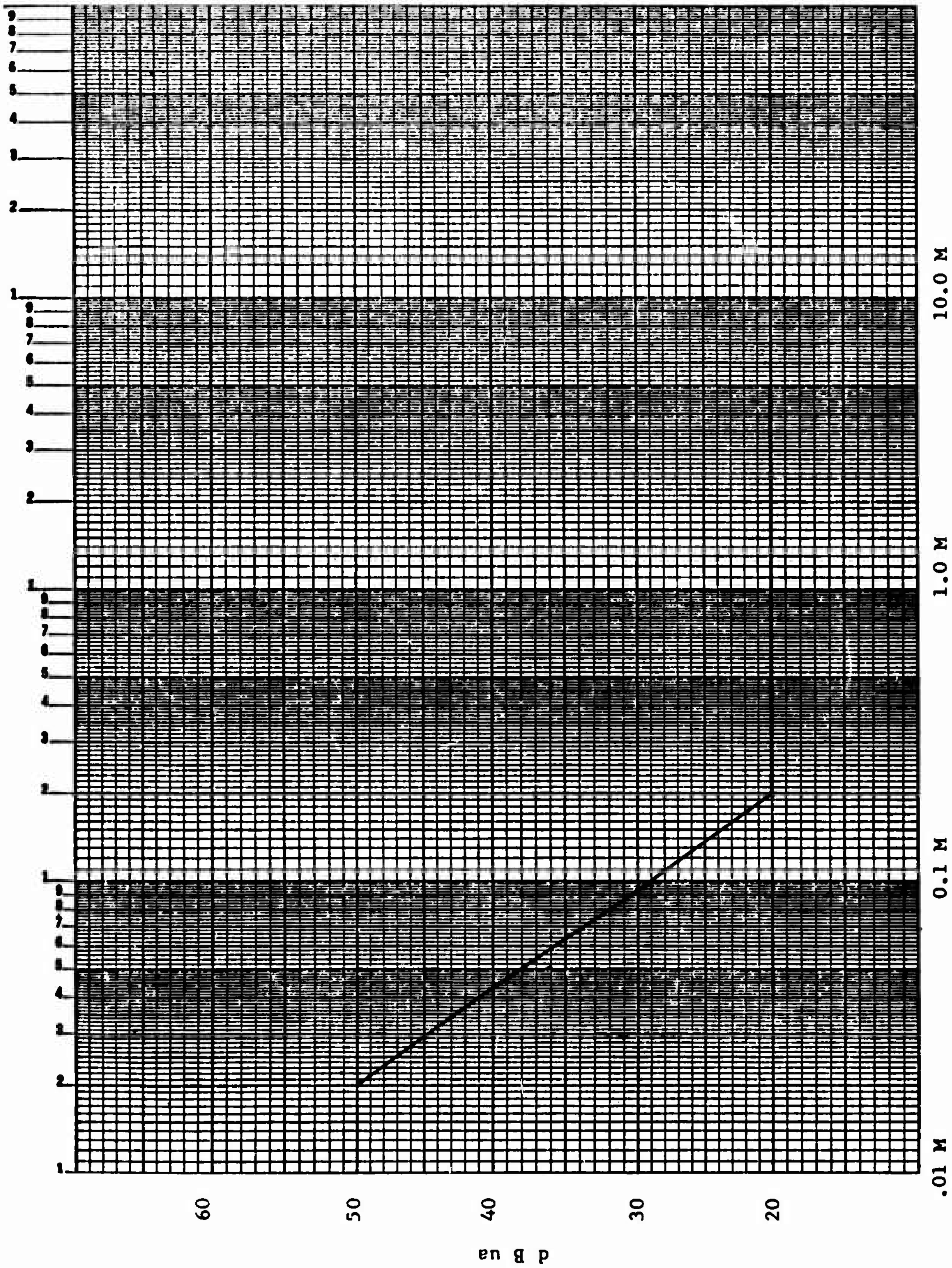
   a. The center of the antenna plane for whips having a plane or the base of the antenna for those not having a plane.
   b. The center of the antenna plane for discone antennas.

1) 0.015 to 20 MHz - The base of the rod antenna shall be 36 inches above ground and at the required test distance.
2) 20 to 1000 MHz - The discone antenna will have the configuration of rods shown in Figure 6. The axes of the cone shall be tilted from the vertical so that an imaginary line from the center of the interference source to the center of the ground plane bisects the angle formed between the surface of the cone and the plane.

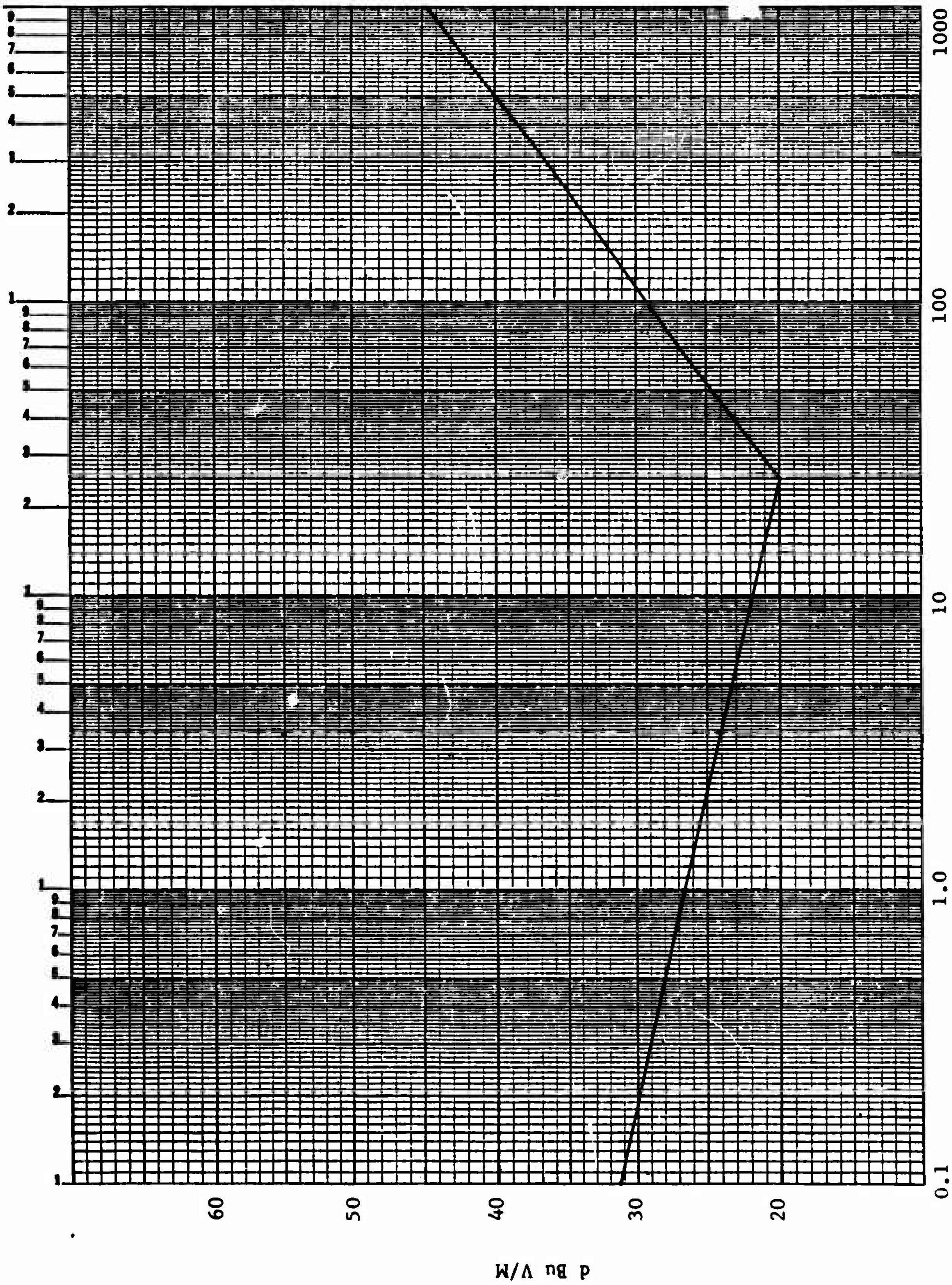


BROADBAND EMISSIONS

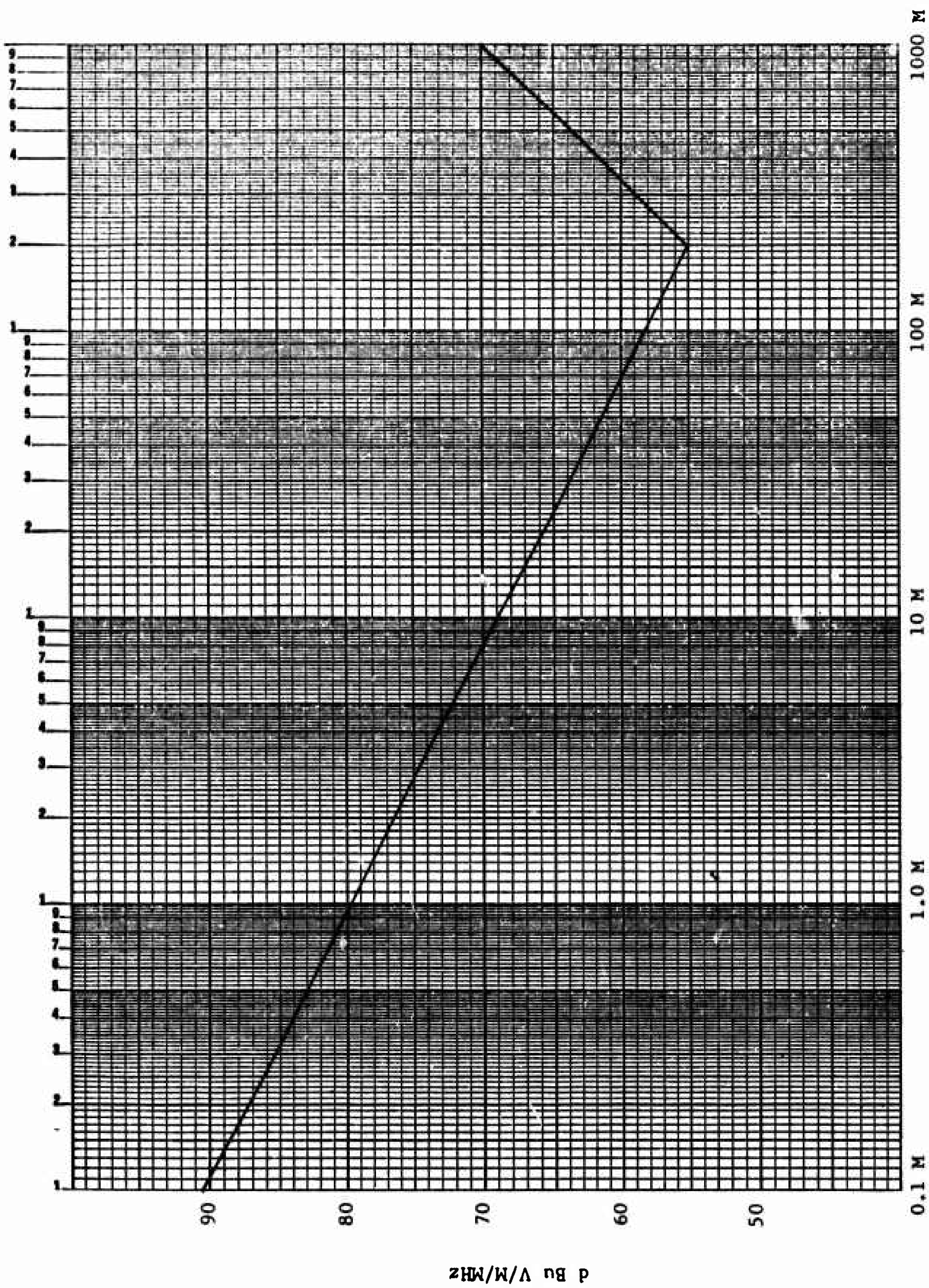
FIGURE 7



FREQUENCY (HZ)
NARROW BAND EMISSIONS
FIGURE 8



NARROW BAND EMISSIONS
FIGURE 9



BROADBAND EMISSIONS
FIGURE 10

b. For each reading which exceeds the limit allowed for a particular band (see Figures 7 and 8):

1) Measure and record the intensity of the interference with the power on.
2) Measure and record the intensity of the background interference when the power to the fan is removed.

NOTE: For those bands which do not contain an out-of-limit reading, record the location, frequency, and level of the highest reading in the band.

c. Repeat steps a and b at intervals of 15°, or as specified in the test plan, about the test item.

6.2.3.2.2 Line Conducted Interference - Perform the following:

a. Connect the field intensity meter to one of the output connectors of the impedance stabilization networks.

NOTE: All lines will be terminated in 50 ohms when the field intensity meter is not connected to them.

b. Scan the interference spectrum from 0.15 to 65 MHz.
c. For each reading which exceeds the limit allowed for a particular band (see Figures 9 and 10):

1) Measure and record the intensity of the interference with the fan power on.
2) Measure and record the intensity of the background interference when the power to the fan is off.

d. Repeat a through c for each power line.

NOTE: For those bands which do not contain an out-of-limit reading, record the connector, frequency, and level of the highest reading in the band.

6.2.4 <u>Balance Test</u>

a. Place the test item in its normal operating condition/position and attach a vibration amplitude measuring set, as required, to take a measurement of step b.
b. Measure and record the amplitude of vibration in at least two places on each exposed face of the fan set.
c. Record the location of each measuring point.

NOTE: Measurements should be made at locations which are remotely removed from the point or points at which the fan is mechanically secured to its mounting.

6.2.5 Durability Test

a. Prepare the test item for operation as directed in paragraph 6.2.2.1.

b. Operate the test item continuously for 100 hours.

c. At intervals of 10 hours, during the run, measure and record the following:

1) Input power
2) Motor housing temperature
3) Duct pressures

a) Velocity
b) Static

d. At the end of the run, measure and record the test item's d-c motor winding resistance and dielectric strength as described in steps b and d of paragraph 6.2.1.

NOTE: These measurements shall be made immediately at the end of the test run while the fan is still at its operating temperature.

6.2.6 Transportability

Determine the transportability of the test item as described in the applicable sections of MTP 10-2-503 and the following:

6.2.6.1 Shock Test

a. Subject the test item to the applicable shock tests of reference 4Z (MIL-STD-202C) Method 205C.

b. At the completion of the test visually inspect the test item for damage.

c. Subject the test item to the procedures of paragraph 6.2.2 to determine if there has been any change in the test item's operating efficiency.

6.2.6.2 Vibration Test

a. Subject the test item to the applicable vibration tests of reference 4Z (MIL-STD-202C) Method 201A.

b. At the completion of the test visually inspect the test item for damage.

c. Subject the test item to the procedures of paragraph 6.2.2 to determine if there has been any change in the test item's operating efficiency.

6.2.7 Environmental Tests

6.2.7.1 Salt Spray Test

a. Subject a minimum of 4 test items to the salt spray conditions of reference 4Z (MIL-STD-202C) Method 101B.

b. At the completion of the exposure, perform the following:

1) Visually inspect the test items and record any signs of corrosion.
2) Disassemble 1/2 of the test items and record the presence of corrosion or other deterioration.
3) Subject the remaining test items to the procedures of paragraphs 6.2.1 and 6.2.2.

6.2.7.2 Temperature Cycling Test

a. Subject a minimum of 4 test items to the temperature cycling procedure of reference 4Z (MIL-STD-202C) Method 102A.
b. At the completion of the test, perform the following:

1) Visually inspect the test items and record any indications of damage.
2) Disassemble 1/2 of the test items and record any indications of damage.
3) Subject the remaining test items to the procedures of paragraphs 6.2.1 and 6.2.2.

6.2.7.3 Humidity (Steady State) Test

a. Subject a minimum of 4 test items to the applicable procedures of Method 103B of reference 4Z (MIL-STD-202C).
b. At the completion of the test, perform the following:

1) Inspect the test items and record evidence of corrosion or other indications of deterioration.
2) Disassemble 1/2 of the test items and observe and record the presence of corrosion or other deterioration.
3) Subject the remaining test items to the procedures of paragraphs 6.2.1 and 6.2.2.

6.2.7.4 Immersion Test

a. Subject a minimum of 4 test items to the applicable procedures of Method 104A of reference 4Z (MIL-STD-202C).
b. At the completion of the test, perform the following:

1) Disassemble 1/2 of the test items and observe and record the presence of corrosion or other signs of deterioration.
2) Subject the remaining test items to the procedures of paragraphs 6.2.1 and 6.2.2.

6.2.7.5 Barometric Pressure (Reduced) Test

a. Subject a minimum of 4 test items to the procedures of paragraph 6.2.2 while exposed to the applicable conditions of reference 4Z (MIL-STD-202C) Method 105C.

b. At the completion of the test, perform the following:

1) Inspect the test items and record evidence of damage.
2) If applicable inspect the power capacitor and record any indications of damage.

6.2.7.6 Moisture Resistance Test

a. Subject a minimum of 4 test items to the applicable procedures of reference 4Z (MIL-STD-202C) Method 106B.

b. At the completion of the test, perform the following:

1) Visually inspect the test item and record all indications of corrosion or deterioration.
2) Disassemble 1/2 of the test items and observe and record indications of corrosion or other signs of deterioration.
3) Subject the remaining test items to the procedures of paragraphs 6.2.1 and 6.2.2.

6.2.7.7 Life at Elevated Ambient Temperature

a. Operate the test item in its normal operating mode using the applicable criteria of reference 4Z (MIL-STD-202C) Method 108A.

b. At intervals of 10% of the total test time, subject the test item to the procedures of paragraphs 6.2.1 and 6.2.2.

6.2.7.8 Explosion

Subject a minimum of 2 test items to the procedures of Method 109A of reference 4Z (MIL-STD-202C).

6.2.7.9 Sand and Dust Test

a. Subject a minimum of 4 test items to the applicable procedures of reference 4Z (MIL-STD-202C) Method 110.

b. At the completion of the test, perform the following:

1) Inspect the test items and record indications of damage.
2) Disassemble 1/2 of the test items and inspect the components for damages and/or the presence of sand and dust.
3) Verify the performance of the remaining test items by subjecting them to the procedures of paragraph 6.2.2

6.2.8 <u>Maintainability and Reliability Evaluation</u>

Evaluate the maintenance-related factors of the test item as described in MTP 10-2-507 with emphasis on the following:

a. Organizational (O), Direct Support (F), and General Support (H) Maintenance requirements.

b. Operator through General Support Maintenance Literature.

c. Repair parts.
d. Tools.
e. Test and handling equipment.
f. Calibration and maintenance facilities.
g. Personnel skill requirements.
h. Maintainability.
i. Reliability.
j. Availability.

6.2.9 Safety

a. During the conduct of this MTP, test personnel shall observe and record the following:

1) Safety hazard(s), if any
2) Cause of safety hazard(s)
3) Steps taken to alleviate safety hazard(s)

b. Inspect the test items and record any failure to meet the following safety requirements:

1) Electrical parts shall be so located or enclosed so that suitable protection against accidental contact with uninsulated energized circuits is provided.
2) All internal wiring shall be protected against heat and contact with moving parts.
3) Where connections are made to internal wiring a barrier type terminal board or equivalent shall be used for secure lead attachment and protection against accidental contact of leads attached adjacent to each other.
4) Where line cords are used they shall be of sufficient current carrying capacity, shall be protected against rubbing against access parts by insulated bushings and shall be sufficiently strain relieved to withstand approximately five pounds of pull.
5) Where line fuses are used they shall be of a value consistent with the requirements of the fan.
6) Where switches are used they shall be of sufficient current capacity and mounted so as not to allow movement.
7) All metal parts shall be electrically bonded and grounded to prevent static electrical buildup.
8) The materials used in the motor and fan set shall be inherently nonflammable and nonexplosive.
9) Where the normal operating temperature of the motor shall be sufficient to cause a burn the motor shall have a plate attached stating this fact.
10) All moving parts of the set shall be enclosed to avoid accidental contact when the fan is in its operating position.
11) The propeller or impeller shall be accurately attached to the motor shaft.
12) All external surfaces and internal surfaces (those exposed during maintenance) shall have no sharp edges.

13) Where a thermal overload is provided for the motor it shall be tested for operation and the method of reset (manual or automatic) verified.
14) The blades or impellers and shafting shall be sufficiently strong and designed with adequate clearance to prevent contact with castings or prevent distortion under conditions of deposit loading or other factors.
15) Where the fan is to be used with explosive vapors the rotating elements shall be constructed of a non-ferrous or non-sparking material.
16) Where capacitors are used they shall be housed in a suitable enclosure which will provide protection and also prevent the emission of flame or molten material in the event of a failure.

c. Check for presence of ground voltage in frame, ducting, etc.
d. Issue a safety release in accordance with USATECOM Regulation 385-6.

6.2.10 Human Factors Evaluation

Human factor tests and considerations shall be conducted as described in applicable sections of MTP 10-2-505, and the following to obtain noise level interference measurements:

a. Mount the test item in its normal operating mode, on a nonresonant stand at the geometric center of the room or at least six feet from any sound reflecting surfaces.

NOTE: The set-up will be located preferably in a reverberant or semi-reverberant room. It may also be set up out-of-doors. However, in either case the location must be qualified on the basis of measurements revealing the ambient sound pressure levels.

b. Prepare sound measuring equipment for the test as follows:

1) Position a microphone at a point three feet from the approximate center of the test item observing the following restrictions:

a) The microphone should be oriented for maximum pickup.
b) There should be no obstruction between it and the test item, and where possible the measuring equipment should be remotely operated (outside the room).
c) The microphone shall not be placed at angles plus or minus 45° to the normal to the fan inlet or outlet.

2) Calibrate a sound level meter and set the weighting network switch of the meter to the "flat response" or C position.

c. Apply power to the fan.

d. Measure and record the highest sound pressure level in each band over all of the bands (See Table II).

TABLE II

Series 2 Frequency Analysis

BAND	FROM	TO	CENTER FREQUENCY*
1	45	90	63
2	90	180	125
3	180	355	250
4	355	710	500
5	710	1400	1000
6	1400	2800	2000
7	2800	5600	4000
8	5600	11,200	8000

*Defined as geometric mean of cut-off frequencies.

e. Repeat the procedures of step d at 6 approximately equally spaced points (60°) on a circular path around the test item.

f. For the point of highest sound pressure in each band, remove power from the test item and measure and record the ambient noise level.

6.2.11 Value Analysis

During the conduct of the test observe and record any unnecessary, costly, or nice-to-have features of the test item as stated in USATECOM Regulation 700-1.

6.3 TEST DATA

6.3.1 Preparation for Test

6.3.1.1 Initial Inspection

6.3.1.1.1 Packaging Inspection -

Record the following:

a. Evidence of package damage or deterioration
b. Identification markings

1) Name of contractor
2) Number and date of contract
3) Date of manufacture
4) Other pertinent markings

c. For each package record the following:

1) Weight, in lbs.
2) Length, width and height, in inches
3) Cubage, in ft^3
4) Package contents

6.3.1.1.2 Test Item Inspection -

Record the following:

a. For the test item, defects in the following:

1) Manufacturing
2) Material
3) Workmanship

b. Evidence of damage
c. Evidence of wear
d. Presence of an identification tag with the electrical requirements data on the motor.
e. Correlation of accompanying printed material with the test item's markings.

6.3.1.2 Physical Characteristics

Record the data collected as described in the applicable section of MTP 10-2-500.

6.3.1.3 Operator Training and Familiarization

Record the following:

a. Adequacy of draft technical manuals for training purposes
b. Any unusual difficulties in training personnel
c. Test personnel data as required by MTP 10-2-501

6.3.2 Test Conduct

6.3.2.1 Preliminary Electrical Tests

Record the following:

a. Continuity of each winding of the motor
b. Adequacy of grounding connections, when applicable
c. Direct current resistance of each motor winding in ohms
d. Insulation resistance, in megohms:

1) Between each winding
2) Between each winding and the test item housing

e. Dielectric strength between each winding and all other windings and the housing tied together, in mehohms.

6.3.2.2 Performance Test

Record the following:

a. For the motor

1) Power input (P), in watts
2) Voltage (V), in volts
3) Current (I), in amps
4) Number of motor phases
5) Operating temperature (T_0) in °F

b. Dry bulb temperature at the measuring plane in °F
c. Ambient meteorological data:

1) Barometric pressure (P_b), in inches Hg
2) Ambient dry bulb temperature (T_{a2}), in °F
3) Ambient wet bulb temperature (T_{a1}), in °F

d. For each static pressure setting:

1) Static pressure setting (at middle of duct), in inches of water.
2) Static pressure (P_s) at each of the 20 traverse duct locations, in inches of water.
3) Velocity pressure (P_v) at each of the 20 traverse duct locations, in inches of water.

e. Dynamometer force (T), in lbs.
f. Rotor speed (N), in rpm.
g. Radius of the duct at:

1) The fan outlet (r_1), in inches
2) The measuring plane (r_2), in inches

6.3.2.3 Electromagnetic Interference

6.3.2.3.1 Radiation -

Record the following:

a. Location of test (chamber or outside)
b. For the highest reading in each band:

1) Band.
2) Location, with respect to front of test item, in degrees clockwise.

3) Frequency in MHz
4) Interference level, in db:

c. For each reading which exceeds the specified limit:

1) Band.
2) Location, with respect to front of test item, in degrees clockwise.
3) Frequency in MHz.
4) Interference level, in db:

a) With fan power on
b) With fan power off

6.3.2.3.2 Line Conducted Interference -

Record the following:

a. For the highest reading in each band:

1) Band
2) Power line
3) Frequency in MHz
4) Interference level, in db:

b. For each reading which exceeds the specified limit:

1) Band
2) Power line
3) Frequency in MHz
4) Interference level , in db:

a) With fan power on
b) With fan power off

6.3.2.4 Balance Test

Record the following:

a. The points on the fan housing where the measurements were taken
b. The vibration level at each of the measurement points
c. Location of measuring points

6.3.2.5 Durability

a. Record the following every 10 hours of the test run:

1) Input power, in watts
2) Motor housing temperature, in °F
3) Duct pressures, in inches of water

a) Velocity
b) Static

b. Record the following as described in paragraph 6.2.1:

1) D-C motor winding resistance, in ohms
2) Dielectric strength in megohms

6.3.2.6 Transportability

Record the data required by MTP 10-2-503 and the following:

6.3.2.6.1 Shock Test

Record the following at the completion of the shock test:

a. "G's" applied
b. Number of drops made
c. Damage to test item resulting from shock tests
d. Performance data as required by paragraph 6.2.2

6.3.2.6.2 Vibration Test -

Record the following:

a. Frequency of vibration
b. Amplitude of vibration
c. Damage to test item
d. Performance data as required by paragraph 6.2.2

6.3.2.7 Environmental Tests

6.3.2.7.1 Salt Spray Test -

Record the following for each test item:

a. Test item serial number
b. Length of time test item is exposed to salt spray in minutes
c. External signs of deterioration
d. Evidence of internal damage or deterioration
e. Data as required by paragraphs 6.2.1 and 6.2.2

6.3.2.7.2 Temperature Cycling Test -

Record the following for each test item:

a. Test item serial number
b. External indications of damage
c. Internal indication of damage
d. Data as required by paragraphs 6.2.1 and 6.2.2

6.3.2.7.3 Humidity (Steady State) Test -

Record the following for each test item:

a. Test item serial number
b. Test condition (A, B, C, or D)
c. External evidence of corrosion or damage
d. Internal evidence of corrosion or deterioration
e. Data as described in paragraphs 6.2.1 and 6.2.2

6.3.2.7.4 Immersion Test -

Record the following for each test item:

a. Test item serial number
b. Test conditions (A, B, or C)
c. Internal evidence of corrosion or other deterioration
d. Data as described in paragraphs 6.2.1 and 6.2.2

6.3.2.7.5 Barometric Pressure Test -

Record the following for each test item:

a. Test item serial number
b. Test conditions (A, B, etc)
c. Data as required by paragraph 6.2.2
d. External evidence of damage to the test item.
e. Evidence of damage to the power capacitor, if applicable

6.3.2.7.6 Moisture Resistance Test -

Record the following for each test item:

a. Test item serial number
b. External evidence of damage to the test item
c. Insulation resistance, in megohms

    1) Between each winding
    2) Between each winding and the test item housing

d. Internal evidence of corrosion or other deterioration
e. Data collected as described in paragraphs 6.2.1 and 6.2.2

6.3.2.7.7 Life at Elevated Ambient Temperature -

Record the following for each test item:

a. Test item serial number
b. Test temperature, in °F
c. For each time interval:

1) Total time operated, in hours.
2) Preliminary electrical data collected as described in paragraph 6.2.1.
3) Performance data collected as described in paragraph 6.2.2.

6.3.2.7.8 Explosion -

Record if the test item ignites the explosive atmosphere under any of the test conditions.

6.3.2.7.9 Sand and Dust Test -

Record the following for each test item:

a. Test item serial number.
b. Test conditions (A, B, and C).
c. External indications of damage.
d. Internal indications of damage and/or the presence of sand and dust.
e. Data as required by paragraphs 6.2.1 and 6.2.2.

6.3.2.8 Maintenance

Record the data collected as described in the applicable sections of MTP 10-2-507.

6.3.2.9 Safety

Record the following:

a. Safety hazard(s) observed, if any
b. Cause of safety hazard(s)
c. Steps taken to alleviate safety hazard(s)
d. Failure to meet safety requirements, if any
e. Presence of ground voltage in frame or ducting, if any

6.3.2.10 Human Factors

Record the following:

a. Data as required by MTP 10-2-505
b. For each position at which noise measurements are made:

    1) Location with respect to the front center of the test item, in degrees clockwise.
    2) Highest sound pressure in each band.
    3) Frequency of highest sound pressure in each band.
    4) Ambient sound pressure for each band.

6.3.2.11 Value Analysis

Record any unnecessary, costly, or nice-to-have features of the test item that could be eliminated without compromising its performance.

6.4 DATA REDUCTION AND PRESENTATION

6.4.1 General

a. Data obtained from all subtests covered by applicable MTP's shall be summarized, compared with the technical performance characteristics specified in the QMR's, SDR's, or other specifications, and evaluated according to procedures described in those applicable MTP's. Appropriate charts, graphs, and tabulated summaries shall be used to present the data in a clear manner.

Calculations shall be performed as specified by the individual MTP's, wherever applicable, and all photographs, motion pictures, and illustrative material shall be suitably identified.

b. All data not evaluated as described in a above or paragraphs 6.4.2 through 6.4.6 shall be tabulated and summarized as appropriate and compared with the test items applicable technical performance characteristics when required.

6.4.2 Preliminary Electrical Tests

Present the results of the test in tabular form indicating the winding, its continuity, resistance, insulation resistance and successful completion of the dielectric strength test.

6.4.3 Performance

For the first performance run perform the following:

a. Determine the velocity pressure, P_{v_1}, at the measuring plane by the following:

$$P_{v_1} = \left[\sum_{1}^{20} \frac{\sqrt{P_{v_i}}}{20} \right]^2$$

where P_{v_i} = velocity pressure, in inches of water, for duct location i.

b. Determine the static pressure, P_{s_1} at the measuring plane by the following:

$$P_{s_1} = \frac{\sum_{1}^{20} P_{s_i}}{20}$$

where P_{s_i} = static pressure, in inches of water, for duct location i.

c. Determine the density of atmospheric air, d_a, by the following:

$$d_a = \frac{70.73\ (P_b - 0.378\ p_p)}{R\ (T_{a_2} + 459.7)}$$

where:

P_b = barometric pressure in inches Hg

R = gas constant (53.3 ft - lb°R/lb)

T_{a_2} = ambient dry bulb temperature °F

p_p = partial vapor pressure

NOTE: $$p_p = \frac{(p_s - P_b)\ (T_{a_2} - T_{a_1})}{2700}$$

where:

p_s = saturated vapor pressure at wet bulb temperature. (Between 40°F to 80° F) p_s is equal to:

$$2.9599 \times 10^4\ T_{a_1}^{\ 2} - 1.5927 \times 10^2\ T_{a_1} + .4102)$$

T_{a_1} = wet bulb temperature

d. Determine the density of air, d, at the measuring plane by:

$$d = da \left[\frac{T_{a_2} + 459.7}{T_2 + 459.7}\right] \left[\frac{P_b + \frac{P_{s_1}}{13.62}}{P_b}\right]$$

where:

da = density of ambient air

T_{a_2} = ambient dry bulb temperature in °F

T_2 = dry bulb temperature at the measuring plane in °F

P_b = ambient barometric pressure in inches Hg

P_{s_1} = static pressure at the measuring plane in inches Hg

e. Determine the velocity of air, v_1, at the measuring plane by:

$$v_1 = 1097 \sqrt{\frac{P_{v_1}}{d}}$$

where:

P_{v_1} = velocity pressure at the measuring plane in Hg

d = density of air at the measuring plane

f. Determine the cross-sectional area, A_1 of the duct at the measuring plane by:

$$A_1 = \pi r_1^2$$

where:

r_1 = the duct radius at measuring plane, in ft

g. Determine the volume air flow, V_1, at the measuring plane by:

V_1 = $v_1 A_1$ in ft^3/min.

where:

v_1 = air velocity at the measuring plant in ft/minute

A_1 = area of duct at the measuring plant in ft^2

h. Determine the total pressure, ΣP_1, at the measuring plane by:

$$\Sigma P_1 = P_{s_1} + P_{v_1}$$

where:

P_{s_1} = Static pressure at the measuring plane

P_{v_1} = Velocity pressure at the measuring plane

i. Determine the fan velocity pressure, P_v, by:

$$P_v = P_{v_1} \left[\frac{A_1^2}{A_2} \right]$$

where:

P_{v_1} = the velocity pressure at the measuring plane

A_1 = Area of duct at the measuring plane

A_2 = Area of the fan-outlet

j. Determine the total pressure, ΣP, at the fan outlet by:

$$\Sigma P = \Sigma P_1 + 0.2 \left[\frac{L + 4D}{D} \right] P_{v_1}$$

where:

ΣP_1 = Total pressure at the measuring plane

L = Distance between measuring plane and fan outlet, in ft
D = Diameter of the duct, in ft
P_{v_1} = the velocity pressure at the measuring plane

k. Determine the static pressure, p_s, at the fan outlet by:

$$p_s = \Sigma P - P_v$$

where:

ΣP = The total pressure

P_v = The velocity pressure

l. Determine the volume air flow, V, at the fan outlet by:

$$V = V_1 \frac{d}{d_a}$$

where:

V_1 = Volume air flow at the measuring plane

d = Density of air at the measuring plane
d_a = Density of ambient air

m. Determine the brake horsepower, bhp, required to drive the fan:

$$bhp = \frac{2\pi + 1N}{33{,}000}$$

where:

T = dynamometer force in lbs.
l = length of dynamometer arm from shaft center to knife edge in ft.
N = rotational speed in revolution/minute

n. Determine the motor power factor, Pf, and phase angle, θ, (the angle whose cosine is equal to the power factor) by:

$$Pf = K \frac{P}{IV} \qquad \cos \theta = Pf$$

where:

K = 1 for single phase line voltage and
= 0.577 for 3 phase line voltage
P = motor input power, in watts
I = motor input current, in amps
V = motor input voltage, in volts

o. Determine the total mechanical efficiency, E_T, by:

$$E_T = \frac{V(\Sigma P)}{6356\ (bhp)}$$

where:

V = volume air flow at the fan outlet
ΣP = the total air pressure
bhp = the motor brake horsepower

p. Determine the static efficiency, E_s, by:

$$E_s = \frac{VP_s}{6356\ (bhp)}$$

where:

V = volume air flow at the fan outlet
P_s = Static pressure at the fan outlet
bhp = the motor brake horsepower

q. Determine the motor efficiency, E_m, by:

$$E_m = \frac{TlN}{(7.04)P}$$

where:

T = dynamometer force in lbs
l = length of dynamometer arm from shaft center to knife in ft
N = rotational speed in rev/min
P = motor input power, in watts

r. Determine the air horsepower, ahp, by:

$$ahp = \frac{V\ (\Sigma P)}{6356}$$

where:

V = volume air flow at the fan outlet
ΣP = the total air pressure

s. Determine the motor horsepower,

$$mhp = \frac{1.34\ P}{1000}$$

where:

1.34 is a constant = hp/kilowatt
P = motor input power, in watts

t. Determine the motor-fan set efficiency, E, by:

$$E = \frac{ahp}{mhp}$$

where:

ahp = air horsepower of fan
mhp = motor horsepower

u. Calculate the static pressure P_{s_1} using the formula in step b and the volume air flow using the formula in step g for readings obtained at ± 50% static pressure settings (at middle of duct).

Use the data for air flow and static pressure as ascertained from the three determinations for a comparison with the fan characteristic curve or manufacturers' supplied tables. Record the results of these comparisons on a quantitative basis.

6.4.4 Electromagnetic Interference

a. Radiation - prepare a table showing measuring locations, frequency bands, out of limit reading(s) or highest reading in the band and frequencies, indicate by a circle those readings which exceed the maximum allowed. Refer to Figures 7 and 8, as appropriate, for limits. Correct all readings for the ambient interference.

b. Line Conducted - repeat part a. using where necessary the measurements recorded. Refer to Figures 9 and 10, as appropriate, for limits. Correct all readings for the ambient interference where necessary.

6.4.5 Durability

a. Prepare a table presenting the values recorded during the life run (in chronological order). Circle those values which show a marked increase from the values recorded at the preceding time.

b. Record the results of the dielectric strength test. Denote failures.

c. Calculate the final temperature, t_f, for each motor winding as follows:

$$t_f = \frac{R_{t_1}}{R} \left(C + t_r\right) - C$$

where:

t_r = room temperature of the winding in °C

R_{t_1} = the final resistance value of the winding, in ohms

R_1 = the initial resistance value of the winding, in ohms

C = 234.5 for copper windings and 221 for aluminum windings

d. Compare the temperature rise with the insulation class to determine the allowable temperature rise.

Class A insulation - not more than 40°C rise
Class B insulation - not more than 60°C rise
Class C insulation - not more than 15°C rise

6.4.6 Human Factors Evaluation

Present human factors data as directed in MTP 10-2-505 and the data obtained from noise level measurements as follows:

a. Prepare a table showing measurement locations, the highest noise readings in each band and the ambient noise. Include a column for corrected noise readings, with the new readings to be determined in the following manner:

1) If the difference between the noise reading and the ambient reading is 3 decibels or less, mark corrected reading "undetermined".
2) If the difference is between 4 and 10 decibels consult Table III.
3) If the difference is greater than 10 decibels, no corrections are necessary.

b. Circle those readings which are out of limit by consulting HEL Standard S-1-63B, Maximum Noise Level for Army Materiel Command Equipment, June 1965.

TABLE III

CORRECTIONS FOR AMBIENT SOUND PRESSURE LEVELS

Difference in decibels between sound pressure level measured with sound source operating and ambient sound pressure level alone.	4	5	6	7	8	9	10
Corrections in decibels, to be subtracted from sound pressure level measured with sound source operating to obtain sound pressure level due to sound source alone.	2.2	1.7	1.3	1.0	0.8	0.6	0.4

GLOSSARY

1. Sound Power Level

In decibels is 10 times the logarithm number to the base 10 of the ratio of the acoustic power in watts to the reference power. The reference power used will be 10^{-12} watts.

$$L_w = 10 \log_{10} \frac{\text{Watts}}{10^{-12}}$$

2. Electromagnetic Interference

Any steady state or transient conducted, induced, or radiated electromagnetic energy which may interfere or impair the operation of electronic equipment.

3. Radiated Interference

That type of interference which results from the emission of electromagnetic waves which move away from the source by propagation through the surrounding atmosphere.

4. Conducted Interference

That type of interference which appears as undesirable voltage changes on power lines which are common to both the source of the interference and other electronic equipment.

5. Ambient Interference

That interference indicated by the measuring equipment at the test site but not due to the item under test.

6. Narrowband Interference

Interference due to continuous wave (cw) whether modulated or not. The response of the measuring set to narrowband interference is substantially independent of the bandwidth of the set. The units used are decibels above 1 microvolt (db/1 uv).

7. Broadband Interference

All interference other than narrowband is included in this category including disturbances of random or regular amplitudes and repetition rates. The energy here is distributed over a spectrum of frequencies which is wide when compared to the bandwidth of the measuring set so that resolution of a given frequency is impossible. Interference is considered broadband when the measuring set can be tuned over a range of plus and minus 6 db bandwidth around the center tuned frequency without changing the peak response by more than 3 db.

APPENDIX A

FANS

A. Axial Flow

1. Propeller Fan: Used for moving large quantities of air against very low static pressures and is most commonly used for general ventilation or dilution ventilation work.

   a. Disc or Bucket Blade Type: Used for moving clean air against no duct resistance.
   b. Narrow or Propeller Type Blade: Used for moving air against low static pressures. Air volume exhausted is sensitive to added resistance, small increase gently reduces volume handled.
   c. Tubeaxial Type (Duct Fan): Same as "b" except that it is fabricated within a short section of round duct. Best suited to moving air with condensable fumes.

2. Vane axial Fan: Provides economy in horsepower and space of propeller type and develops higher pressure. Use with clean air.

B. Centrifugal

1. Forward-Curved Blade Types: A multi-bladed, "Squirrel Cage" wheel in which the leading edges of the fan blades curve toward the direction of rotation. Have low space requirements, low tip speeds, and are quiet. Normally used against low to moderate static pressures. Not used with dust or fume movement applications.

2. Straight or Radial Blade (Paddle Wheel, Long Shaving Wheel): Has large air horsepower and is used in most exhaust systems where materials are likely to clog the fan wheel. Have medium tip speed and a medium noise factor.

3. Backward Blade Type: Fan blades are inclined in a direction opposite to the fan rotation. Usually has a high tip speed, provides high fan efficiency and has non-overloading characteristics. Blade shape is conducive to material buildup and should be used only with clean air.

C. Special Fan Types

1. Airfoil - Backward Curved Blade Centrifugal: Has variations in characteristics depending on blade shape. With proper blade design, the fan is quieter, has higher efficiency and functions smoothly without pulsations throughout its performance range.

2. In-Line-Flow-Centrifugal: Has a backwardly curved blade with a special housing which permits a space saving straight line duct installation. Pressure-volume-horsepower performance curves are similar to a scroll type centrifugal fan of the same blade type. Space requirements are similar to a vane axial fan.

The units of broadband interference are decibels relative to 1 microvolt per megahertz of bandwidth (dbmc).

APPENDIX B

MOTOR DIELECTRIC STRENGTH TESTS

General Requirements: This specification is applicable before and after a prolonged run period. The frequency of the test voltage shall be 25-60 Hz and the peak value shall be the specified test voltage multiplied by $\sqrt{2}$. The test voltage shall be applied for one minute except that an equivalent test can be conducted for one second if the test voltage is 1.2 times that voltage used for the one minute test.

Motor Types

A. Universal Motors - The high potential test for all motors regardless of horsepower and for operation upon circuits not exceeding 250 Volts shall be made by applying 900 VRMS.

B. Direct Current and Induction Motors -

1. Motors rated ½ horsepower and larger.

   a. Apply 1000 VRMS plus twice the rated voltage of the motor windings.
   b. For motors with armatures or rotors with insulated windings not connected to the line apply 1000 VRMS.

   Exception: The standard test voltage for secondary windings of wound rotors of induction motors shall be 1000 VRMS plus twice the maximum voltage induced between slip rings on open circuit at standstill (or running if under this condition the voltage is greater) with primary voltage applied to the stator terminals as in service. Since the voltage induced in the rotor is a function of both the speed of the rotor and the voltage impressed on the stator, the test voltage applied to the rotor shall be determined from that combination of those two conditions which give the highest voltage induced in the rotor.

   For reversing motors the test voltage shall be 1000 VRMS plus four times the maximum voltage induced between slip rings on open circuit at standstill with rated primary voltage applied to the stator terminals.

2. Motors Rated at Less than ½ Horsepower

   a. For motors rated less than ½ horsepower and operated by circuits of less than 250 volts the test voltage shall be 900 VRMS. Above 250 volt operation the test voltage shall be 1000 VRMS plus twice the motor rated voltage.

b. For motors rated less than ½ horsepower where armatures or rotors have insulated windings not connected to the line the test voltage shall be 900 VRMS.

APPENDIX C

A CIRCUIT FOR MEASURING THE RESISTANCE OF ENERGIZED A-C WINDINGS

A simple means of measuring the electrical resistance of a-c energized windings has long been desired inasmuch as it would permit the determination of winding temperatures while the windings are operating under actual load conditions. The circuit as outlined in this paper makes such measurement possible.

Present Methods

The present procedures for determining windings or coil temperatures are either thermometers or thermocouples or to calculate the winding temperature from winding resistance values obtained at room temperature and after shutdown. Each of these procedures has certain inherent disadvantages.

a. The inherent disadvantages of thermometers for measuring winding temperatures are:

1) The thermometer tends to measure only the temperature of the spot where it is located and, in general, can only be used in an attempt to measure surface temperatures of winding.
2) There is frequently a considerable difference between the temperature as measured by a thermometer and the actual surface temperature of a winding. This difference between actual surface temperature and the thermometer reading can vary considerably, depending on the manner in which the thermometer is applied to the winding.
3) Because of the poor thermal contact between a thermometer and a winding, there can be a large temperature lag between them when the winding temperature is changing rapidly.
4) The thermometer frequently cannot be applied to the windings of a small apparatus without modifying the enclosure of the apparatus.

b. The disadvantages of a thermocouple for measuring winding temperatures are:

1) The thermocouple measures only spot temperatures.
2) There can be a side variation in the thermocouple temperatures resulting from the manner in which thermocouples are applied to the windings.
3) The use of different types of thermocouples and of different size thermocouple wire can also result in a consderable difference in the measured temperature.
4) There can be temperature lag between the winding temperature and the thermocouples temperature when winding temperatures are changing rapidly.
5) It is frequently necessary to disassemble the apparatus under

test to install thermocouples.

6) With hermetically sealed apparatus, it is necessary to build special test units to bring out the thermocouples.

c. The method of determining winding temperature by measuring winding resistance after shutdown also has the following inherent disadvantages:

1) Accurate winding resistance measurements cannot be made because of the changing resistance.
2) Since resistance readings cannot be made immediately after shut down, it is general practice to obtain a number of resistance readings after various time intervals and to plot these values back to zero time on logarithmic graph paper. This procedure is time-consuming and somewhat inaccurate since the cooling curve is not entirely logarithmic.
3) Winding temperatures cannot be followed under changing load conditions by this method.
4) Equipment such as refrigeration equipment cannot be frequently shut down during tests without disrupting the entire test.

New Resistance Method

It will be realized that, if attempts were made to measure the resistance of an a-c energized apparatus using a Wheatstone bridge or an ohmmeter, the alternating current voltage would damage or burn out the bridge or ohmmeter. Even if it were possible to connect the bridge directly to an a-c energized apparatus it still would be impossible to measure the resistance of this apparatus since its resistance would be paralleled by the resistance of all of the other loads on the line and, also, by the resistance of the secondary winding of the line transformer. It was, therefore, necessary to devise a circuit which would circumvent these two basic obstacles.

The circuit in Figure C-1 illustrates the manner in which this was accomplished. First, the voltage problem was surmounted by the use of a substantially equal and opposite bucking voltage as supplied by a potential transformer. This allows a bridge or ohmmeter to be connected to one terminal of the apparatus on test and to one side of the secondary of the transformer since there is substantially zero voltage between these points. It was originally thought necessary to use a variable transformer to buck the voltage to zero, but it was found unnecessary since a few volts of alternating current would not adversely affect a bridge.

The necessary isolation of the windings under test so that the direct current from the bridge or ohmmeter will not flow through the other paralleling resistance in the circuit is accomplished by the use of the capacitor bank in the circuit of Figure C-1. It will be noted that the primary winding of the bucking transformer is also on the line side of the capacitor bank. As such, this permits the bridge to measure the sum of the resistance of the winding in question, the secondary of the transformer, and the leads. The actual winding resistance is then obtained by subtracting the resistance of the transformer and leads from the total resistance as obtained from the bridge.

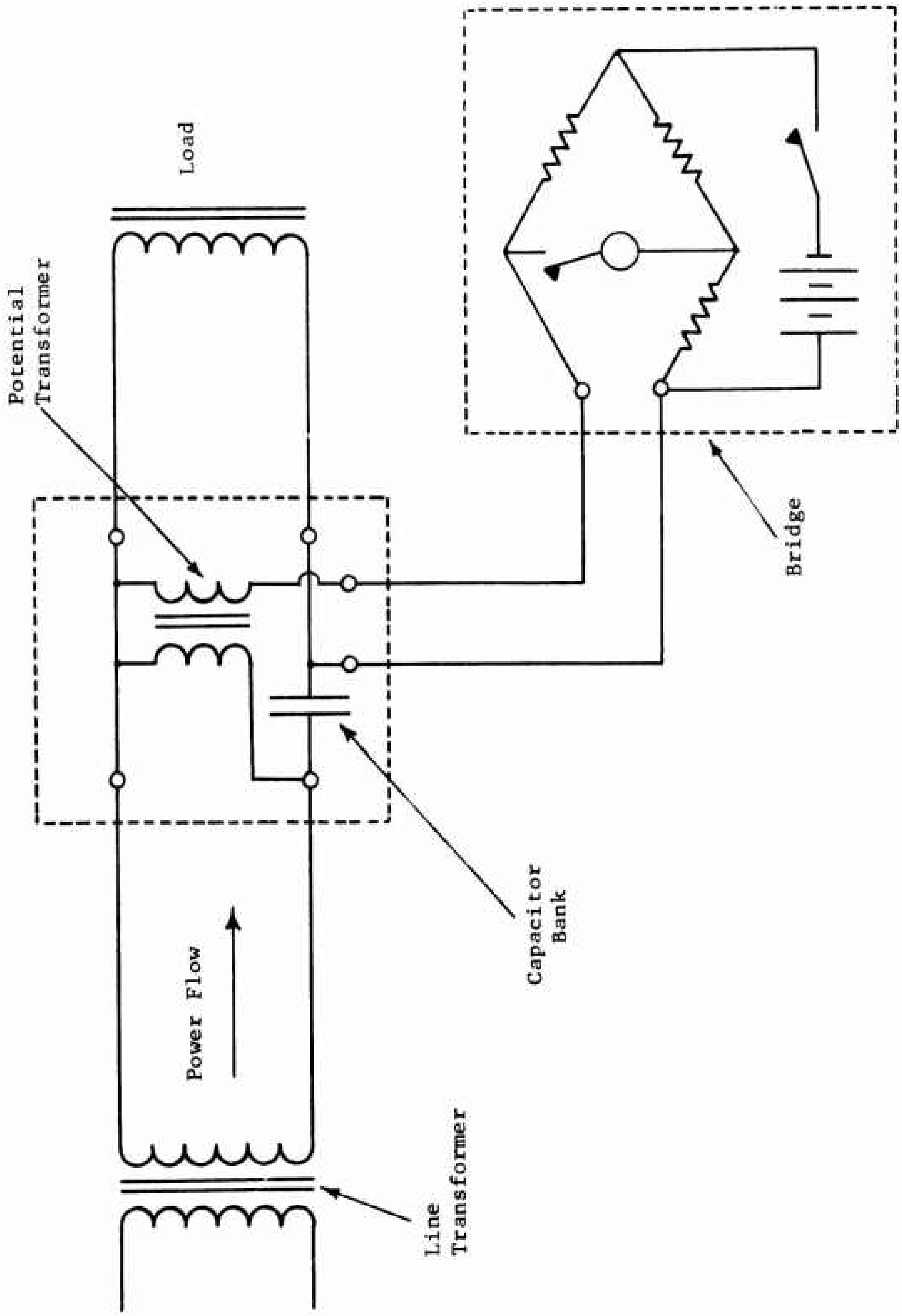


Figure C-1. Basic Circuit for Measuring Resistance of A-C Energized Windings Receiving Power

The winding temperature, of course, can then be obtained by using the equation

$$T_h = (R_h/R_c)\ (K + T_c) - K$$

where:

R_h = hot winding resistance
R_c = cold winding resistance at the start of test
T_c = cold winding temperature as obtained from thermometer at start of test
K = constant

For temperatures in degrees centigrades, this constant is 234.5 for copper windings and 221 for aluminum windings. For temperatures in degrees Fahrenheit, it is equal to 390.1 for copper and to 365.8 for aluminum. Figure 2 illustrates how this circuit can be used in reverse to measure the resistance of a-c energized windings which supply a-c power such as alternator windings or a transformer secondary winding.

Whereas, the circuit shown in Figures C-1 and C-2 illustrated the fundamentals of this circuits operation, it will be realized that further circuit refinements were necessary for successful use in a test department. The circuit shown in Figure C-3 incorporates refinements such that it can be successfully used to measure the winding resistance of either single-phase or polyphase equipment. To measure the resistance of energized polyphase equipment, it is necessary to insert another capacitor bank in the third line so that the direct current of the bridge cannot flow back through the line transformer. With grounded neutral polyphase equipment, it is necessary to go a step further and to have a capacitor bank in all three supply lines to isolate the flow of bridge current. When used with wye-connected polyphase equipment, the resistance of 2-phase windings in series is measured. With delta-connected equipment, the resisance of a phase winding paralleled by the other 2-phase winding in series is measured.

It will be noted that a 4-pole double-throw switch has been incorporated into the circuit, as shown in Figure C-3. This switch has a number of purposes. First, it serves to connect the potential transformer into the circuit when the switch is thrown to its READ or ON position. This is desirable so that the potential transformer is only energized when it is necessary to take a resistance reading. In this manner, there is very little heating of the transformer which would change the resistance of the transformer secondary winding. It should again be noted that the purpose of the potential transformer is only to supply a bucking voltage and not to supply power. As such, the temperature rise would normally be small even if it were energized continuously. In the OFF or CHECK position, as shown this switch shunts the capacitor banks C1 and C3 and connects the secondary of the potential transformer directly to the bridge terminals. Normally, the impedances of the capacitor banks are such that there is a few volt drop across them at the full-load capacity of these circuits. It is desirable to shunt the capacitor banks C1 and C3 such that there will be no voltage drop across

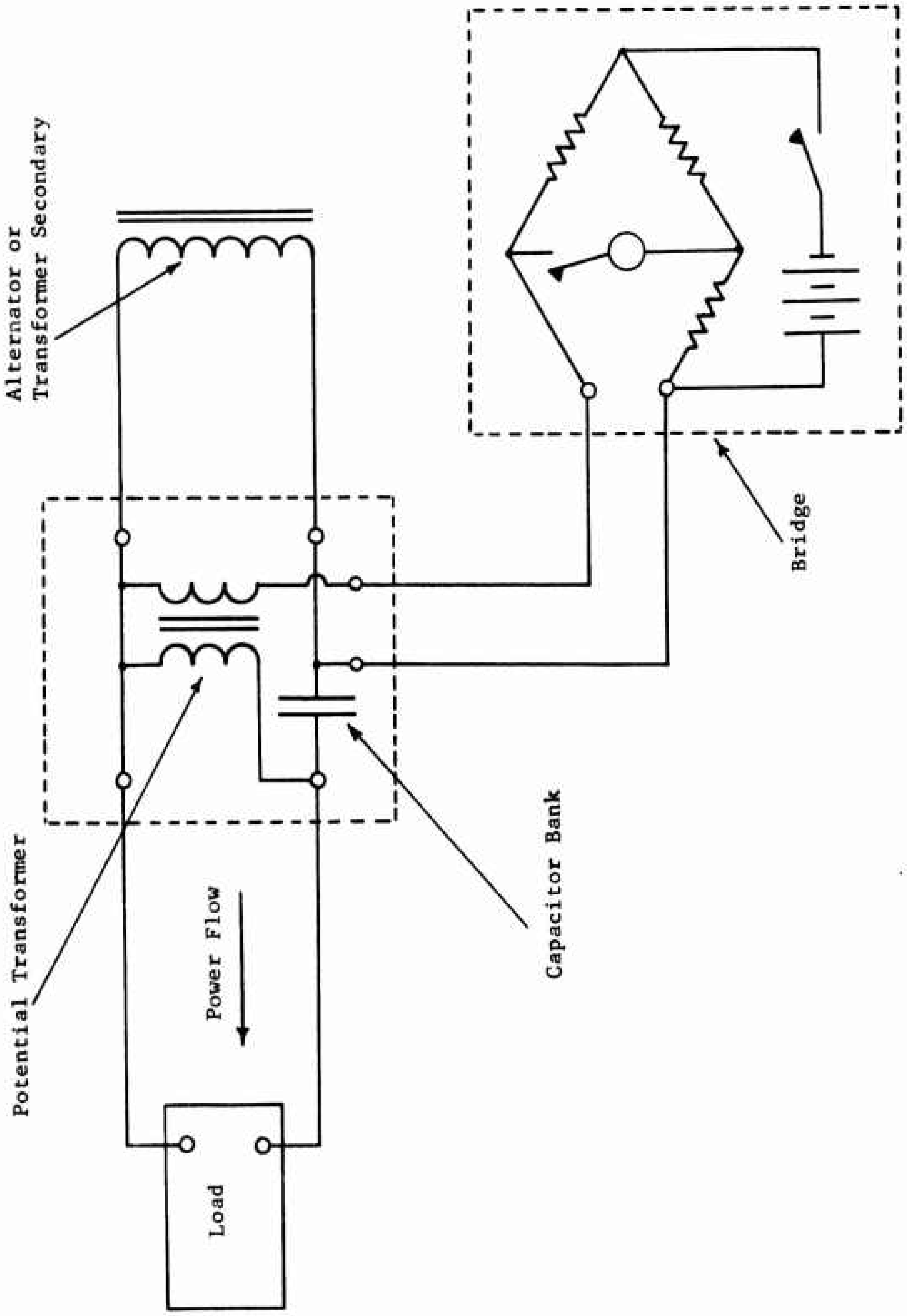


Figure C-2. Basic Circuit for Measuring Resistance of A-C Energized Windings Producing Power

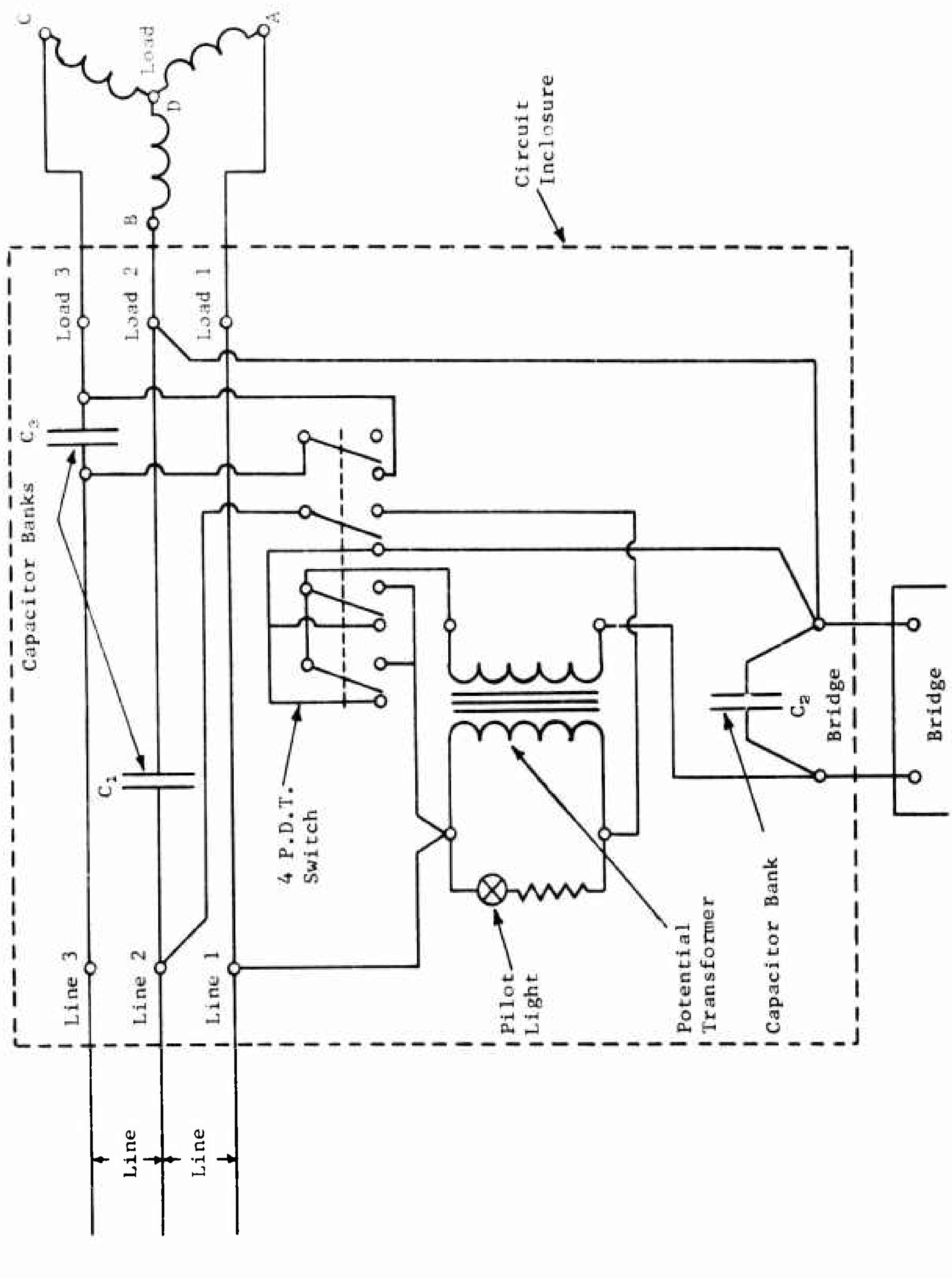


Figure C-3. Refined Test Circuit for Measuring Resistance of A-C Energized Single-Phase or Poly-Phase Windings them when the circuit is OFF. This allows voltmeters and wattmeters to be connected on the line side of the circuit such that their readings will be correct when the circuit is in the OFF or CHECK position. These meters can be connected to the load if provisions are made to disconnect them while a resistance reading is being made. Connecting the secondary of the transformer to the bridge terminals on the CHECK or OFF position permits its secondary resistance to be checked periodically for any slight change of the tare resistance. It will be noted that two blades of the switch to the secondary of the transformer are connected in parallel. This was found to be desirable to obtain a low and stable resistance through the switch.

The circuit, as shown in Figure C-3, is intended to be used to make periodic resistance readings during a heat run, but it also can be used to make continuous readings should they be desired. To do this, it is necessary that a circuit be energized for a few hours at the desired test voltage with the switch in the READ position and with no load being applied to the load terminals. This permits the potential transformer to heat and allows its tare resistance to become stabilized, as can be determined by occasionally switching to the CHECK position.

Another refinement of the circuit in Figure C-3 is the addition of a capacitor bank C2 directly across the bridge terminals of the circuit. The use of this additional capacitor bank was found to be desirable to minimize the effect of line surges on the galvanometer of the bridge. Without this additional capacitor bank, it occasionally was found that the switching surges on the line or a pulsating motor load would cause the galvanometer to be unstable. To minimize galvanometer unstability caused by these surges, it has also been found desirable to operate this circuit from a "stiff" line or, better yet, to operate from a seaprate voltage regulating transformer or separate alternator, if available. The addition of a pilot light to the circuit is desirable so that the circuit will not be energized any longer than necessary. In this manner, heating of the transformer is very slight and, hence, the change in the transformer resistance is negligible.

In the original circuits which were built in 1953, standard 1-and 1½-kva power transformers were used because they were readily available. They were connected for 230/230-volt operation, and as such the circuits could be used for voltages up to about 250 volts. Transformers of this size were employed so that the tare resistance of their secondary winding (about 0.3 ohm) would not be greater than the resistance of the induction motor windings to be measured. It was found desirable to limit the use of these test circuits to an apparatus having a resistance greater than the tare resistance to obtain sufficiently accurate resistance reading. It was soon realized that, if a special potential transformer having a much heavier secondary winding than the primary winding were used, considerable saving in weight could be realized. Consequently, special potential transformers were designed and are presently used in existing circuits. The original circuit also used banks of standard 110-volt a-c electrolytic motor-starting capacitors, rated 850 to 900 microfarads, since they were readily available. Here again, it was realized that these capacitors were many times larger than needed, since even under full loads the voltage across them was only

4 or 5 volts. Subsequently, electrolytic capacitors rated 15 volts a-c and having a capacity of 4,000 to 9,000 microfarads were obtained. As such, it has been possible to reduce the size of the capacitor banks by a ratio of about 10 to 1. At this point it should be mentioned that the internal leakage resistance of these capacitors, in effect, parallels the resistanc being measured, and establishes the maximum resistance which can be measured with sufficient accuracy. It is for this reason that a maximum resitance rating is applied to a given circuit.

Although, the measuring circuit was originally developed to determine the temperature of motor windings by the resistance method, it also has been used to determine the winding temperature of alternators and transformer windings. Figure C-4 shows the heating and cooling curves of the primary and secondary windings of a 1-kva transformer, as obtained by using measuring circuits in both the primary and secondary windings. In this test, the transformer was first loaded to full and then reduced to 50-per-cent load after 5½ hours. Figure C-5 shows a temperature rise curve of the winding of a 1.5-kva 3-phase 115-volt 430-cycle motor alternator which was first loaded to a full load and then to 50 per cent load.

Figure C-6 illustrates a very important use for this measuring circuit. Shown here are curves of winding temperature and power of a 1/6-horsepower hermetic refrigerator motor, as obtained when the refrigeration system reduced the refrigerator cabinet from room temperature of approximately 40 degrees centigrade to its normal operating temperatures. It will be noted that, under such a test, the power and winding temperature reach a peak and then fall off as the cabinet temperature is pulled down. Without the use of this resistance-measuring circuit it would be difficult or impossible to determine accurately the peak winding temperatures.

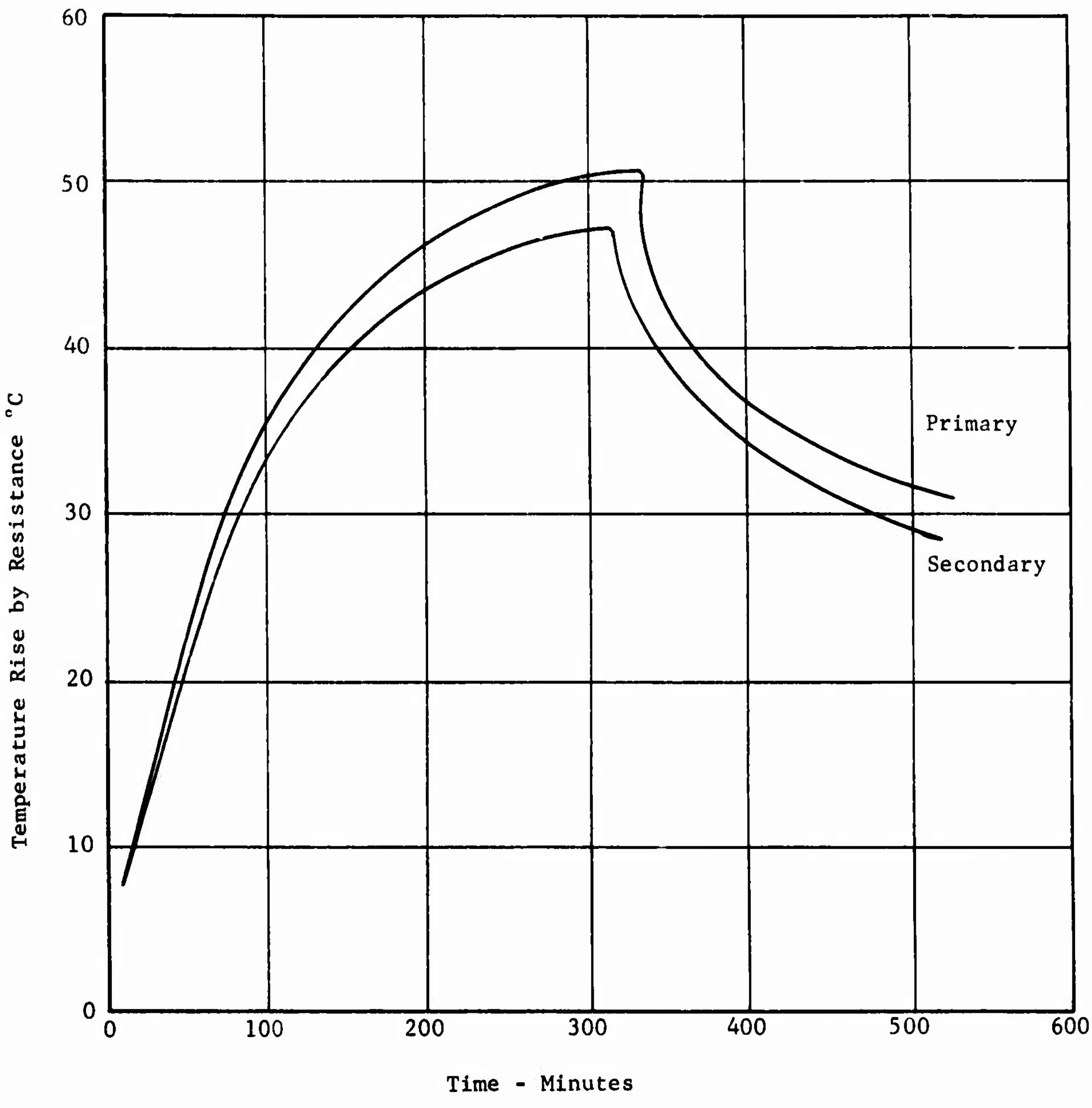


Figure C-4. Heating and Cooling Curves of Primary and Secondary Windings of a 1-kva Transformer as Obtained by Using Two Resistance Measuring Circuits

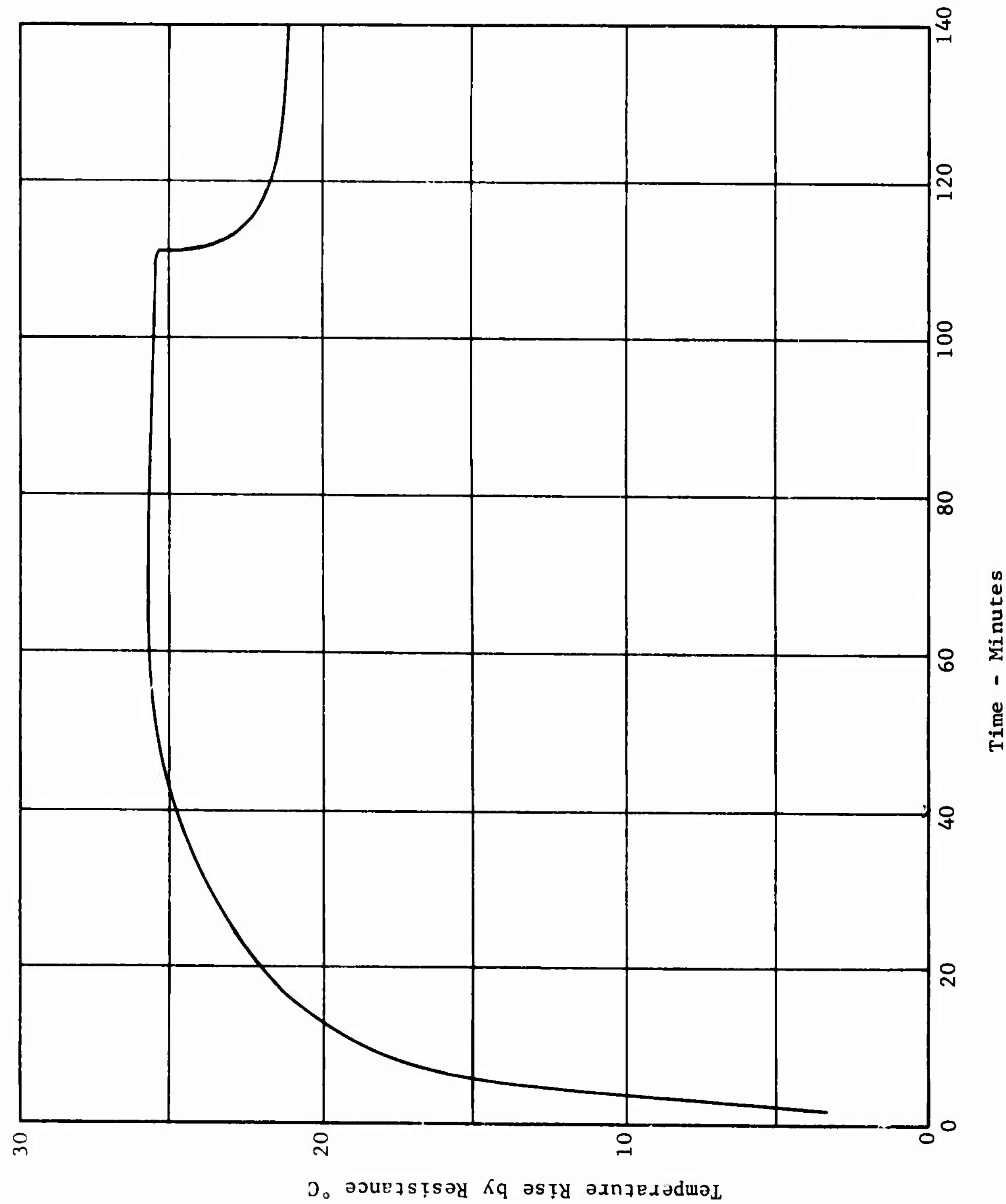


Figure C-5. Temperature Rise Curve of Windings of a 1.5-kva 3-Phase 115-Volt 430-cycle Mounting Alternator Which Was First Loaded to Full Load and then to 50-Per-Cent Load

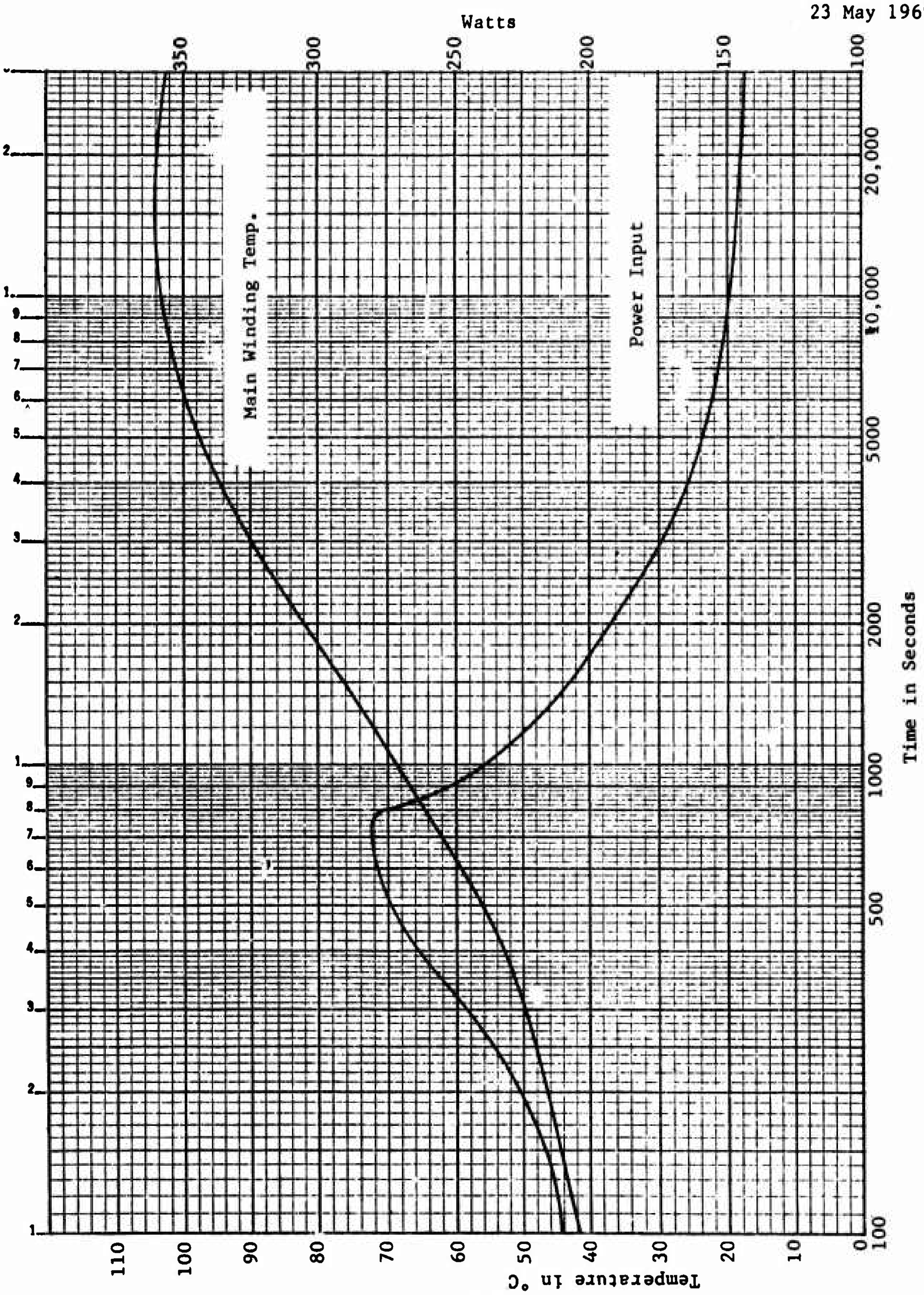


Figure C-6. Curves of Winding Temperature and Power Input of a 1/6-Horsepower Hermetic Refrigerator Motor